GROUP REPORT
&
ABSTRACTS

Group 7

Recovery & Reconstruction
Assessment and Repair of Damaged Structures

GROUP 7 REPORT
RECOVERY AND RECONSTRUCTION
ASSESSMENT AND REPAIR OF DAMAGED STRUCTURES

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Co-Recorders: Sigmund Freeman and Shunsuke Sugano

Discussion Issue 1. Identify critical issues that have emerged in recent earthquakes.

In the discussions it became clear that urban lifeline issues were distinct from building issues. Real time monitoring systems for lifelines are needed to report the operational status of these systems following the earthquake. These systems must be able to identify and locate damage or local failure so that essential information is available for management decisions on priority repair. It was stated that such decision management should include the effects of multiple lifeline interactions. For example, the failure of the electrical distribution system will result in local failure-disruption of traffic controls, emergency water pumping, etc. If the management decisions do not include the effects of "secondary consequence," it is likely that the wrong priorities will be used during the repair-recovery response phase.

The need for lifeline system strength, redundancy or alternative paths, and critical element fail-safe items was recognized. This issue will be discussed in more detail in the next section.

The main issue for buildings was the need to establish and calibrate a reliable building damage assessment system and to educate appropriate professionals for its operation. This applied to both structural and nonstructural damage assessment. In addition there is a recognized need to establish repair criteria, and rational implementation procedures and methods prior to the damaging earthquake. In some earthquakes, where a damage assessment program is in place, there have been problems with enforcement. In some cases, building owners have disregarded the damage assessment and have continued to occupy the structure.

Discussion Issue 2. Identify lessons learned in recent earthquakes.

For the purposes of Group VII discussion, recent earthquakes were defined as Miyagi-Ken-Oki, 1978, for Japanese experiences and Loma Prieta, 1989, for U.S.A. experiences.

Redundancy of lifeline and transportation systems is essential for speedy recovery and reconstruction. The failure of the Bay Bridge was somewhat mitigated by the multiple other bridge crossings and alternative modes of transportation in the Bay Area. In assessing the transportation systems, critical links must be identified and made as fail-safe as possible. For other lifeline systems, critical nodes should be made fail-safe.

Simultaneous multiple utility (water, gas, sewer, telephone, electric, etc.) cooperative repair of earthquake damage resulted in minimal inconvenience to users and high efficiency for the utilities. Cooperative agreements and plans should be in place before the damaging earthquake occurs.

Examples of weak links preventing catastrophic failures were noted. For example, the Bay Bridge link failure probably prevented a collapse of one or more of the Oakland approach truss spans. Failure of one of these truss spans would have delayed reopening of the bridge by many months.

Although several cities have now established rules for damage assessment and associated repair criteria, the lack of these rules and criteria before the earthquake delayed many repairs and put other owners into financial conflict between the city demands, the insurance company proposed settlement, and their individual financial resources. By having established rules and criteria, and by having the earthquake insurance policies recognize these mandated requirements, the liability for repair-reconstruction including upgrades will be understood before the event by all parties (the government (e.g., FEMA), the insurance writer and underwriter, and the owner). This will eliminate much of the litigation and speed the reconstruction.

One of the biggest problems for the design professionals and researchers is the lack of access to damage information and other technical information, such as strong motion records. Individual owners and institutions hide information on building damage to limit their perceived liabilities. Some action (probably legislation) must be taken to ensure the rights of the citizens to understand the reasons for structural and nonstructural damage and to have access to other technical information in order to lessen the likelihood of similar damage resulting from future earthquakes. This information is needed from both public and private property.

The lack of design professional coordination during original design of building systems has led to avoidable local seismic damage. Damage to mechanical and electrical linkages across seismic structural joints was given as an example observed as a consequence of the Loma Prieta earthquake.

Although building pounding was not as serious in these recent experiences as was the case in Mexico City (1985), the need to consider building separations and/or building interactions during reconstruction was noted.

Finally, the influence of local site properties on the performance of buildings and lifeline nodes and links was noted. Although this lesson should have been learned from most of the past earthquakes, its lessons have not been adequately implemented yet.

Discussion Issue 3. Note changes in practice that have resulted from recent earthquakes and ensuing research.

The recent earthquakes have had a profound effect on individuals and governments to upgrade existing buildings and facilities for improved performance during the next earthquake. It has also encouraged the utilization of innovative upgrading techniques, such as base isolation and energy dissipation through mechanical damping devices.

Some cities are in the process of establishing rules for building seismic resistance assessment and criteria for repair-upgrading for damaged buildings. The next step will be to ensure that earthquake insurers recognize and write into their policies the need for seismic upgrading during reconstruction and that the associated costs are covered by the insurance policy.

Those professionals who have studied the recent earthquakes are paying more attention to mechanical equipment and architectural components during their design of new buildings and reconstruction of damaged buildings. However, these lessons need to be distributed broadly throughout the design profession.

Governments and utilities have recognized the need to identify and strengthen critical nodes and links in their distribution systems. These design changes are being combined with enhanced system redundancies and backup systems.

Media coverage during and following the recent earthquakes has increased the public awareness of the earthquake hazard. This awareness should translate into public official action to locally mitigate the consequences of the next earthquake on their community-county-state.

