GROUP REPORT
&
ABSTRACTS

Group 1

Pre-Event Period
Preparedness and Mitigation

GROUP 1 REPORT
PRE-EVENT PERIOD—PREPAREDNESS AND MITIGATION

Co-Chairpersons: Patricia Bolton and Masanori Hamada

A variety of issues were raised or implied by the central topics of discussion in the working group. Working to a great extent from the research interests of the participants, these topics included education and training related to the enhancement of preparedness and of seismic safety, increasingly refined information on the effects of liquefaction and ground shaking on building performance across a range of building types and on lifeline systems, the difficulties in arriving at credible assessments of potential damage to lifelines, the factors that contribute to injuries to building occupants during earthquakes, and the implications of various kinds of urban housing solutions for preparedness and mitigation.

There have been few major urban earthquakes in Japan in recent years, such as 1983 in Nihonkai-Chubu and 1989 Off-Chiba Prefecture, however, many of the participants had studied the impacts of such recent earthquakes as the 1989 Loma Prieta and 1987 Whittier Narrows earthquakes in California, and the 1985 earthquake that affected Mexico City. Other working group participants had recently conducted studies of various elements of preparedness and loss reduction, in anticipation of future earthquakes in their country or region.

Critical issues pertaining to earthquake hazard reduction that have emerged in recent earthquakes.

A very important issue that has arisen based on observations of the consequences of recent earthquakes, particularly in modern urban areas, is that of the redefinition of what is acceptable damage. The major emphasis used to be on an ultimate goal of life safety, that is, designing and constructing to avoid structural collapse. However, the problems posed for recovery when functionality of critical facilities and major portions of housing was lost have raised serious questions about the appropriate goal of standards and practices to minimize loss.

The problems of earthquakes in high-density modern urban settlements are in many respects different than those of less modern cities. For example, in recent U.S. earthquakes, the long-term effects were disproportionately concentrated in low income and minority groups, for whom past sheltering and housing recovery programs have little relevance. This not only raises issues about recovery policies, but about mitigation program priorities for other cities with a high earthquake risk (see Greene abstract). Also, other types of housing solutions in urban areas, such the adaptation of former single family dwellings or apartment buildings to condominium arrangements, raise thorny issues related to seismic safety in such buildings, both from the engineering and the organizational point of view. While mitigation efforts may be technically feasible, the acceptability to all owners of structural assessment and retrofit may be at issue, creating a problem different from that of requirements placed on the owners of commercial property, single family dwellings, or rental residential property to strengthen selected buildings (see Nagonoh, et al., abstract).

Following several different earthquakes in the 1980's in both Japan and the U.S. research was conducted on the behavior of building occupants during the period of shaking. In these areas, where building collapse is relatively rare, injuries are much more common than deaths and are clearly related to the interaction of building occupants with the non-structural elements and moveable contents of the spaces in which they find themselves during earthquakes. This raises the questions about what are the critical factors in this outcome, and under what circumstances should the emphasis be put on the manipulation of the physical elements in spaces used by humans to reduce specific hazards, versus an emphasis on attempting to achieve widespread education of the public about the principles of protective action during earthquake shaking (see Rahimi abstract).

The appropriate use of automatic safety devices linked to earthquake sensors was touched on. The technology is being refined for the linking of information from seismic monitoring devices with control systems for various lifeline and production systems. However, some issues remain about the wisdom and appropriateness of using this technology in some instances.

Discussion about earthquake preparedness education indicated that there is still some issue as to the appropriate blending of engineering knowledge about structural performance and social science knowledge about the behavior of persons in roles of responsibility and the practices of building occupants before and during earthquakes. Education issues revolve around who needs to know what, who should teach it, and what type of material is most needed and usable.

The lack of recent earthquakes also raises issues about the importance of, and the appropriate means for keeping government officials and citizens aware of the hazard and concerned about the need to prepare. Earthquake predictions have raised issues about the type of educational material necessary to counter non-scientifc predictions, and promote appropriate response to credible predictions.

Lessons learned in recent earthquakes

A major lesson from several recent earthquakes is that of the interaction between building performance and the type of soil under the building. This is also true with respect to the facilities used in lifelines, such as conduits of various types, tanks, roads, and bridges. The clear examples of the consequences of liquefaction in particular, and the implications of this soil behavior for the built environment, have provoked considerable concern for the need to identify such areas, and to attend to this hazard both for the design of new development and in providing protection to existing lifelines and other structures.

An analysis of lifeline damage that occurred as a result of the Loma Prieta earthquake provided information on the nature of the interaction of damage to one type of lifeline on the functionality of other types (see Hayashi abstract). The findings suggest several important lessons for preparedness, including that failure of the electrical system will have impacts on all other systems. A synthesis of information on earthquake-related fires indicated that there is no particular pattern of post-earthquake fires that can be used for planning, suggesting that comprehensive detection systems for post-earthquake fires can be valuable for effective response

Also of great importance to the objective of earthquake mitigation are specific lessons learned through the study of building performance in recent earthquakes. Recent earthquakes have indicated that many types of buildings, otherwise thought to be appropriately engineered to withstand earthquake damage, have not performed as well as expected (see Bertero and Miranda abstract). Focused case studies of individual buildings damaged by major earthquakes have helped to shed light on unanticipated damage and needed strengthening measures for similar buildings. Also, such examinations point the way to further theoretical and experimental engineering studies At the same time, post-earthquake observations of damage patterns provide examples where mitigation efforts have reduced damage, or of damage that has occurred for which there exist proven methods for minimizing it These observations provide lessons for consideration of mitigation priorities (see Bolton abstract).

Recent earthquakes in the United States in particular have raised critical issues surrounding the provision of recovery housing for renters, and in particular the low income groups seen to be most directly affected by recent U.S. urban earthquakes (see Greene abstract). One implication of this for mitigation is the need to focus on vulnerable residential structures when designing both earthquake mitigation programs and policies for replacing sub-standard urban housing.

A Japanese study of the awareness and preparedness of condominium governance groups for potential earthquake damage also raises important issues related to residential earthquake mitigation in densely settled urban areas (see Nagonoh, et al., abstract). Condominiums and other variations of multi-owner buildings raise many interesting organizational questions about how to distribute requirements and costs, not only for post-earthquake repair, but also for pre-quake structural and non-structural loss reduction efforts. Many such buildings have common areas, as well as privately owned areas, and independently applied strengthening measures in any of these areas may affect other parts of the building.

Changes that have been made in practice as a result of recent earthquakes and ensuing research.

The working group noted a variety of changes in practice related to preparedness and loss reduction objectives, many of which are in the early stages of implementation, or perhaps even in the planning stage.

