URBAN DESIGN VULNERABILITY COMPONENTS

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SUMMARY

As part of regional hazards mitigation programs, it is increasingly necessary to anticipate and predict the performance of the entire urban system in our metropolitan centers prior to, or during, major earthquake events for planning purposes. Despite recent technological advances in the testing and analysis of individual buildings and other physical facilities, it is clearly evident that components of the urban infrastructure in major cities remain vulnerable to major seismic activity.

The urban environment is a complex and closely knit system composed of many interdependent activities, services, functions, building types, lifeline elements, communication lines, and other critical facilities. The failure of any single, major component can severely affect the functioning of others and render the entire metropolitan area inoperable.

In this paper assessment is made of specific components which are essential to the continued operation of urban areas during earthquake events. Interrelationships between specific component parts are identified and assessed on the basis of urban scale considerations and impact on the infrastructure of metropolitan centers. They are examined for greater understanding of vulnerability characteristics of metropolitan areas so that cities can effectively anticipate their seismic performance and recovery after a major earthquake event on an urban scale.

INTRODUCTION

The San Fernando, California, earthquake of 1971 focused attention on the importance of seismic vulnerability on an urban scale when major freeway systems and several emergency service facilities collapsed, or were sufficiently damaged, to obstruct recovery efforts. In a similar manner, damaging earthquakes, with which the author has personal knowledge and which are the basis for this paper, occurred in the following cities after the San Fernando event and confirmed the lessons learned from an urban scale point of view as shown in Table 1 below.

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TABLE 1

URBAN CENTERS IMPACTED BY DAMAGING EARTHQUAKES SINCE 1971

Urban Center/Region	Location	Year
Managua	Nicaragua	1972
Tangshan	China	1976
Campania-Basilicata	Italy	1980
El-Asnam	Algeria	1980
Coalinga	California	1983

Despite considerable technological advances in the analysis and design of individual building systems after the referenced earthquakes shown in Table 1, it is clear that the total urban infrastructure in major cities remains vulnerable to severe, damaging earthquakes. While the design of individual buildings may be the primary responsibility of the design professional, urban-scale seismic resistant design is a shared responsibility between all parties involved in the planning, design, delivery, administration, and occupancy of cities: the architect, engineer, planner, consultant, seismologist, geologist, geophysicist, social scientist, developer, government official, private sector representative, and public. It is obvious in dealing with such a complexity of interrelationships as exhibited by a metropolitan center that life safety can not be achieved without the contribution of all parties involved. When coping with a major, damaging earthquake, it has been calculated that total damage to the urban infrastructure system can exceed by a margin of three to ten times the damage absorbed by all of the building stock located in the metropolitan area (EERI 1983).

URBAN SCALE VULNERABILITY COMPONENTS

The factors which define the components of urban scale vulnerability have received consideration by the earthquake engineering community on an individual basis, but due to the complexities of the problem, the interrelationships which make up the entire urban fabric are difficult to assess in a wholistic manner and it is only recently that they have received attention. Accordingly, it is appropriate to identify the major components of urban scale vulnerability and to understand how they may be evaluated by the role which they are expected to assume in earthquake hazard reduction programs. As presented in this paper, some of the major components which have a significant role to play in the vulnerability assessment of specific and critical metropolitan areas are indicated in Table 2 below.

TABLE 2

LISTING OF URBAN SCALE VULNERABILITY COMPONENTS

Component	Function/Implication
Existing Building Stock Classes	Urban Pattern
Adjacency of Buildings	Urban Density
Hazardous Contents	Fire/Explosion/Toxic Fumes
Location of Buildings/Systems	Land Use/Site Planning
Emergency/Critical Facilities	Response/Recovery
Lifelines	Life Support/Circulation
Bridges/Overpasses	Transportation
Communication Lines	Mass Media/Public Information
District Zoning	Urban Character
Street Patterns	Access/Egress
Reservoirs/Dams	Water Supply/Downstream Pop.
Open Spaces	Evacuation Areas

Failure of any components listed in Table 2 to perform effectively during an earthquake could lead to serious consequences in the function and operations of an urban system. A poor performance by any one of them can drastically exacerbate immediate post-earthquake recovery efforts.

Existing Building Stock Classification

This is perhaps the most important component in the vulnerability assessment of an urban area. In taking a comprehensive inventory of the existing building stock by building type classification to obtain construction data and characteristics, it is possible to evaluate the performance of buildings and assess potential damage losses by calculating the probable maximum loss on an aggregate basis for the entire urban region. Data rendered from building loss evaluations will produce important information for the computation of life loss, injuries, debris removal, residual capacities of urban functional and operational capabilities, and post-earthquake recovery time estimates.