Discussion Issue 4. Identify problems that continue to challenge improved preparedness, response and reconstruction practices.[1]

Coordination of multiple utility damage assessment and simultaneous repair is very difficult. No organization currently exists that can integrate or coordinate such activities. The creation of a common understanding of lifeline damages and recovery procedures and priorities is difficult and time-consuming.

On-line seismic monitoring systems that are capable of intelligent decision actions need to be developed. Lifeline system network performance models need to be established and calibrated so that when adequate system performance and damage data are available the model can be used to select alternative operational modes. These models can also be used to assist in reliability assessments of the current system during scenario earthquake events.

Discussion Issue 5. Identify existing research needs and areas of future collaboration.

An information management system for lifelines should be developed which can provide an understanding of the impact of damage at various locations and the consequences of various repair-reconstruction sequences on system performance during recovery. This management system will require an effective monitoring system. However, the following research is needed to develop this monitoring system: definition of damage-related ground motions, spatial interpolation of earthquake ground motions, development of appropriate sensors, sensor data processing and interpretation, and system operation optimization.

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[1] Group 4 met with Group 7. Their comments on the last two questions are included in the Group 4 report.

WORKING GROUP ABSTRACTS

ASSESSMENT OF STRUCTURAL DAMAGE AND CRITERIA FOR REPAIR

Sigmund A. Freeman

Introduction

For the past thirty years California structural engineers have been concentrating their efforts on developing earthquake provisions for the design of new construction. For the past twenty years work has been progressing on evaluation and upgrading techniques for existing (undamaged) buildings. Also during that period procedures have been developed for earthquake emergency preparedness and methods for engineers to rapidly assess earthquake damage for hazards to occupants (i.e., red, yellow, or green tag buildings). However, during all that time it seems that nobody thought of what to do with the damaged buildings after the earthquake. Thus, shortly after the Loma Prieta earthquake of 1989, cities such as San Francisco, Oakland, and Santa Cruz had no available guidelines on how to assess and repair the earthquake damaged buildings so they could be put back into use.

Effects of the Loma Prieta Earthquake on the San Francisco Bay Area

Although the Loma Prieta earthquake would be considered moderate, with a short duration and located some 50 miles away, the ground motion was fairly significant in some soft soil areas of San Francisco and Oakland. A large number of buildings were damaged to the point that they were considered hazardous and had to be evacuated. Of particular interest are moderate-rise (e.g. 5 to 8 stories) residential and office building. Most of these buildings were constructed in the first quarter of this century of steel or concrete frames with unreinforced masonry (URM) infill and facade. Other types of buildings of interest are old URM bearing wall buildings and a small number of newer reinforced concrete buildings.

City of Oakland Experience

After the initial assessments were made of damaged buildings, the City of Oakland developed a procedure for reassessing the damage and criteria for repairing the buildings. An emergency ordinance was passed that defined a limit on damage that could trigger a requirement for a seismic upgrade of the building. Prior to a final ordinance on earthquake damage and repair, meetings were held with a coalition of interested parties to be able to address the concerns of the public.

Development of a Procedure for Damage Assessment

The first step is to define classifications of damage. Of prime importance is structural damage that results in loss of capacity to resist future earthquakes. If a prescribed percent of lost capacity is used as a triggering device to require a seismic upgrade, then guidelines are required to aid in the evaluation procedure. A damage assessment report (DAR) will include a description of the building, an illustrative presentation of the observed damage, an engineering evaluation of the damage and proposed concepts for repair. If analytical procedures are used to evaluate the damage, the results of such an analysis should be consistent with the observed

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damage. The DARs can serve as a useful data base for learning about how buildings perform when subjected to earthquake ground motion. It would be useful to have similar reports on buildings not damaged by the earthquake. For example, it could show by analytical procedures why the building was not damaged and how close it was to being damaged.

Case Histories

Three types of buildings are of prime interest: URM bearing walls, steel or concrete frame buildings with infill URM, and older reinforced concrete buildings. Based on actual case histories from the Loma Prieta earthquake, representative sample buildings can be used for purposes of discussing procedures for evaluation and repair criteria. Also of interest are buildings built since the 1960s that are damaged by earthquakes. In most cases, the damage will be due to some deficiency in the design or construction. Should these buildings be required to be brought up to current standards or can just the deficiencies be corrected?

Repair Criteria and Their Impact

In the development of a repair ordinance, consideration must be given to the social and economic issues as well as earthquake hazard mitigation. What is the purpose of an earthquake repair ordinance? The prime purpose would appear to be life safety; but then, isn't that the purpose of the seismic provisions of the building code? Life-safety must be defined. A general description of life-safety is to prevent collapse of the building and to place some limitation on damage. The damage limitations are required to reduce the potential for falling debris and to allow safe exit of the occupants. The public does not usually understand the implications of the earthquake provisions of building codes. Whereas, the engineers that developed the code think of the seismic provisions as a minimum standard to prevent collapse, the public often thinks of it being an overly conservative engineering approach for designing buildings. Alternatives to the standard static lateral force procedures should be encouraged; however, guidelines and review procedures are required to ensure reasonable compliance with the intent of the seismic provisions. Even when reduced standards are adopted some elements of the public sector will demand further reductions. It should be noted that the cost of seismic upgrade is not necessarily a major part of the total costs of repairing damaged buildings, particularly if mechanical, electrical, and fire safety systems will also be upgraded. Consideration must be given to both costs and benefits as well as the availability of financing for the owners.

