11 WCEE
Paper No. 2017. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC RISK ANALYSIS FOR URBAN SYSTEMS

M. ERDIK

Bogaziçi University, Kandilli Observatory and Earthquake Research Institute,
Department of Earthquake Engineering, 81220, Çengelköy, Istanbul, Turkey

ABSTRACT

The impact of earthquakes in urban centers prone to disastrous earthquakes necessitates the analysis of associated risk for rational formulation of mitigation strategies. In urban centers the seismic risk is best qualified and portrayed through the preparation of "Earthquake Damage and Loss Scenarios". The components of such scenarios are the assessment of the hazard, usually portrayed in terms of microzonation maps, and the vulnerabilities of various urban systems, such as physical and socioeconomic structures. This paper will discuss the present approaches and provide insights to the future developments.

KEYWORDS

Earthquake; risk; urban; vulnerability; hazard; loss.

BACKGROUND

In recent decades earthquake disaster risks in urban centers of both developed and developing countries have increased. The increase in the developed countries is due to aging urban systems and population, greater dependence on technology and simply, more values exposed to risk. Whereas in developing countries the main sources of the increased seismic risk can be attributed to overcrowding, faulty land-use planning and construction, inadequate infrastructure and services, and environmental degradation. Recent destructive events in Mexico City (1985, M8.1); Spitak, Armenia (1988, M7.0); Loma Prieta, USA (1989, M7.1); Manjil, Iran (1990, M7.7), the Philippines (1990, M7.8); Erzincan, Turkey (1992, M6.9), Northridge (1994, M6.8) and Kobe (1995, M6.9) exemplified the consequences of earthquake risk in urban areas and have attracted increasing attention of world community, at large.

The inevitability of the occurrence of earthquakes in earthquake-prone urban centers makes it imperative that certain preparedness and emergency procedures be contrived in the event of and prior to an earthquake disaster. In urban centers the seismic risk best portrayed and quantified through the preparation of “Earthquake Damage and Loss Scenarios”. In urban centers these scenarios are essential for risk mitigation, emergency response planning and the associated resource allocation /retrofit prioritization. The first ingredient of such scenarios is the assessment of the hazard, usually portrayed in terms of microzonation maps. The vulnerabilities and the damage statistics of lives, structures, systems, and the socioeconomic structure constitute the second ingredient. Earthquake damage scenarios are based on the intelligent consideration and combination of the hazard, secondary hazards and the vulnerabilities.

EARTHQUAKE HAZARD ASSESSMENT (MICROZONATION)

Earthquake hazard assessments, conducted in connection with risk analysis in urban centers, has been traditionally linked to a (or set of) scenario earthquakes in a deterministic manner. As such, the assessment of the urban earthquake hazard entails the specification of the scenario earthquake, compilation of information on propagation path characteristics, topographical, geological and geotechnical data, and the identification of the proper attenuation and site response analysis models. Urban earthquakes, notably 1985 Mexico City and 1989 Loma Prieta earthquakes, have demonstrated that, in addition to source distance, the wave propagation characteristics and site conditions play a deterministic role on the spatial distribution of losses. This shows the importance of macro- and micro-scale hazard assessment in the analysis of urban seismic risk.

In addition to the vibratory ground motion, urban seismic hazard assessments should encompass, tsunami inundation, soil failures, terrain movements, and surface fault ruptures, as appropriate. Although, a rational hazard assessment methodology should obviously provide for uncertainties associated with the input parameters, most of the past applications have been based on scenario events with minimum quantification or even qualitative treatment of uncertainty. Pertinent issues are discussed below:

Scenario Earthquake

The geological and seismological information forms the basis to predict the appropriate scenario earthquake, which is usually given broad terms, involving rupture length, location and the magnitude. The earthquake(s) may be associated with local, nearby and distant sources. For "worst case" scenarios the maximum event size is adopted. Scenario earthquake has also been defined as the largest earthquake(s) expected in a reasonable period time (generally 500 years). Although, the use of multiple scenario earthquakes can provide for the range of risk mitigation efforts to be planned, it can also decrease the public credibility of the risk assessment. A rational procedure for the selection of scenario earthquake in future investigations can be based on the deaggregation of the hazard to show which events contribute most to the loss (McGuire, 1995). As such, it will be an event with a high likelihood of occurrence in the source region, relative to other events that can cause the same loss. In light of the recent developments in earth sciences it will not be imprudent to state that the future specifications of scenario earthquakes will be more predictive in nature (WGCEP, 1995).