The group believed new information was being applied to changes in construction codes. For example, changes in codes in the United States for bridge construction are under development, based in particular on newly emerging information on lateral movements associated with areas prone to liquefaction during earthquakes. It is believed that codes for dam construction are being changed in Japan. Also, greater attention is being paid in Japan to new information on the hazards of liquefaction-prone areas, since much new urban development is taking place in reclaimed waterfront areas. Based on lessons from the Loma Prieta earthquake, assessments of lifelines in such areas are underway in order to determine the extent to which reinforcing measures are called for, although such measures have not yet been initiated (see Hamada abstract).

In California, the Golden Gate bridge is undergoing a strengthening program, based on concerns raised by recent California earthquakes, which have led to careful efforts to bring together the latest engineering information and careful study of the bridge itself. A newly imposed toll for users of the bridge provides support for this research and strengthening effort.

Relative to earthquake education, in Japan the Ministry of Education is providing support for school preparedness, in the form of developmental funds for earthquake education materials (see Miura and Takimoto abstract). This also has been done at both the national and in some states in the U.S. Research into Japanese school teachers' understanding of evacuation procedures has led to an effort to develop a set of guidelines for teachers and other school personnel for the appropriate protective actions during and immediately following earthquakes during school hours (see Omachi abstract). Both Japanese and U.S. participants believed there are increasing instances of professional engineers stepping forward to use their knowledge to advocate mitigation and education.

It was noted that an early warning system for tsunamis has been established in some parts of Japan, based on improved techniques for identifying earthquake epicenters and transmitting a signal to populations in vulnerable areas. Seismic monitoring systems also are in use in Japan, linked to automatic emergency shut-down devices for selected life-line systems.

Identification of problems that have not yet been addressed adequately.

A perennial problem is lack of concern on the part of the general public about their vulnerability to earthquake damage, or a lack of understanding about ways in which they can reduce many of the hazards around them. Many of the other working groups, as well as this one, acknowledged that education about earthquakes and training in appropriate methods for preparedness, mitigation, or response are important keys to effective action in many arenas. While considerable work has been done, in particular in California, in the development of earthquake education materials, and in the development of techniques for preventing or reducing damage, the effectiveness of educational materials, mitigation techniques, and the targeting and dissemination of this information, has not yet been adequately addressed.

It was noted that preparedness is difficult to achieve if education is not widespread and appropriately tailored for various audiences, and if plans and appropriate protective actions are not practiced from time to time to improve and maintain preparedness. Persons whose positions make them responsible for the safety of others, such as school teachers or plant managers, need to understand what their role will be when an earthquake occurs, as well as what can be done ahead of time to reduce potential problems. Programs of drills need to be implemented by many types of organizations. Likewise loss reduction techniques with demonstrated effectiveness need to be adopted on a broader scale.

The basis for sound research and practice starts with appropriately trained professionals, yet it is still the case that seismic safety is not an important part of the curricula of many relevant professional groups. Related to this, those professionals with important technical knowledge about earthquake forces and damage need to play a more important role, in collaboration with social scientists and educators, in the education of frequently ignored groups such as government officials, social service agencies, and the media. This assures that correct technical information is being used as the basis for preparedness and mitigation, and lends credibility to the importance of promoting seismic safety. Another related problem calling for a more careful application of new knowledge is that of the content of training about appropriate protective actions during earthquakes. As further evidence is shed on the root cause of earthquake-related injuries, it is becoming possible, and imperative, to match this information with instructions provided to the public about appropriate actions during an earthquake.

Certainly new lessons about liquefaction-prone areas, and the increasingly detailed information on the performance of a variety of types of buildings under various conditions, while recognized as lessons, often have not yet been put work in the form of widespread practices to address these problems. In particular solutions to the liquefaction problem in the form of practices to maintain functionality of lifelines and other structures have received less attention than identification of the source of such problems in post-earthquake investigations.

The assessment of potential damage in future earthquakes is the basis for preparedness and mitigation actions. A lack of current and accurate information on lifelines was noted as a problem. Basic assumptions and methods for assessment of potential damage to life lines were of particular concern to the group's participants, in terms of the use of such information for targeting areas for mitigation projects, and establishing priorities for such work. Better databases and mapping of the placement and characteristics of existing lifeline systems (water, gas, electricity, etc.), and especially for older portions of systems, and better methods for arriving at relatively accurate assessments of vulnerability within a reasonable time frame to permit mitigation planning, are needed. Several efforts to address such methodological issues are underway (see abstracts by Hamada, Katayama, et al., Kameda and Takada, and Hayashi, et al.).

With respect to engineering issues, research is needed that will shed further light on strength demand reduction due to inelastic behavior and overstrength in buildings that has been suggested by damage observed in recent earthquakes (see Bertero and Miranda abstract).

This information is necessary for the development of better engineering approaches and construction standards.

Another problem raised was that of how best to use the opportunity provided when the earthquake epicenter is at some distance, thus permitting maybe a few seconds to as much as a minute of lead time for initiating various types of protective actions before local groundshaking begins. Research is needed on several aspects of this situation, including the best techniques for sensing a major earthquake, how to establish thresholds for activating automatic protection devices (such as shut-off valves), how to perfect such automatic systems, which critical functions can most benefit from such technology, and when and how to involve human decision making as part of the sequence from signal to action.

Identification of further research needs and areas of possible collaboration.

The problem and critical nature of lifeline system vulnerability to earthquakes as described above, suggest this as an important area for collaborative work. Research is needed both on methods to assess vulnerability in long-established urban areas, and on methods for reducing damage to various lifeline systems. One specific area for more research is that lateral movement related to liquefaction.

Since condominiums are increasing as a residential solution in major urban areas, joint research on various aspects of earthquake preparedness for this type of development could be fruitful. This would include not only organizational research on various solutions to establishing requirements and distributing costs for needed retrofits or post-earthquake repairs that could be valuable for owner organizations, but also engineering research on the implications of retrofits or repairs undertaken by various owners for their own space, but not applied in all areas of the building.

Research on general earthquake preparedness also was discussed as an area in which collaborative research would be informative, in particular in the form of cross-cultural research. Similar studies could be done in each country, on such topics as effective methods for developing neighborhood preparedness, maintenance of preparedness over time, and preparedness education for small business. Cross-cultural collaborative research also could be done to gain further insights on the behavior of building occupants during the period of shaking, and on how best to reach special needs populations, such as those without the primary language of the culture, or the elderly or disabled in order to find out what are the barriers to effective behavior related to earthquakes and how best to present and disseminate information to them.

Further research is needed on the effectiveness of various types of educational materials and dissemination approaches, including the way in which the content of educational materials needs to be altered for various target populations. Another topic of interest was that of how to depict scientific earthquake predictions so they might better serve as motivators of preparedness. This would include research on the impact of the prediction depending on its probable accuracy, the likely intensity of the predicted quake, or how far in the future it is predicted. On the other hand, the development of approaches that can be used by the scientific community to address non-scientific predictions would also be useful. In general, evaluation studies on the effectiveness of education approaches and materials would lend themselves to a collaborative effort.