The Need to Develop Rational Procedures and Methods of Implementation

Although public safety is the prime concern, there has to be some balance between seismic hazard mitigation and social and economic issues. How well do we know the effectiveness of seismic upgrade procedures? This question applies to repairs of damaged buildings as well as to seismic upgrades of existing buildings that are labeled as being hazardous. For existing buildings, standard code procedures that were developed for new construction are sometimes difficult to implement and there is no guarantee that they will satisfy the intended performance level. A performance criterion or limit-state procedure would appear to be a more rational approach to hazard mitigation; however, it should be noted that it will not always lead to a less expensive seismic upgrade. Procedures are presently available; however, there is a lack of experience and understanding within the engineering profession on how to implement these alternative procedures. There is a need to develop some sort of rating system for categorizing the seismic safety of buildings so that users, owners, and financial institutions can make decisions on balancing safety and costs. Users have a right to know the status of compliance a building has with respect to earthquake resisting design and construction. Owners have rights, within limits, to make cost-benefit decisions on the level of seismic upgrade that they can justify. The public must decide what level of safety is required. The engineering profession must provide the means to meet these objectives.

SELECTION OF APPROPRIATE REPAIR AND RECONSTRUCTION STRATEGIES

Robert D. Hanson

Introduction

Recent post-earthquake experiences, such as those from Mexico City following the 1985 Mexico earthquake and from the San Francisco Bay Area following the 1989 Loma Prieta earthquake, have shown that cities are not prepared to provide repair criteria for design or construction. Although both locations have a large pool of expert designers and constructors, the public officials did not have a basis on which to approve designs and reconstruction. The Mexico City technical community quickly formulated and enacted a provisional seismic design code and specified that all repaired buildings needed to meet the same criteria as new buildings. They simultaneously increased the seismic design requirements for all these buildings. Repair and reconstruction in Mexico City has progressed slowly.

Similar actions were not taken by most of the Bay Area governments; nevertheless, repair and reconstruction are proceeding slowly. Several city governments did constitute a technical advisory panel to advise them on their needs for repair and construction criteria, notably Oakland and Watsonville.

One of the major problems is the lack of understanding by the public official of the repair and reconstruction options available and their costs both in terms of time and money. This is further complicated by technical disagreements among the design professionals as to the necessary level of repair and reconstruction for public safety.

Return to Pre-Earthquake Condition

Many techniques have been used to restore the strength of damaged structural members to their initial strength. For lightly damaged members the repairs are relatively simple and easy to accomplish. For example, cracks in reinforced concrete shear walls have been repaired by injecting epoxy to reconnect the adjacent surfaces. In cases with more severe damage, broken concrete has been removed, fractured reinforcing steel rewelded, and new concrete placed. In the former situation the repair probably restored the member strength, but not the member stiffness. In the latter case the repair probably resulted in increased local strength and increased local stiffness. Thus, both cases result in a change in the dynamic properties of the building, the distribution of seismic forces in the building and its expected performance during the next earthquake.

The point is that even for relatively simple repairs care must be taken so that the performance of the entire structural system is not degraded while increasing the strength locally. This can be easily controlled by appropriate language in the seismic design and construction criteria for repair and reconstruction.

Several of the currently used member repair/strengthening techniques have been subjected to experimental evaluation in a controlled laboratory setting and others have experienced subsequent earthquake action to validate their performance characteristics. Other techniques are being utilized without the benefit of such validation. It is recommended that new techniques be carefully evaluated, including experimental verifications when appropriate, before being accepted in a repair/reconstruction program.

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Enhanced Seismic Resistance

Ideally all buildings to be reconstructed should utilize the best current knowledge which can be interpreted as satisfying the criteria of the current building codes or, in the case of Mexico City, something better than the current code. The difficulties in increasing the earthquake resistance of existing buildings have been clearly seen by our Mexican colleagues, but they concluded that public safety required this action. Oakland and Watsonville have established repair/reconstruction criteria which are less severe than current new building code requirements.

Utilization of traditional repair/strengthening techniques to develop enhanced earthquake resistance usually results in increased building weight and increased building stiffness. These result in large increases in foundation loads. For buildings on strong foundation materials this is not a severe problem, but for buildings on weak foundation materials this becomes a major factor in the reconstruction costs.

New techniques and materials, such as base isolation, supplemental damping, combined passive control systems, and multiple passive control systems will play an increasingly important role in new construction and in repair/strengthening reconstruction. The advantages of these systems are that the weight of the building increases very little and usually the seismic forces decrease. Thus, no increases in the foundation loads occur when these systems are utilized. While these systems eliminate many of the traditional problems associated with repair/strengthening, they add new problems unique to themselves. It is recommended that these new systems be experimentally and analytically evaluated prior to their use. Some systems have already been evaluated, but others need further study before they can be utilized.