The inventory will also reveal the amount and location of existing, older, hazardous buildings which are known to be extremely vulnerable to earthquake forces. The City of Coalinga is the most recent example in the United States of this phenomenon in which an entire eight block area in the central business district was demolished due to the collapse, or severely damaged condition, of older, unreinforced, masonry bearing wall type buildings. In this seismic event which occurred in 1983, it remains a miracle no immediate deaths occurred as a direct result of the earthquake and that there were few serious injuries.

Hazardous Contents

Fire following earthquake is a distinct threat to the urban area. This situation is exacerbated in metropolitan areas where the storage of hazardous materials occurs inside buildings or outside on the open ground. This is particularly true in industrial areas of the city where LPG plants, chemical materials, and other toxic substances are manufactured and kept in storage on inventory for later use.

All such locations of hazardous materials should be identified and mapped for future reference as potentially precarious areas which warrant monitoring during and after a severe earthquake. Unless the risk in these areas is taken into account before the event, consequences can be severe following a damaging earthquake if they are not given appropriate attention and respect.

Adjacency of Buildings

Several recent earthquakes have indicated that the spacing between buildings on adjacent properties is a critical component from the site planning point of view in congested areas of a metropolitan center. Rather than limit the vulnerability to the performance evaluation of a single, individual building, it obviously is necessary to analyze the performance of a cluster, or group of buildings, to fully realize their behavior on an urban scale. Examples have been recorded which clearly illustrate how a tall, slender, flexible building may be severely pounded to the point of collapse by a closely placed short, squat, stiff structure which is its immediate neighbor (Managua 1972 and Campania-Basilicata 1980).

On hill sites it has been documented that the collapse of older, existing, hazardous buildings may cascade down the hillside on top of the neighboring, newer, more earthquake resistant structures below and destroy them in a "domino effect" (Campania-Basilicata 1980). The three dimensional implications here, by their very nature, are peculiar to urban scale vulnerability aspects found in the topography and topology of a hilly metropolitan area not unlike those found in many cities located in the West Coast areas of the United States.

Location of Buildings/Systems

Another aspect of urban scale vulnerability which must be given serious attention is consideration of the location of buildings and systems within the city from a geologic point of view. Geologic mapping of hazardous areas is essential to a comprehensive understanding of critical areas in a metropolitan setting which have the potential of creating problems due to severe ground shaking effects. Poor soils areas known to have a high potential of liquefaction, subsidence, or landslide need to be mapped and designated critical zones. From an urban scale perspective, major damage to all physical facilities including buildings, lifelines, overpasses and bridges, communication lines, and dams, may be expected.

From an urban planning and design point of view, such areas are to be avoided, or identified as special study zones. No new construction, with the exception of single family wood frame houses, should be considered for these areas without a prior study of all geological conditions of the site to insure public safety (California, Alquist-Priolo Act, 1972). Mapping of such vulnerable areas has become an essential part of microzonation maps used in conjunction with post-earthquake reconstruction activities (Campania-Basilicata 1981, Ech-Chleff 1983).

Emergency/Critical Facilities

Hospitals, police stations, fire stations, communication centers and other emergency facilities are essential structures for the operational and survival functions of an urban area following a disaster. These facilities should be designed to higher performance standards to resist earthquake forces than other less critical facilities. The threat of an urban conflagration following an earthquake depends on the continued functioning of fire stations and other fire fighting equipment. The survival of hospitals is essential for immediate post-earthquake recovery efforts and their construction requires higher standards so that they may remain operational and functional after a damaging earthquake (California Hospital Act 1972). Without the availability of communication centers, it would be impossible to transfer information on the extent of the disaster or to assess total damage in the urban area. These three examples are not meant to be all inclusive, but are used as representative illustrations of the importance of emergency and critical facilities remaining operational and functional during and after major disasters.

Lifelines

It is clear that an urban center can not exist, or continue to operate, without the use of its lifelines. Even though there may not be any structural collapses of buildings or emergency facilities in an area, a city will not survive without electric power, water supply, sewage treatment systems, natural gas lines, freeways, and other types of lifeline facilities if its function depends on the continued operation of any one. Failure of one may cripple a city for a long period of time and render it inoperable during the emergency period. There have been many examples of this situation being confronted by specific cities after a major earthquake. Lifeline systems, therefore, require special attention to be certain that they will continue to function after a major disaster (Coalinga 1983, San Fernando 1971).