WORKING GROUP ABSTRACTS

SEISMIC UPGRADING OF EXISTING STRUCTURES

Vitelmo V. Bertero and Eduardo Miranda

Introductory Remarks

Most human injury and economic losses due to earthquake ground motions are caused by failure of civil engineering facilities, many of which were presumed to have been designed and constructed to provide protection against natural hazards. This has been dramatically confirmed during recent earthquakes around the world (the 1988 Armenia, 1989 Loma Prieta, 1990 Iran and 1990 Philippines earthquakes).

Objectives and Scope

The ultimate goal of this paper is to discuss guidelines for efficient seismic upgrading of existing structures. To achieve this goal, the paper will first identify the different aspects involved in such upgrading of structures, and then discuss the issues and future directions of each of these aspects.

Assessments of Seismic Hazards

Seismic Hazards

Brief review of the different seismic hazards at a given facility's site. Emphasis is placed on the hazards created by the effects of the earthquake ground motions on the whole facility (soil-foundation, superstructure and nonstructure--real components).

Uncertainties in Establishing the Critical EQ Ground Motions. These uncertainties are consequences of the uncertainty in estimating:

- EQ Source
- EQ Occurrence in Space and Time
- EQ Source Mechanism
- Amount of Energy Released at the EQ Source
- Seismic Wave Propagation and Attenuation
- Local Site Conditions

States of the Practice and of the Art in Establishing Design EQ's. Need for improving zonation and microzonation of the urban area.

Vulnerability Assessment

Seismic Evaluation of Existing Structures

Overview of present screening and multilevel evaluation methods. Emphasis is placed on discussing advantages and disadvantages (deficiencies) of the methodology used by the Tri-service manual and by the ATC.

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Overstrength in Existing Buildings

Difference between actual strength and that required by the design codes. Factors contributing to local and global overstrength. Difficulties of evaluating actual mechanical behavior (stiffness, strength, stability, energy absorption and energy dissipation capacities) of real structures. Examples: Observed building overstrengths.

Guidelines for a More Rational Evaluation of Existing Structures

Probabilistic and deterministic approaches are discussed.

Seismic Evaluation and Upgrading of Existing Buildings: Two Case Studies

Low-Rise Building in Northern California

This is a three-story building constructed in 1959, which suffered nonstructural as well as structural damage during the 1989 Loma Prieta EQ. A seismic evaluation for both serviceability and safety (survivability) limit states was conducted. The development of an efficient upgrading technique is presented. Special emphasis is given to the usefulness of nonlinear spectra in evaluating and upgrading this building.

Four-Story RC Building

This building suffered some structural damage during the 1985 Mexico EQ. After evaluating the seismic behavior and selecting efficient upgrading strategies, different techniques were studied, and the most efficient ones have been selected.

Summary Conclusions and Recommendations

Summary

The different problems involved in seismic upgrading of existing facilities and the state of the practice and knowledge is presented. Applications to two case studies are presented.

Conclusions

Based on the results obtained in the studies reported in this paper, a series of conclusions regarding assessments of hazards, vulnerability, and selection of efficient strategies and techniques will be presented.

Recommendations

Future research is needed to estimate realistic seismic demands on existing buildings and their real overstrength To increase the reliability and transparency of current seismic design provisions, strength demand reduction due to inelastic behavior and overstrength should be considered explicitly. There is an urgent need for focused research in this area of seismic upgrading of existing facilities.

EFFECT OF INFORMATION FROM THE LOMA PRIETA EARTHQUAKE ON THE SELECTION OF MITIGATION PRIORITIES IN THE SAN FRANCISCO BAY REGION OF CALIFORNIA

Patricia A. Bolton

The Loma Prieta earthquake of October 17, 1989, caused billions of dollars in damage throughout the San Francisco Bay region and counties to the south. Much of the damage from the earthquake involved structural elements and geologic areas for which vulnerability to seismic forces is well understood.

As part of the National Earthquake Hazard Reduction Program (NEHRP) various federal, state, and regional programs have been carried out in past years to promote local-level earthquake preparedness and loss reduction activities. Major legislation in California regarding the enhancement of seismic safety typically falls on the heels of a major earthquake, in California or elsewhere, that calls attention to some flaw in design technology or application of knowledge. Since the 1930s, the State of California has passed legislation to require local jurisdictions to identify seismic hazards, specify hazardous geologic areas immediately adjacent to active faults, and reduce risks associated with various types of critical use structures considered to lack adequate seismic resistance. At the time of the earthquake many California communities were in the process of completing a state-required inventory of unreinforced masonry type building stock and devising plans for addressing the hazard represented by these buildings. As might be expected, due to various economic and social factors some communities have been more aggressive than others in identifying hazardous areas and in attending to the lessons learned from previous earthquakes about important construction and strengthening techniques for vulnerable structures. Cities also differ with respect to their success of fully implementing measures after they have been adopted.

A critical issue with respect to the adoption of mitigation measures is that of the effectiveness of the various measures. Effectiveness refers to the extent to which a certain mitigation approach leads to a reduction of damage during a subsequent earthquake. The Loma Prieta earthquake provided an opportunity to address the question of effectiveness. For example, following the earthquake, those communities that had implemented some type of mitigation measure would be likely to consider whether or not a significant amount of damage had been averted by their program. Also, those communities that had not yet taken steps to implement a certain mitigation measure would be likely to consider what kinds of damage in their community might have been averted had they had a mitigation program before the Loma Prieta earthquake.

Examples of types of mitigation activities that various communities in the Bay Area had adopted include: mapping of hazardous areas and land use zoning practices to prohibit building or assure appropriate engineering approaches, retrofit of buildings housing essential public services such as schools, hospitals, government activities, and utilities; programs to encourage retrofit of privately owned unreinforced masonry buildings; programs to identify and eliminate potential sources of injury and damage related to nonstructural elements and contents of buildings; strengthening of chimneys; appropriate tieing of older homes to their foundations; and removal or bracing of parapets on older buildings.

The Loma Prieta earthquake, although of only moderate intensity in much of the area, provided many specific lessons and reminders about vulnerable structural design, certain building practices, and locational decisions for development. Extensive descriptions of the types of post-earthquake damage and disruption, and observations on the cause of certain

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types of structural failures are generally available. The types of damage observed in the Loma Prieta earthquake provide information that can be used by local planning, building, and emergency services departments to reconsider mitigation needs for their community, and to enhance existing efforts or promote new practices and programs.

Also, soon after the earthquake, scientists pointed out that there was geologic evidence of seismic sequences which suggested that further significant seismic activity could be expected on one or more Bay Area faults within the next decade. Thus the communities of this region, whether or not they incurred substantial damage in the Loma Prieta earthquake, have ample reason to consider the need for earthquake hazard mitigation measures. They also have insights into ways in which damage was averted in some places, because of previous mitigation efforts, and illustrations of damage that most probably could have been averted had certain measures been adopted in the past.