Needed Action

The Federal Emergency Management Agency (FEMA) has a current effort to develop professional consensus documents which will provide Recommended Guidelines for Seismic Rehabilitation for Existing Building and a Commentary to these Guidelines. These Guidelines and Commentary will serve as a resource document for building officials after it it completed (1994?). It is necessary for the building official to establish acceptable criteria for the repair/strengthening of existing buildings now, prior to a damaging earthquake. Because it is recognized that the greatest earthquake hazard in our U.S.A. cities is the existing building inventory, the building official can establish criteria for upgrading these existing buildings, thereby providing the first step in establishing a criterion for the repair/reconstruction following a damaging earthquake. The lessons learned in administering an upgrading program can be used to fine-tune the repair/reconstruction program.

Action Items

1. Establish criteria for the seismic hazard reduction of existing buildings.
2. Approve techniques for upgrading existing buildings. These techniques will not require additional experimental and/or analytical verification prior to their use in the city.
3. Establish design criteria for the repair/reconstruction of buildings damaged during an earthquake.

4. Approve techniques and systems for the repair and/or reconstruction of damaged buildings. Those techniques for which the strength and stiffness characteristics are established by the profession do not need additional verification. Encourage approval of new alternative systems for repair and/or reconstruction utilizing new products as they become available and are verified.

5. Maintain a close working relationship with the earthquake hazard mitigation professionals in your community. Use these professionals as a resource to assist in solving community problems.

Building officials are encouraged to utilize the professional talents available in their communities and/or nearby communities. These earthquake professionals from the breadth of the earthquake hazard mitigation field can cooperatively provide vital information to enhance public safety and welfare.

EFFICIENT INFORMATION PROCESSING INCORPORATING SYSTEM INTERACTIONS OF LIFELINES UNDER URBAN EARTHQUAKES
PART I

Hiroyuki Kameda[1] and Shiro Takata[2]

Information management under earthquake emergencies is discussed on the basis of the activities of the Committee on Lifeline System Interactions Studies and Development of Information Management System under Urban Earthquakes (LSI & IS Committee). This paper will explain the objectives of the Committee as well as some of its achievements. This paper, together with a companion paper by Hayashi, Iemura and Kameda, will give a comprehensive overview.

Objective of LSI & IS Committee

The LSI & IS Committee was organized as a part of technical activities of the Japan Society of Civil Engineers, Kansai Chapter. The official period of its activities was April 1989 - March 1991. Its final report was completed in November 1991 (JSCE Kansai Chapter, 1991).

The objective of the Committee was to identify system interactions between different lifelines under earthquake emergencies, and thereby to develop an agenda for engineering research and development to enhance comprehensive seismic safety and reliability of urban lifeline systems. It was regarded as an important issue, in discussing the system interaction under earthquake emergency, to have the problem linked with the establishment of an efficient information management system. For these reasons, "lifeline system interactions (LSI)" and "information systems (IS)" were the main key words of the Committee activities.

The Committee members consisted of 36 official members and observers. The most significant feature of the membership was that engineers from all categories of the lifeline industry came together to discuss the subject matter frankly. Government engineers and university researchers engaged in lifeline and urban earthquake risk issues also formed a major part of the membership.

Outline of Accomplishments

The final report of the Committee activities consists of three parts: (1) Overview: introduction, historical review and status-quo of earthquake protection of lifelines; (2) Part 1: state-of-the-practice of earthquake protection of individual lifeline systems, and (3) Part 3: disaster information management under system interaction.

Among the items indicated above, Part 3 presents the results of discussion on three major topics that were identified as important issues on the basis of the contents of the Overview and Part 1. Three topics were dealt with in work groups:

WGI: Seismic monitoring systems for early detection of earthquake damage.

WGII: Conceptual design of information management systems incorporating lifeline system interactions.

WGIII: Case study of the Loma Prieta Earthquake.

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The following part of this paper will summarize the results from WG I; results from WG II and WG III will be presented by Hayashi, Iemura and Kameda.

Seismic Monitoring Systems for Early Detection of Earthquake Damage to Lifelines

1. The concept of seismic monitoring systems is closely connected with information management and automatic systems control under earthquake emergency. It is particularly important to make quick and accurate estimations of damage to lifeline network components immediately after an earthquake. There was consensus among the committee members that early damage detection is essential for efficient restoration of lifelines. Seismic monitoring systems will be a powerful means to achieve this information.

   Typical systems for seismic monitoring can be realized by installing seismometers at various locations. Automatically telemetered systems combined with data processing packages generate useful information for emergency response activities. This type of system will be useful not only for lifeline systems but also more comprehensive urban seismic hazard reduction. Besides the activities of LSI & IS, detailed discussions were also made by Kameda and Morikawa (1991). Takada et al. (1991), and Kameda (1991).

2. Existing seismic monitoring systems for Japanese lifelines are mainly used for emergency shutdown to maintain safety and serviceability. Figure 1 shows a shutdown system for water services. Table 1 is a list of such systems including other examples. They are all cases where seismographs are used as seismic sensors. Besides, monitoring systems to observe flow characteristics like electric current, gas and/or water flows are also being operated.