Bridges/Overpasses

In contemporary cities, the flow of surface traffic is an important element in its day to day operations. Automobile freeways which allow high speed access to, and egress from, important areas of a city are dependent on overpasses and bridges to keep all vehicles moving in an orderly manner. Damage or collapse of overpasses or bridges due to earthquake forces will serve to cut off and isolate a metropolitan center from the surrounding area, and disrupt vital transportation routes, including railroad lines. Search and rescue teams, and other emergency vehicles, will not be able to reach their target areas. After the San Fernando earthquake in 1971, the State of California concluded a multi-million dollar program which achieved the reinforcement of all its major, existing freeway overpasses and bridges throughout the state as testimony to the importance of this urban component.

Communication Lines

During the period immediately following a major, damaging earthquake, it is essential that an urban area have the capability fo communicate with areas outside of the impacted area for emergency assistance in many categories. Communication lines must be kept open so that the extent of damage and public needs may be indicated to emergency service units and emergency management agencies. In many cases it is wise to have "back-up" systems available in order to keep communication lines open following an earthquake.

District Zoning

It is important to remember that a city is made up of many districts which are quite distinct from one another in character, topography, and topology. This is part of the urban scale fabric which makes our metropolitan centers distinctive from surrounding rural areas. Accordingly in earthquake hazards mitigation criteria must be established for different zones of the city. For example, a performance criteria for a residential area must be quite different than that required for the central business district, or financial district. Industrial areas require a performance criteria all their own. Each district must be reviewed for its own unique characteristics, and mitigation plans developed accordingly.

Street Patterns

Debris in the street which blocks access and egress from severely impacted areas following an earthquake is a common occurrence in congested urban centers. It is a function of the heights of buildings on each side of the street and the width of the street itself. Many downtown centers of metropolitan areas are represented by older, congested parts of the city with narrow streets and financial districts with dense population. Access and egress from these areas, especially if there is the potential of a fire break-out following the earthquake, is essential. Accordingly, street patterns on an urban scale need close examination and should be made part of any mitigation plan developed for an urban area. Part of the plan should also indicate potentially safe evacuation routes and/or alternate, secondary arterials which would be relatively free from falling debris. Wide streets, the centers of which would not be blocked by falling debris, are a particular asset in hazards mitigation when dealing with urban vulnerability.

Resevoirs/Dams

The catastrophic failure of major dams and resevoirs in an urban area is a distinct threat to public safety, particularly to downstream population. The near failure of the Van Norman Dam during the 1971 San Fernando earthquake led to the evacuation of over 70,000 persons who occupied the downstream flood plain area. Other examples, such as in Italy, have been recorded where the primary cause of life loss and building damage were related to dam failure in hill areas which channeled mud, flood waters, and debris into the centers of inhabited spaces.

Urban hazards mitigation programs should contain an element dealing with the potential failure of major dams and reservoirs. Part of the element should deal with the calculation of the downstream population at risk and its evacuation. Analysis of the extent and size of the downstream flood plain and the rate of water flow in case of a catastrophic failure should also be completed (California Dam Safety Act 1972).

Open Spaces

Open spaces in metropolitan areas have always been considered an important planning element by contemporary occupants of our cities as population pressures and urban growth place a strain on the urban fabric. Primarily serviceable as parks, and for recreation purposes, they are also useful as evacuation areas, emergency housing and medical treatment spaces, or emergency feeding and food distribution points following a major earthquake disaster (San Francisco 1906, Managua 1972, Campania-Basilicata 1980, Coalinga 1983). In California and other areas, public schools designed under higher seismic standards and their grounds have also been targeted for such uses after a major disaster.

Urban vulnerability mitigation programs should identify all public, serviceable open spaces in the metropolitan area for potential use after a damaging earthquake. These should be earmarked as having the capacity to serve specific post-earthquake recovery functions.

CONCLUSION

This paper has presented a general overview of eleven major components dealing with the urban scale vulnerability of metropolitan areas. It is not intended to be an exhaustive list, but rather singles out the components believed to be the most critical in earthquake hazards reduction. By identifying the interrelationships of these components to the urban environment, it recognizes the fact that some earthquake hazards are more correctly approached on an urban scale rather than from the analysis of an individual building or facility. It is hoped that this paper gives a better understanding of the characteristics, range, and features of earthquake hazards reduction programs as an urban scale problem.

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