The author is conducting a study of the extent to which communities in the Bay Area, whether or not substantially damaged as a result of the Loma Prieta earthquake, have reconsidered their pre-earthquake priorities for earthquake preparedness and mitigation since the earthquake. The study is examining the way in which local decision-makers may have altered mitigation priorities and programs for their communities, based on the lessons of the Loma Prieta earthquake for Bay Area communities. The study is attempting to identify (1) ways in which pre-quake preparedness and mitigation efforts are perceived to have paid off by lessening or averting some types of damage, (2) the effects of the earthquake as a major regional event on local level mitigation priorities and activities since November 1989, and (3) the utility of hazard mitigation information and assistance provided through regional, state, and federal programs. The presentation will address examples of the ways in which mitigation priorities were shaped by the mitigation lessons provided by the Loma Prieta earthquake. For example, examination of inspection reports of damaged buildings provides suggestions into various types of damage that could easily have been averted, such as strengthening chimneys, or tieing older houses to their foundations better. Other examples include increased awareness of the improved performance of masonry buildings that had been strengthened in recent years, and awareness of geotechnical hazards that had not previously been observed, leading to changes in the land use code.

The findings from this study suggest further research along these lines. This study is based on the perception of the effectiveness of certain mitigation measures. Study is needed to try to validate some of the observations with more objective measures. Also, analyses of the various kinds of trade-offs between adopting one type of measure over another would be useful, since some measures are more easily adopted, but may prevent less damage than others. Also, policy analyses of approaches that might be taken to encourage adoption of mitigation programs at the local level would be useful.

A STUDY ON DETECTION SYSTEMS OF URBAN FIRES

Toshikatsu Iwami,[1] Yoshiteru Nojima[2] and Eiichi Itoigawa[2]

A large earthquake produces many fires and resulting damage in an urban area. In order to mitigate the damage, we must detect the fires and make an efficient fire-fighting plan, as quickly as possible.

There are various ways to detect urban fires. They are: detection with monitor cameras or sensors, reports by citizens, search by satellites, observation from an airplane or helicopter, etc. Each has its own advantages and disadvantages. We must design a comprehensive detection system for urban fires, taking into consideration their specific characteristics.

This paper reports on a study of detection of urban fires using monitor cameras. I report on the possibility of identifying urban fires and their exact locations with monitor cameras placed on the roofs of high-rise buildings.

The main part of this paper is the result of a joint study with Toshiba Incorporated Company.

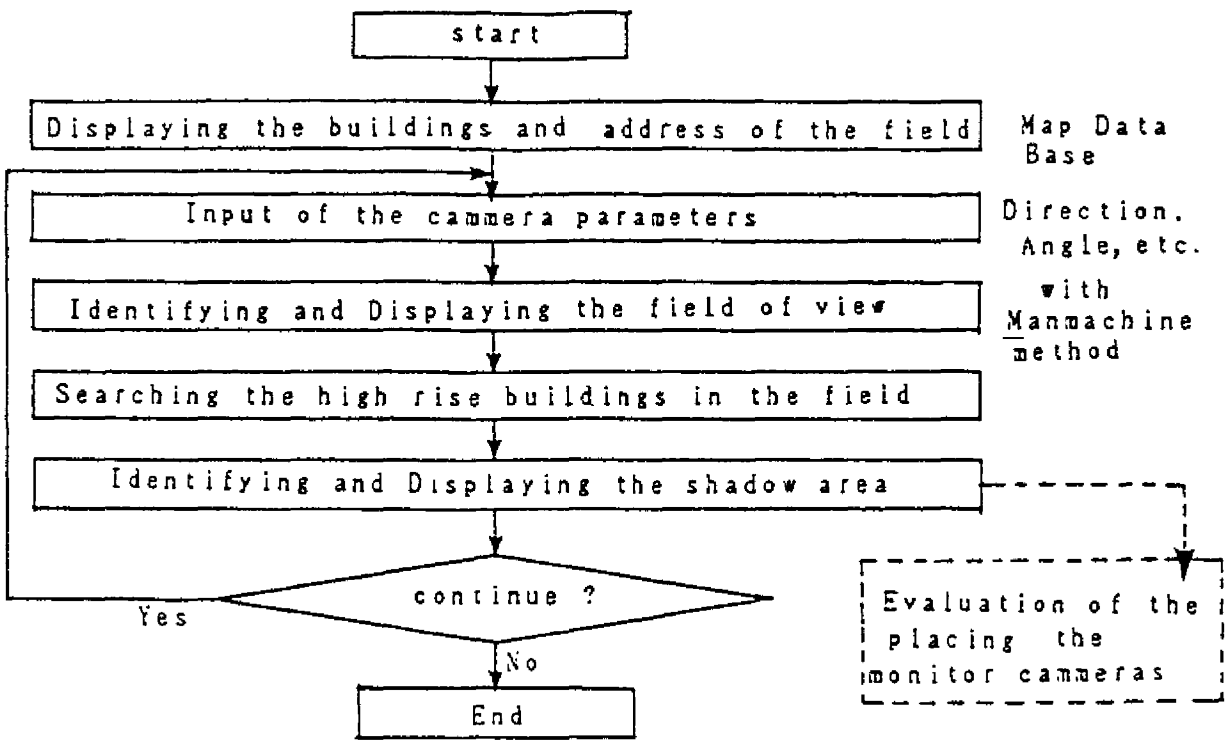

Figure 1. The Procedure of Checking the Camera Condition in Various Locations.

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2. Building Research Institute, Ministry of Construction