Acknowledgments

The LSI & IS Committee activities which lay the basis for this paper were performed by researchers and engineers from (1) lifeline industries in power, gas and water supply, sewer, highways, railways and telecommunications; (2) government offices involved in earthquake emergency management and construction infrastructures; and (3) university academicians. We are not able to mention their names because of limited space but gratefully acknowledge their great contributions.

References

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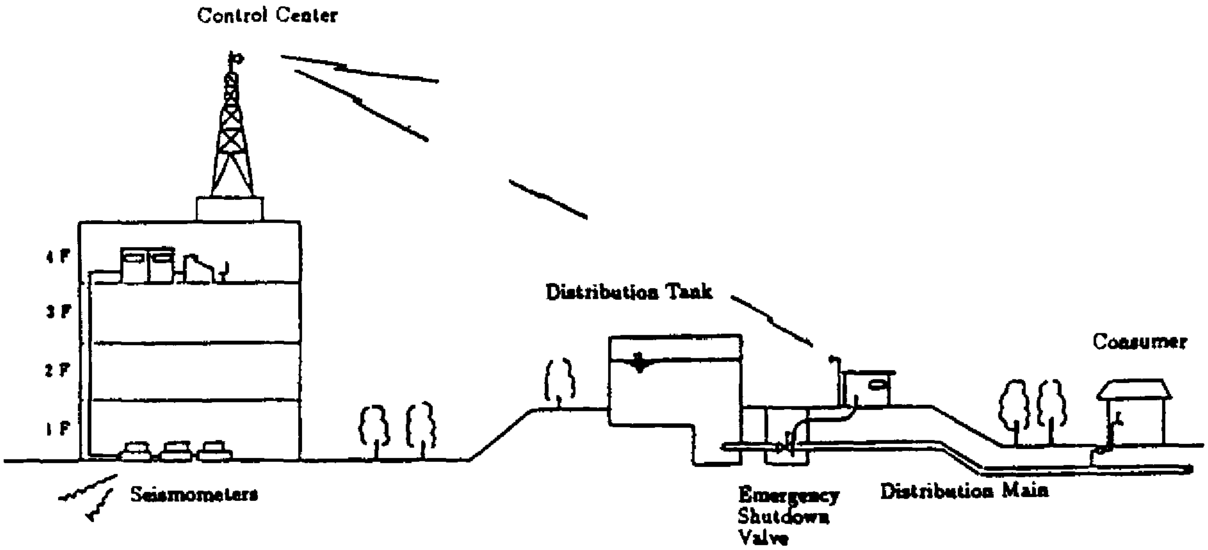

Figure 1 Emergency Shutdown of water service under earthquakes.

	organization	object of shutdown	who or what activates shutdown order	method of shutdown operation
water supply	Kobe C.	distribution storage	seismograph at Control Center	automatic remote control
	Osaka C.	distribution storage	seismograph	automatic shutdown
	Tokyo M.	distribution storage	seismograph	automatic shutdown
highway	Hanshin Expwy.	vehicle traffic	Director of Control Dept.	information board
	Shuto Expwy.	vehicle traffic	-	radio and information board
railway	JR(narrow gage)	trains	Control Manager	announce to trains and stations
	JR(Shinkansen)	trains	seismograph	automatic shutdown
	Osaka C. Rapid Trans.	trains	Train Operation Center	announce to trains + automatic shutdown
	Tokyo M. Rapid Trans.	trains	Train Operation Center	announce to trains and stations
power	Kansai Elec.	turbine generators	seismographs	automatic shutdown
	Tokyo Elec.	turbine generators	seismographs	automatic shutdown
gas	Osaka Gas	plants, holders, governors	Central Control Center	announce to local offices
		customers	micro-comp. gas mater	automatic shutdown
	Tokyo Gas	plants, holders, governors	Central Control Center	announce to local offices
		customers	micro-comp. gas mater	automatic shutdown

Figure 2 Emergency shutdown of lifeline systems based on seismograph information (JSCE Kansai Chapter, 1991)

EFFICIENT INFORMATION PROCESSING INCORPORATING SYSTEM INTERACTIONS OF LIFELINES UNDER URBAN EARTHQUAKES
PART II

Haruo Hayashi[1], Hirokazu Iyemura[2], and Hiroyuki Kameda[3]

The System Interactions of Lifelines

Loma Prieta Earthquake

Based on various research reports, as well as their own field survey, Working Group III studied lifeline system interactions in the 1989 Loma Prieta earthquake. The purpose of this study was to provide a clear picture of how the interdependence among lifeline systems produced damages and use it as a basis for further earthquake preparedness. In this study, the following seven lifelines were selected: electric power supply, gas supply, water supply, sewage disposal, transportation (road traffic and urban railway), and telephone. Table 1 shows how the troubles with one of these lifelines resulted in damages to other lifelines.

As shown in Table 1, no lifeline was unaffected by electric power failure. It affected the other six lifelines such as cooling system shutdown for computers controlling gas supplies, pumping system shutdown for water supplies, traffic control system failure, and PBX system shutdown. Gas leaks also created a wide range of damages such as fires, electric power failures for fire protection, road closures, and gas meter shutoff. Telephone and communication system failures made the recovery process of various lifeline systems slow, as did highway disruption.