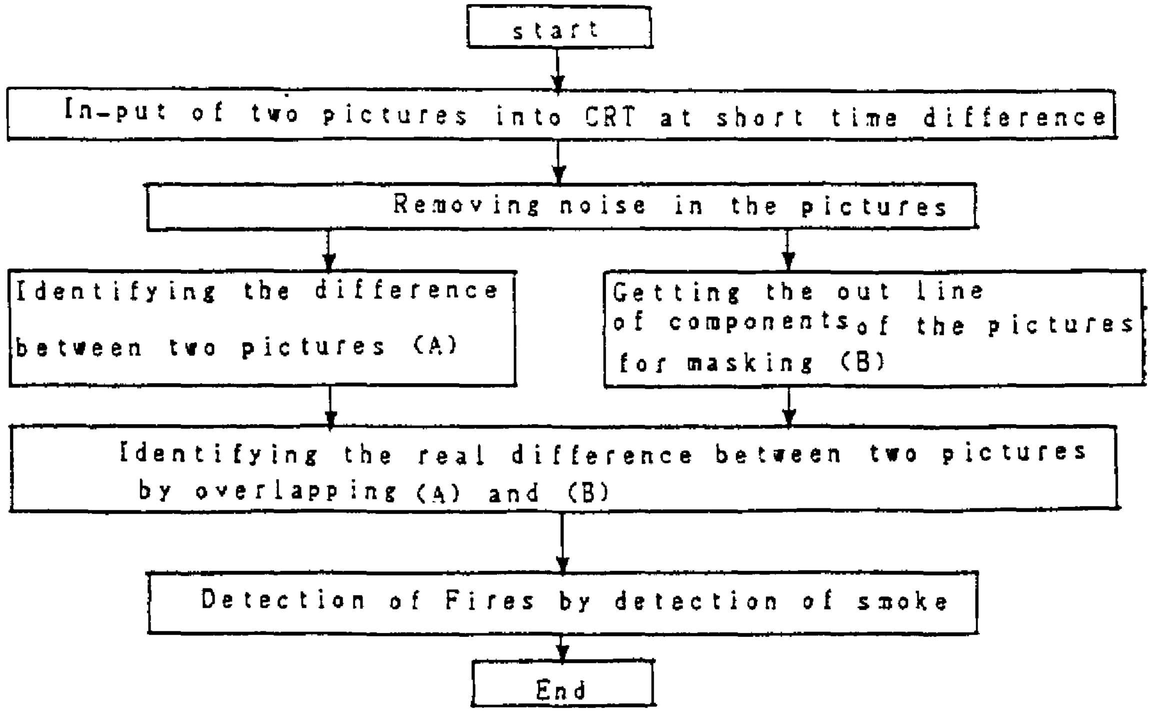

Figure 2. The Procedure of Detection of Smoke in Daytime.

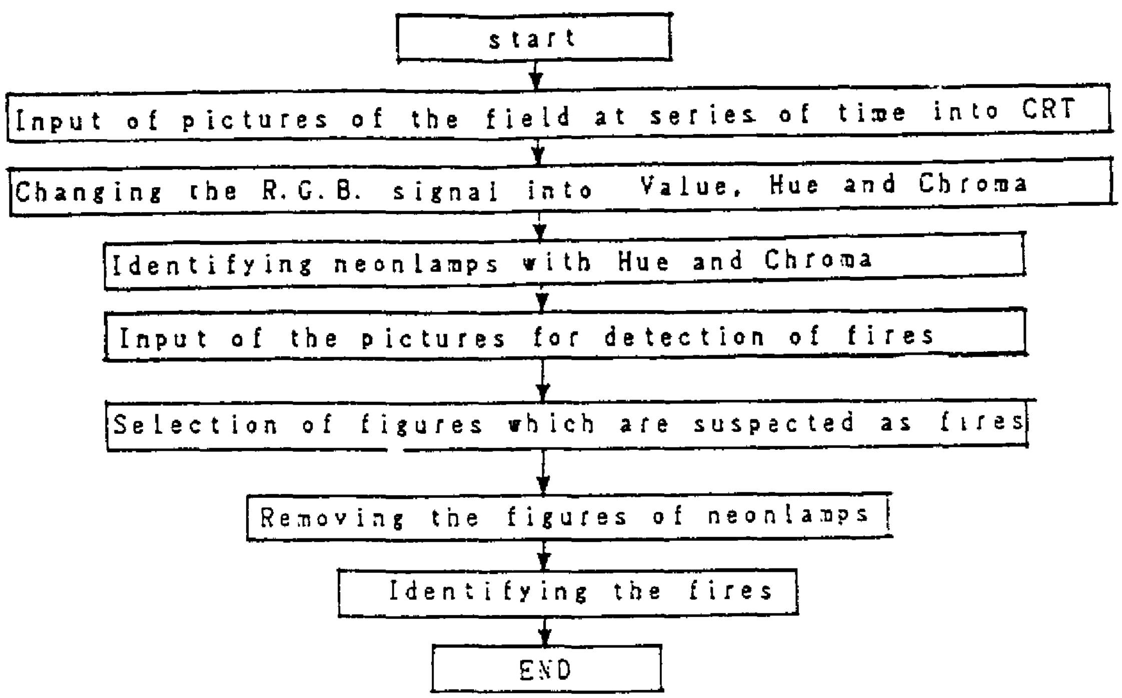

Figure 3. The Procedure of Detection of Fires at Night.

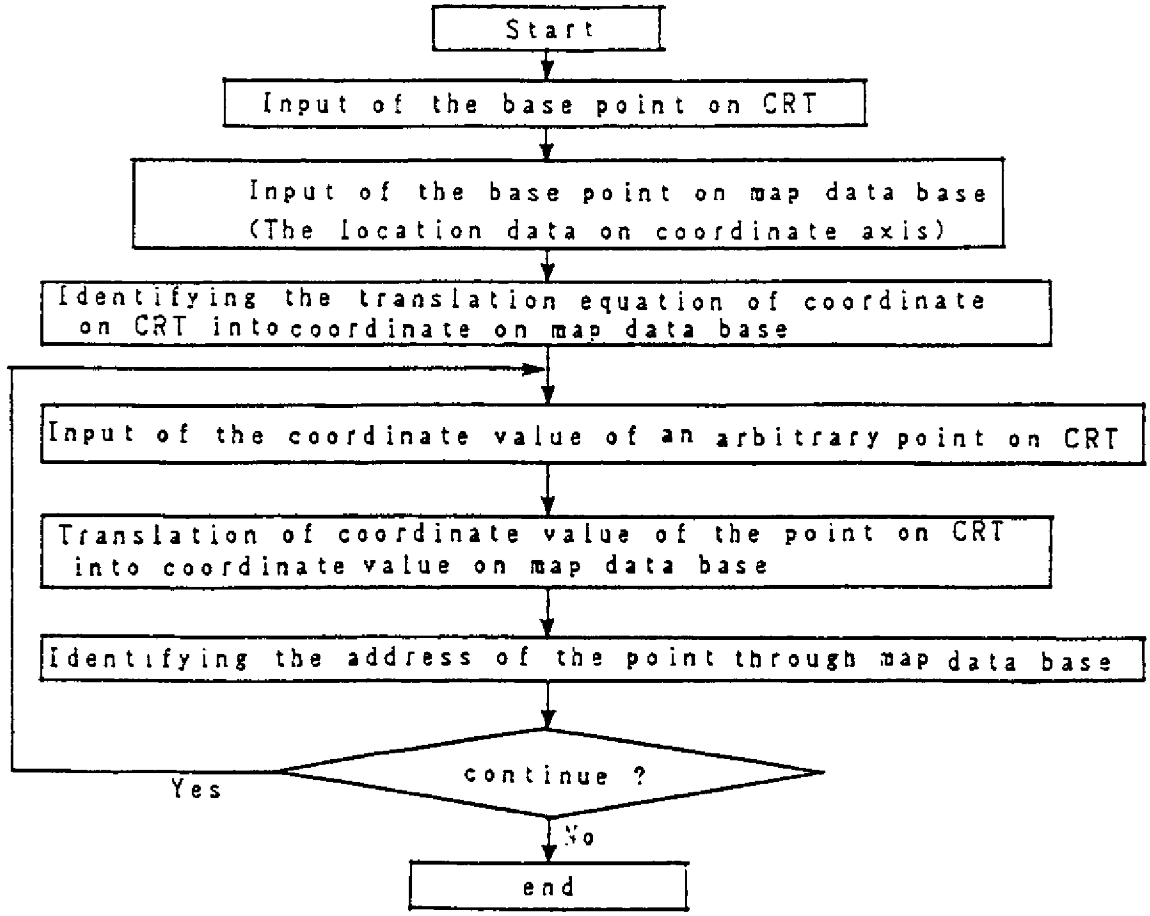

Figure 4. The Procedure of Identifying the Location of Fires.

EARTHQUAKE SCENARIO DAMAGE ASSESSMENT OF UTILITY SYSTEMS IN TOKYO

T. Katayama,[1] R. Isoyama,[2] T. Sasaki [3] and M. Nonaka[2]

Object

Daily lives and industrial activities in an urban area are much dependent on the service of various kinds of utility systems. In order to mitigate the seismic disaster in that area, it is necessary to assess the damaged properties of the utility systems first of all.

An earlier assessment of utility system damage was carried out for the Metropolitan Tokyo area with some 11 million population by assuming the recurrence of the 1923 Kanto earthquake (M7.9), which resulted in the conflagration that extensively burned both Tokyo and Yokohama and caused the deaths of 143,000 people. The report published in 1978, however, did not contain much about utility damage, although damages to buried water and gas pipes were quantitatively estimated. In 1985, a similar assessment was carried out for the suburban area of Tokyo, in which a network analysis for the water system was performed.

The Tokyo Metropolitan Government has been upgrading the old version of assessment for the whole area of Tokyo, as a five-year project since 1986, by taking into account recent methodologies and data. The assessment of physical damage, associated impairment, and restoration of utility facilities in each area have been performed on the water supply, gas, electric power, telecommunications, and sewage disposal systems. The seismic hazard in Japan is highest in Tokyo, where the population and lifeline networks are also the most dense. This combination makes for a serious seismic problem. In this paper the methods of the damage assessment of utilities are induced, and some results are presented.

Methods

The work of this damage assessment of utilities was divided into five steps (Figure 1). Components of these utility systems were classified in six levels in accordance with their roles in the utility network system (Table 1). Based on damage data of the components due to past earthquakes in Japan and the components' seismic capabilities, the components on level 1, 2, 4 were excepted from the ones which would be assessed for damage potential, because the earthquake-resistant capabilities of these levels of components were considered to be very high. In case of level 6, the components excepted for water supply and sewage disposal systems were included, because the effects of damaged components on function of all systems and the recovery process were considered to be critical.

The database utilized in this assessment was made up of the data on ground motion intensities, ground conditions, liquefaction potential, all of which were represented by 0.5x0 5km cells in the whole area of Tokyo. The numbers of components and customers in each utility were collected and added to the database cells.

"Physical damage" of utilities in this assessment was defined as follows.

Water Supply:	remarkable leakage
City Gas:	leakage
Electric Power:	disconnection of cable
Telecommunication·	disconnection of cable
Sewage Disposal:	choked with earth and sand inflowed from damaged parts of pipe in liquefaction areas.

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The relationship between the damage rates of utilities and the peak accelerations of ground motion in each area were obtained from past earthquakes and was defined as the standard damage rate R. While buried pipes of the sewage disposal system were considered to be fairly damaged in liquefaction area, the standard damage rate of these pipelines was derived with relation to liquefaction potential of pipelines' site. For example, the standard damage rate R (number of failures per km) of water pipelines was shown below.

$$R = 1.7 \bullet A^{1\cdot 6} \bullet 10^{-16} \quad \text{(A : peak ground acceleration(gal))}$$

The standard damage rates obtained above were modified by various factors, representing the effect of ground motion, liquefaction potential, the type of structure, depth and so on, and used together with the number of kinds of components in each cell to estimate the numbers of component failures in a cell, in a ward, and then in the whole area of Tokyo.

$$N_d = (C_1 \bullet C_2 \cdots C_n) \bullet R \bullet L$$

where,
- N_d: number of damages or damage length
- C: weighting factors
- R: standard damage rate
- L: number or length of respective component

In the case of water supply and electric power, the system impairment and the number of affected customers were evaluated by the serviceability of the damaged transmission network and distribution lines. Since the damage to system performance of all systems in both city gas and telecommunication were considered to be negligible, the system impairment and the number of affected customers were evaluated by distribution line performance. When a strong seismic motion larger than 250 gal is detected, automatic shutoff valves close supply to the distribution lines. Then city gas system impairment in a supply area is evaluated based on the average value of ground motion intensities in that area. Because no quantitative evaluation of the sewage disposal system was able to be carried out, the system impairment was evaluated quantitatively by distribution line performance.

The restoration process considered in this assessment was restricted to temporary restoration but not to permanent restoration. Restoration simulations were carried out for damaged utilities by using the restoration strategy which gives a restoration priority to supply, and taking into account the physical damage of components, the amount of manpower available, and the restoration efficiency, the last of which was determined from previous earthquake experiences and/or earthquake disaster countermeasure plans in each utility. Degree of recovery of a utility system at each restoration stage was obtained by calculating the number of the customers for whom the limited utility service was restored at that stage.

Results

Physical damage, system impairment, and restoration periods in each utility system for all of Tokyo were shown in Table 2 and Figure 2. Findings from these results may be summarized as follows.

1. City gas pipelines are contained within vulnerable steel pipes with a screw joint. They account for 7,000 km in length or about one third of the total pipelines and are responsible for some 25,000 failures or about 90% of the total failures.

2. Eighty-seven percent of city gas system customers are not supplied in accordance with performed automatic shutoff values designed to prevent a secondary fire disaster after the earthquake. In the case of the other utility systems, only about 10% of customers are affected by system impairment

3. Restoration work to the sewage disposal system takes about three months, more time than the other utility systems. To finish restoration within a shorter period requires development of appropriate manpower arrangements, more efficient restoration methods, and so on.

Conclusions

The effects of damage of one utility on the others was beyond the scope of this assessment. Results from this assessment were considered as a whole to be fitted to past earthquake experiences and/or to be probable. Outcomes from these assessments will be reflected in a revised edition of the Tokyo Metropolitan Plan for Disaster Prevention. They reveal macroscopic damage. Companies and jurisdictions which own utility systems in the Tokyo area need to perform estimate component failures in detail, and to prepare for future earthquakes.