Taking into account the system interactions of lifelines, the following five points should be important goals for earthquake preparedness: 1) Fire fighting is the most urgent business to be done; 2) Communication systems should be kept alive; 3) Furnish back-up generator for important facilities run by electricity; 4) Drinking water should be secured; and 5) Road traffic should be kept open.

Kansai Area, Japan

Working Group II studied system interactions of lifelines in the Kansai area, which includes Kyoto, Osaka, and Kobe. In order to study the present state of the art, a survey questionnaire was administered to the following members of the Committee for LSI & IS: electric power supply, gas supply, water supply, sewage disposal, road and freeway traffic, intercity railways, urban subways, and telephone. The objectives of the study were to: 1) identify facilities which were dependent on other lifeline systems for their functioning, 2) specify how they are dependent, 3) describe devices to maintain their functions when the other lifelines failed, and 4) identify the information they want to obtain from the other lifelines during the emergency and recovery periods.

All the lifeline systems depended on electric power supply for their functioning. For those facilities of each lifeline system that were categorized as "nodes" of the network system, for example, water filtration plants, gas stations, and telephone systems, electricity provides the basic source of power, measurement, control, lighting, and communication. At these facilities, many devices have been adopted to protect their systems from electric power failure. These can be divided into two types. One type is to obtain electricity from at least two different substations. Another type is the installation of back-up generators and/or batteries.

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As to repairing "links" of the network system, for example, underground pipelines, a strong dependence on the road system was revealed. The recovery processes are strongly affected by road conditions. Thus, information concerning road and traffic conditions is the most important and indispensable information to optimize the recovery processes.

Two kinds of information are named to be important to obtain during the emergency and recovery periods. One is information concerning road and traffic as described above, and the other is information concerning damage to each lifeline system.

A Conceptual Design for Information Systems

System Analysis

There should be two different strategies to achieve lifeline preparedness for earthquakes. For those "nodes" of lifelines, which are small in number, the minimization of possible damage is the goal. On the other hand, the optimization of recovery should be the goal for "links" of lifelines because of their huge volume. Thus, it is realistic and feasible to increase preparedness to create a system that could optimize the recovery process from earthquakes. There would be no doubt that knowing damages for each lifeline as precisely and promptly as possible is the fundamental element of such a system. Thus, this system would take the form of an information system.

The information system for lifelines should fulfill the following constraints because lifelines are owned and run by independent organizations with different goals and different systems: 1) There should be no hierarchical structure among those organizations in the information system; 2) There must be some limitation on how far they could cooperate with each other to have a lifeline information system; 3) The main purpose of the information system may be to communicate facts concerning earthquake damage among the various lifelines; 4) Information should be gathered from and conveyed to many terminals; 5) Visualization of lifeline damages and recovery prospects should be done to facilitate intuitive understanding of the new reality; 6) Since the personnel working for lifeline organizations shift their job assignments with a very short cycle, the system should function to train novice and/or give expert advice to the personnel.

Based on these constraints, we could propose a computerized information system based on information concerning damages as well as on the prospects for recovery.

A Prototype

System: Damage mapping system for lifelines

Input: Location of damage
Name of lifeline damaged
Prospect for functional recovery

Output: Five different maps of damages with System Interaction Icon
(scales: 1:1,000 to 1:25,000)

Network: Looped network connected with optical fiber cable.

Table 1

	electric power supply	gas supply	water supply	sewage disposal	transportation		telephone
					road traffic	urban railway	
electric power supply	*	Santa Cruz: gas explosion due to electricity comeback (spark ignition) recovery work arrangement with electric power supply system	Santa Cruz: pump stopped for 10hrs (gravitative flow area survived; no water in pump-based supply area) S.F.: power failuer due to gas leak inspection, no water in pump-based supply area and Marina district no power for repair work EBMUD: short-term loss of power at Lafayette filtration plant, Oakland Control Center power loss, no service	S.F. and Santa Cruz: power failure at pump station	S.F. and Santa Cruz: traffic jam due to malfunction of traffic signal	S.F.: BART omitted stops at some stations to save electricity	capacity diminished due to use of storage cell PBX with no battery, malfunciton Pacific Bell: Bush/Pine Office(S.F.) coolant trouble no service for 3 hrs Hollister Office generator failure no service for 3 hrs GTE: Monte Bello Office (Los Gatos) failure of fuel tank of generator malfunction(6-7hrs)
gas supply	S.F. & Santa cruz: gas leak inspection before recovering electricity	*	Santa Cruz: no home treatment recovery work arrangement with gas supply system		S.F.: road closed due to propane fire (Rte. 80 WB Central Ave.)		
water supply		Santa Cruz: recovery work arrangement with water supply system	*	Santa Cruz: damage detection by analogy	S.F.: road failure due to water leakage (Marina District)		
sewage disposal			Santa Cruz: suspection of underground water contamination due to outflow of crude sewage from pipeline	*			
road traffic			Santa Cruz: no transporting machinery due to damage to bridge	Santa Cruz: damage detection by analogy	*	BART riders increased due to Bay Br. closure (Oct.23 : +60%)	
urban railway						*	
telephone			S.F. and Santa Cruz: overload				*

Nojima & Kameda (1990)

Lifeline Interactions in 1989 Loma Prieta Earthquake.