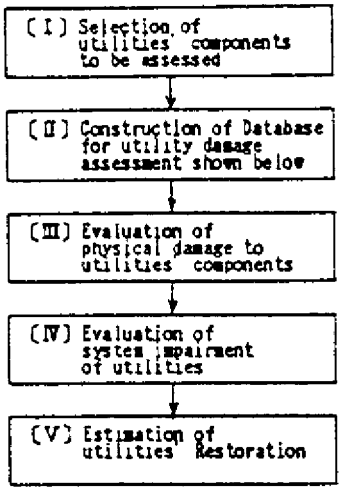

Figure-1 Evaluation Flow of this Assessment

Table-1 Classification of utility system components and sellected ones to be assessed.

	Water Supply	City Gas	Power	Telecommunication	Sewage Disposal
Level-1	reservoir	storage tank	storage tank	—	—
Level-2	purification plant	gas plant	power plant	—	treatment plant
Level-3	transmission line	transmission lines	transmission line	toll line	major sewer
Lever-4	distribution plant	governor	transformer sub-station	telephone exchange	pumping station
Level-5	distribution line	distribution lines	distribution line	local line	minor sewer
Level-6	service installation	service line	service line	service line	lateral sewer

[box] :selected components

Table-2 Results of the Damage Assessment of Lifeline (The whole area of Tokyo)

		Water Supply (A)*	City Gas (A)*	Power (B)*	Power (C)*	Telecommunication (B)*	Telecommunication (C)*	Sewage Disposal (A)*	Remarks
Physical Damage	Level-3	376 I 12 III (0.03)	122 I 4.5 III (0.04)	1,690 I 7.03 IV (0.004)	—	—	—	632 I 24.7 IV (0.04)	1)
	Level-5	20,881 I 7,593 III (0.36)	21,759 I 28,407 III (1.31)	101,449 I 105.3 IV (0.001)	9,024 I 33.9 IV (0.004)	27,587 I 114.56 IV (0.005)	14,361 I 50.0 IV (0.004)	15,694 I 635.7 IV (0.04)	
	Level-6	3,298,164 II 230,684 III (0.07)	—	—	—	—	—	1,973,492 II 159,199 III (0.08)	
System Impairment		4,738,000 383,000 (0.08)	4,772,000 4,132,000 (0.87)	7,213,000 892,000 (0.12)		7,127,000 509,000 (0.07)		9,122,000 358,500 (0.04)	2)
Restoration Period		21	32	7		22		86	3)

* (A):buried pipe, (b):open-wire line, (C):underground line
1) Length, number of failures per km or damage length, and the damage rate of components in each column.
2) Total number of custemers, number of affected customers, system impairment probability of each utility system in each column. Numbers in bracket( ) indicate total number of population, the number of affected population on the case of sewage disposal system.
3) Restoration days of each utility system in each column.
I;length(km) of components, II;total number of components, III;number of failures of components, IV:damage length(km) of componets

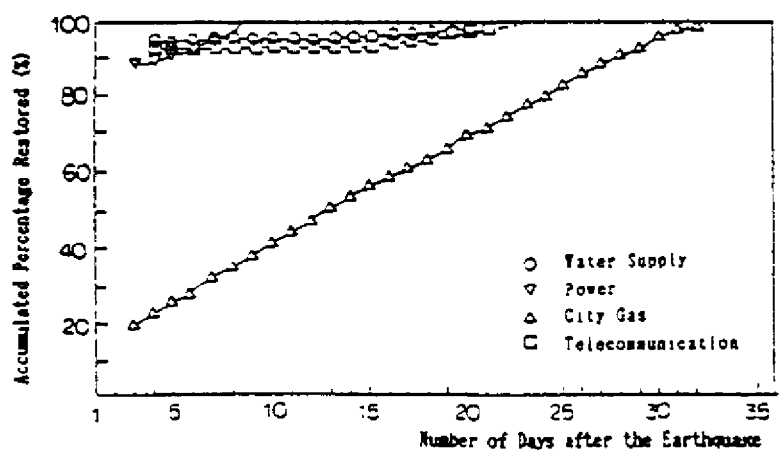

Figure-2 Restoration Curves for Utilities after the Earthquake

OCCUPANT BEHAVIOR AND HAZARDS OF BUILDING CONTENTS

Mansour Rahimi

Introduction

This section focuses on the importance of performing basic and applied research on behavior of occupants interacting with building contents during earthquakes. The premise is that safe occupant behavior in response to hazards caused by major earthquakes helps avoid unnecessary death and injury.

Need

The critical elements of earthquake hazard mitigation lie within planning, preparedness, and response phases. An important aspect of planning and preparedness for occupant safety in earthquakes is to establish appropriate physical, psychological, and behavioral responses of occupants during and immediately after the shaking. The premise that strong ground motions drastically alter living and work environments in earthquake-prone areas is inexorable. For example, it is estimated that the First Interstate World Center (in downtown Los Angeles) will sway five feet in an earthquake of magnitude 8.3. If the building structure remains intact, accelerations produced by such shaking forces may be sufficient to produce projectiles from most interior objects and create hazardous conditions for occupants. In addition, building occupants may face other hazards in their attempts to interact or behave (inappropriately) in response to falling objects, blocked exits, and other secondary hazards. All this occurs in a short period of time affecting normal psychological underpinnings of human behavior. In order to prevent injuries and deaths caused by building contents and nonstructural elements, one needs to know the underlying behaviors of occupants *in relation to* their built environments. Little is known about behavior patterns of building occupants in time of earthquakes, and even less is known about epidemiological and behavioral factors that contribute to occupant injury and death within building interiors.

Regardless, the public receives a large number of earthquake safety tips and "how to" lists. Disseminating earthquake preparedness material through mainstream and specialized media is a powerful tool in providing useful information for the general population in urban areas (Mileti, Fitzpatrick, and Farhar, 1990). However, there is evidence that the contents of these materials have not been tested using scientific research on safe responses of individuals to earthquake hazards.

Organizing Past Research

The risk of injury to building occupants in earthquakes is multifaceted and complex. Numerous factors play interactive roles in injury outcomes. The three main elements relate to geological, structural (nonstructural), and human factors. Based on some recent studies, there is evidence that not only structural failures, but also nonstructural elements and building contents pose significant life and safety hazards to occupant. For example, the percentage of injuries related to nonstructural and building contents (e.g., glass, furniture, fixtures, appliances, chemical substances) appear to be significantly higher than previously expected (Ohta and Ohashi, 1980; Ohashi and Ohta, 1984). Previously innocuous elements of the interior environment, such as light fixtures and file cabinets, can become hazardous in an earthquake. Additionally, building contents that are dislocated by earthquake forces may block exits, restrict access to emergency supplies, and cause secondary hazards (Archea and Kobayashi, 1984). Furthermore, Aroni and Durkin (1985) reported that 50 out of the 133 persons (about 37.6%) injured in the 1983 Coalinga earthquake had some type of disability,

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perhaps unable to perform the desired self-protective activities. In addition, Hutton (1976) and Parr (1987) emphasize that in disaster situations, the needs of children and elderly may be similar to those of disabled individuals. If this is the case, the number of people who may be at higher risk is close to one-half of an affected population.

Reactions of occupants during and immediately after shaking may differ substantially. Archea (1984, 1990) investigated human behavior in the 7.1 magnitude off-Urakawa (Hokkaido, Japan) and the Loma Prieta (California, U.S.A.) earthquakes and concluded that contrary to common belief, people are able to engage in much more activity during the period of strong ground motion than had been thought possible. The average distance travelled during the 10-12 second Loma Prieta earthquake was 13 feet and 10 inches. In the off-Urakawa earthquake occupants travelled an average of 27 feet during the 30 seconds of shaking. The Japanese subjects were more conscious of a secondary fire hazard than the American subjects. In the Urakawa sample, 80.0% stated that taking care of a fire was among the first two actions taken. They were also more protective of personal property; 39% attempted to save personal possessions ignoring zones of refuge, a clear indication of cultural differences in occupant behavior during earthquakes. On the other hand, Goltz, Russell, and Bourque (1991) found that occupant behavior during Loma Prieta was "controlled, rational, and adaptive."

While there were no deaths reported in the three California earthquakes of Santa Barbara, 1978, Imperial County, 1979, and Coalinga, 1983, the number of injuries reported ranged from 78 to 211 per quake (Aroni & Durkin, 1985). Also, the majority of earthquake-induced injuries occurred in residential buildings. Therefore, Rahimi (1991) hypothesized and presented some evidence that even though a large proportion of deaths occur due to the collapse of the structural elements, the majority of injuries can be traced to factors related to nonstructural elements, building contents and human behavior. Arnold et al. (1982) indicated that all 47 injuries in the Imperial County Services building occurred due to occupant behavior and building contents; there was minimal damage due to nonstructural elements and mechanical and electrical components. Ohashi & Ohta (1984) also included that building contents were important in injury causation. Archea (1990), Aroni & Durkin (1985) and Arnold et al. (1982) showed that moving about during the earthquake may increase risk of injury. Ohta & Ohashi (1985) and Rahimi (1991) state that occupants' reaction to the onset of shaking is highly significant in possible avoidance of injury. About 50% of the 47 injuries reported by Arnold et al. (1982) occurred when occupants engaged unnecessarily in evasive behavior. In a number of cases, occupants suffered injuries by "bumping into objects" in an attempt to protect themselves. Also, a common misperception is that moving under a doorway is a safe action. It has been reported that several occupants experienced buckling injuries or impacts by swinging doors while standing in a doorway (Aroni & Durkin, 1985). Another study on residential environments concluded that the majority of injuries sustained by elderly occupants were falls related to the clustering of floors and poor lighting (Watzke, 1989).

Proposed Approach

Two approaches have been suggested by researchers to increase the safety of occupants during earthquakes. The first one is the behavior modification approach where individuals are trained to respond appropriately to minimize perceived and actual risks during shaking (for a review, see Murakami and Durkin, 1988). Behavior of individuals during and after earthquakes is an important component in design of educational materials targeted for general or specific populations. In order to change the perception of controllability and hazard reduction in an earthquake event training and educational programs should contain explicit self-protective actions and procedures. These requirements must begin with general descriptions of behavior and become specific on how these behaviors can be modified or adapted to increase safety. The second approach is the proper design of interior layouts, nonstructural elements, and building contents to minimize sources of hazards inside buildings. Again, very little research has been performed in this area, particularly in regard to the interactive role of these elements when the structure remains relatively intact (for an example on isolating large computers, see Yaghoubian, 1991). Our research is organized to explore the common grounds of both approaches within a multi-disciplinary framework.

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POST-EARTHQUAKE DAMAGE ASSESSMENT DEMAND AND CAPACITY

Charles Scawthorn

A great earthquake striking a major urban area will affect tens of thousands of buildings, with some significant fraction of these buildings sustaining structural damage. Each damaged building will require several stages of damage assessment and repair. A serious problem, noted during the October 17, 1989, Loma Prieta earthquake, will be the timely and effective utilization of qualified professionals to assess damage and develop and supervise repairs.

For example, the San Francisco Bay Area has, very approximately, perhaps 1,000 high-rise buildings, and perhaps 100,000 non-wood buildings (Los Angeles and Tokyo have many more such buildings). In the case of the San Francisco Bay Area, it is conceivable that 20% of the buildings in the area may sustain some damage--to the extent that they are "tagged" yellow or red. While much of this damage will be nonstructural cracking, or light structural damage, each damaged building will require professional effort to (i) assess the damage and (ii) if necessary, develop and supervise repairs. For discussion purposes we might estimate that perhaps 20% of the damaged buildings (i.e., 4% of *all* non-wood buildings in the Bay Area) are structurally damaged and will require structural repairs before they can be reoccupied, while 80% only require professional assessment before they can be reoccupied (although they may still require major nonstructural repairs before they are usable). Further, we might estimate that the 80% nonstructurally damaged buildings may require on average 10 hours of professional effort, in an emergency mode, while the structurally damaged 20% may require on average 200 hours to assess damage and develop and supervise repairs. Using these numbers, we find the total professional effort required to reinstate this building stock is estimated to be approximately 960,000 hours (note that this ignores damage to wood frame buildings). This is equivalent to about 600 professionals working 60 hours per week for six months.

There is little doubt 600 professionals (or two to three times this number, for Los Angeles) can be recruited, from unaffected parts of California as well as the rest of the nation, for the task of assessing damaged buildings and developing repairs. However, substantial time will be required before these professionals can be effectively utilized. Delays in their utilization will be due to a number of causes, including:

1. Each jurisdiction will need to set guidelines as to structural damage. When is structural damage sufficient to warrant prohibiting use of the building? For example, are cracked infill walls in a frame building structural or nonstructural damage? While they are not part of the calculated lateral force resisting system (although they may still contribute to lateral force resistance), cracked infill walls typically pose a life safety hazard (i.e., the building is not structurally damaged, but the partitions are).

2. Each jurisdiction will need to set guidelines as to structural repair, that is, should the building be repaired to its pre-earthquake condition, or to some higher standard? This was a major issue following the October 17, 1989, Loma Prieta earthquake, with different jurisdictions setting significantly different, sometimes inconsistent, policies. Complicating this issue is insurance practice, which often reimburses the building owner only for the cost to restore the building to its pre-earthquake condition. Note, however, that some insurance policies reimburse for increased costs of construction, including the cost to rebuild to standards exceeding the pre-earthquake condition of the building

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Present guidelines do not address these issues. The ATC-20 guidelines, for example, address immediate emergency review of buildings; the issues identified above arise following the ATC-20 yellow or red "tagging" of a building. Examination of these issues prior to the event, and development of guidelines similar to the successful ATC-20 guidelines, is an urgent need. Otherwise, substantial numbers of buildings will be unoccupiable while these issues are resolved in an ad-hoc fashion following the earthquake, with associated personal hardships and economic consequences.