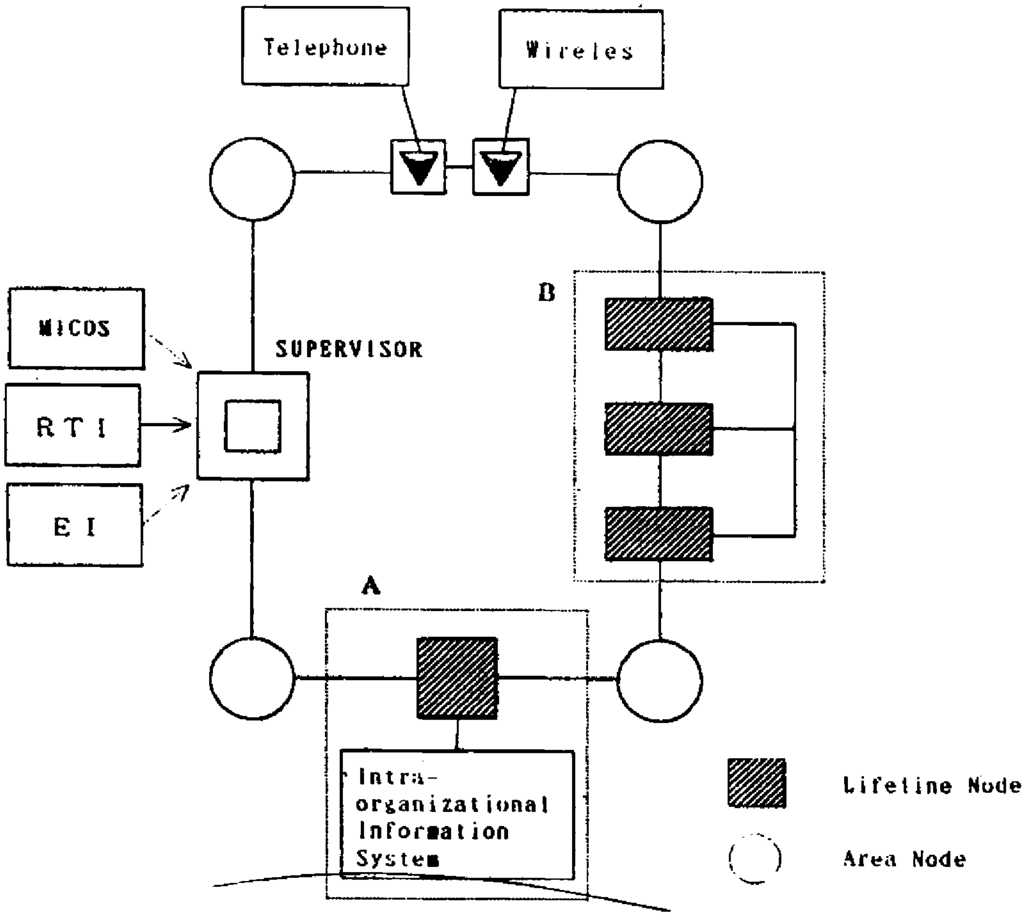

Figure 2. An Information Processing System for Lifelines

SEISMIC ASSESSMENT FOR NONSTRUCTURAL ELEMENTS ATTACHED TO EXTERIOR WALLS

Masamichi Ohkubo

Introduction

The seismic design methodology for new buildings was radically amended after the 1968 Tokachi-oki earthquake in Japan. After the earthquake a methodology to evaluate the seismic capacity of existing buildings, including the development of retrofit techniques, was developed. The seismic performance for structures has been improved both for new and existing buildings since then. A seismic evaluation methodology for nonstructural elements was also developed in 1977. The method developed, however, was somewhat conceptual, so it has not actually been used. Nonstructural damage, such as falling precast concrete curtain walls, window glass, chimneys, or parapets, has been observed at several earthquakes since the 1968 Tokachi-oki earthquake.

When the current seismic evaluation system for existing buildings was reconsidered in 1990 [Ref. (1)], another evaluation method was developed as an alternative technique for nonstructural elements. At the seismic screening the deformation of a nonstructural element forced from the structure and the deteriorated condition are evaluated along with the seismic capacity of the structural itself.

Basic Policy of Seismic Evaluation for Nonstructural Elements

Inertia forces generated into nonstructural elements should be evaluated as follows: (1) evaluate the response acceleration at the story where the nonstructural element is attached; (2) evaluate the amplification of acceleration to the nonstructural element; (3) calculate inertia forces generated into the nonstructural element; (4) calculate the strength of the nonstructural element or the joint; and (5) evaluate possible failure.

The deformation of a nonstructural element forced from the structure should be evaluated as follows: (1) evaluate the response story drift of the structure; (2) evaluate the deformation of the nonstructural element, considering its boundary condition; (3) evaluate the deformation capacity of the nonstructural element; and (4) evaluate possible failure.

Objects for Evaluation

Heavy objects, such as reinforced concrete parapets, handrails, precast concrete exterior walls, chimneys, advertisement panels attached to exterior walls, water tanks on the roof, coolers attached to exterior walls, etc., should be inspected against the inertia force caused by earthquake vibration. Window glass or finishing materials, which form the exterior walls, such as precast concrete panels, mortar, stones, etc., should be inspected against deformation forces from structures during an earthquake.

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Evaluation Techniques for Inertia Force

The inertia force F_n generated into a nonstructural element is computed using the following equation, $F_n = \beta_h \bullet k_{ir} \bullet W_n$ where, the factor β_h signifies the local amplification for the acceleration of the nonstructural element and the value 1.0 to 2.0, depending upon their boundary conditions, should be applied. The lateral seismic coefficient of the structure at the story level k_{ir}, is computer by Eq. (2). The coefficient C_i in Eq. (2) is called the Strength Index, and it is computer at the seismic screening of the structure. [Ref. (2)] The factor W_n in Eq. (1) is the weight of the nonstructural element itself. The factors W_j and H_j signify the story weight and story height of the structure, respectively as shown in

Eq. 1. $k_{ir} = c_i \bullet h_i \left(\sum_{d=i}^{n} w_j / \sum_{d=1}^{n} H_j \bullet w_j \right)$

The strength of a nonstructural element T_n against inertia forces should be calculated as the smaller of the strength of the nonstructural element itself or the joint strength.

The vulnerability level of a nonstructural element against the inertia forces is assumed as follows:

LEVEL-(A): $F_n < T_n$ (may not be vulnerable)
LEVEL-(B): $F_n > T_n$ (may be vulnerable)

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Evaluation Technique for Deformation

The deformation of a nonstructural element forced from the structure, R_n, is identified by the response story deformation angle of the structure, Rresp. The value Rresp is computed by Eq. (3),

$$R_{resp} = R_u \bullet I_{so} / I_{si}$$

where, the value R_u is given in Table 1. The Ductility Index F, Seismic Index of Structure I_{si} and the Seismic Judgment Index I_{so} are obtained from the seismic screening of the structure. [Ref. (2)] The vulnerability levels for failure of nonstructural elements is assumed as shown in Table 2.

Table 1: Relation Between F-Values and R_u

Ductility Index F of structure	0.8	1.0	1.27	1.6	2.0	2.6	3.2
Drift Angle R_u at the story	1/500	1/250	1/150	1/115	1/80	1/50	1/30

Table 2: Vulnerability Levels Depending On Deformation Angle R_n

	Rank-(A)	Rank-(B)	Rank-(C)
Window glass with hard putty	$1/500>R_n$	$1/500>R_n>1/250$	$R_n>1/250$
Window glass with soft putty	$1/115>R_n$	$1/115>R_n>1/50$	$R_n>1/50$
Glass block curtain wall	$1/500>R_n$	$1/500>R_n>1/115$	$R_n>1/115$
Precast concrete curtain wall	$1/250>R_n$	$1/250>R_n>1/50$	$R_n>1/50$
Tiles or mortar on walls	$1/500>R_n$	$1/500>R_n>1/115$	$R_n>1/115$
Metallic curtain walls	$1/50>R_n$	$1/50>R_n>1/30$	$R_n>1/30$
Nonstructural concrete walls	$1/500>R_n$	$1/500>R_n>1/50$	$R_n>1/50$

Evaluation of Deterioration Condition

The actual deterioration condition of nonstructural elements is observed visually by tapping with a hammer at the site. The result is classified into three ranks:

Rank-(a):	No deterioration
Rank-(b):	Visible deterioration
Rank-(c):	Remarkable deterioration

Final Judgment on Vulnerability

The final judgment on the vulnerability of nonstructural failure is discussed by the combination of vulnerability and deterioration as shown in Table 3 or Table 4.

Table 3: Nonstructural Elements Subjected to Inertia Force

Deterioration Ranks	(a)	(b)	(c)
Vulnerability Level (A)	Comment-[I]	Comment-[II]	Comment-[III]
Vulnerability Level (B)	Comment-[III]	Comment-[III]	Comment-[III]

Table 4: Nonstructural Elements Subjected to External Deformation

Deterioration Ranks	(a)	(b)	(c)
Vulnerability Level (A)	Comment-[I]	Comment-[I]	Comment-[III]
Vulnerability Level (B)	Comment-[I]	Comment-[II]	Comment-[III]
Vulnerability Level (C)	Comment-[III]	Comment-[III]	Comment-[III]

No special comment is recommended to the owner of the building in case of the Comment-[II]. Immediate treatment, including adequate repair, demolition, or off-limits designation of the surrounding area should be required in case of the Comment-[III].

Concluding Remarks

The lessons learned from past earthquake damage of nonstructural or structural elements are reflected in the vulnerability levels for the external deformation R_n. Accumulating data from actual earthquake damage is required to improve the details and to make wider use of this method.

References

1. Japan Building Disaster Prevention Association; Standard for Evaluation of Seismic Capacity Existing Reinforced Concrete Buildings, revised in 1990.

2. Masamichi Ohkubo: Current Japanese System on Seismic Capacity and Retrofit Techniques for Existing Reinforced Concrete Buildings and Post-Earthquake Damage Inspection and Restoration Techniques, Structural Systems Research Project Report No. SSRP-91/02 of University of California, San Diego, May 1991.