Attenuation Relationships

Attenuation models provide for the change of ground motion severity with source mechanism, distance and local geology. Currently reliable empirical models exist in terms of peak ground acceleration, velocity and displacement (PGA, PGV and PGD) and, pseudo spectral velocity (PSV), at specific frequencies and damping ratios, for given earthquake magnitude, distance, fault mechanism and local geology (e.g. Boore *et al.*, 1993; Campbell and Bozorognia, 1994; Gregor, 1995; Fukushima and Tanaka, 1990;Ambraseys and Bommer, 1995). Although the data are biased towards well instrumented regions of the world, recent comparisons indicate that, with identical definitions of input parameters, the difference amongst Western USA, Japanese and European based attenuation relationships are less than the scatter in any one of them (Fukushima and Tanaka, 1990; Ambraseys and Bommer, 1995). This finding enhances their utilization in other parts of the world with limited strong motion data. The availability of intensity-based vulnerability information have dictated the use of site-specific intensity attenuation relationships. These relationships are based on macroseismic data obtained from past earthquakes and yield MM, MSK or JMA intensities for given earthquake magnitude, distance and, possibly, for site conditions and fault mechanism. Owing to the subjective nature of the intensity scales, in most cases they are associated with substantial uncertainties reaching 0.6 MM units.

Although highly complex numerical simulation procedures exist for the determination of ground motion on the basis of fault rupture mechanism and wave propagation, problems associated with the parametrization will preclude their routine use in future earthquake loss scenario developments. An exception may be the use of quasi-stochastic models similar to that proposed by Boore (1983) and Boore and Joyner (1991). Future developments in empirical attenuation relationships will strive for smaller uncertainties through increased data and better definition of dependent and independent variables. An alternative approach can be the use of artificial intelligence (AI) programming techniques. Such techniques will use AI neural networks, based on macro-seismic data and local geology as learning sets, to predict ground motion severity. Another approach may be the use of knowledge tree to combine the uncertainties and expert knowledge.

Modification of Ground Motion by Site Conditions

For the quantitative reflection of the "Modification of the Ground Motion by Site Conditions" in the microzonation maps there exist analytical and empirical approaches. Analytical procedures range from simple one-dimensional calculations to three- dimensional, linear/non-linear, time/frequency domain and finite difference/element computations. In general, one-dimensional non-linear analytical procedures are utilized with idealized soil columns. In several blind tests carried out for the examination of these numerical approaches (ESG, 1992) , it has been found that the reliability of any numerical model depend substantially on the measurements of the non-linear characteristics of soils, which inherently exhibit large uncertainties and, furthermore, are expensive to obtain. These facts will tend to prohibit the application of purely analytical-numerical procedures in future developments of earthquake loss scenarios. However, recently developed quasi-stochastic procedures (e.g., Boore and Joyner, 1991 and Safak, 1995) offer wider possibilities of application. Safak (1995) formulates a three-parameter model (lower and upper corner frequencies and the averaged value over the effective frequency band of the Fourier amplitude spectrum) for the site-specific assessment of the Fourier amplitude spectrum of the ground motion.

In hazard assessments based on empirical intensity attenuation relationships, the modification of the ground motion has been traditionally expressed by some ad-hoc judgmental rules or, preferably, in terms of intensity changes empirically correlated with the ground conditions (e.g. Medvedev, 1965 and Everenden *et al.*, 1981). Most of the earthquake loss scenario developments in the USA have utilized such empirical correlations (e.g. Toppozada et al., 1988, 1993 and 1994). In another approach (e.g. Oyo, 1988), the PGA distributions on competent ground have been computed on the basis of attenuation relationships and then modified on the basis of analytical techniques applied to representative soil profiles. The modified PGA values have then converted to intensity values.

Recent empirical developments include the determination of AHSA (Average Horizontal Spectral Amplification) factors, which represent the average spectral ratio between the horizontal ground motion at a site with respect to a nearby rock site (Borcherdt, 1994). AHSA factors has been linked with site-dependent intensity changes (Borcherdt and Gibbs, 1976) and currently constitute the essential elements of the design basis response spectra encompassed in recent code revisions (Rinne, 1994). Future refinement of ASHA factors, especially for larger ground motion levels, will pave the path for their utilization in urban earthquake hazard and risk assessments.

Although several investigations have been made (Bard, 1995), corrections to earthquake ground motion parameters for the effects of topography, in routine applications, is very much a matter of judgment at the present time. Although, practical rules exist in some earthquake codes (e.g. AFPS 90 Recommendations, 1990), they have not yet found their way in the development of earthquake loss scenarios.

It is believed that in the future, integrated empirical procedures will be developed for the assessment of site-specific ground motion estimates corresponding to specified scenario earthquakes. These procedures will be based on GIS representations of spatial distributions of average shear wave propagation velocity and geomorphology. Installation of well designed strong motion arrays will serve to facilitate and accelerate the development of such integrated empirical procedures.

Earthquake Induced Ground Failure

For proper assessment of the seismic risk in urban centers the potential of the earthquake induced ground failure hazard, such as: liquefaction, landsliding and surface fault rupture need to be determined. Ground failure potential is defined as the probability of occurrence given the susceptibility of the ground and the opportunity exhibited by the ground motion severity. The information about the movements and the surface expressions of possible active faults should be considered in the seismic loss scenario developments or to assess their effects on structures and systems.

Techniques to evaluate the liquefaction potential are well established and generally involve the preparation of two types of maps: one showing the liquefaction susceptibility and the other expressing the opportunity for critical levels of shaking. The susceptibility and opportunity maps are merged to depict the areal liquefaction potential (Youd *et al.*, 1979). Although highly reliable site-specific techniques are available, because of their cost and need for extensive data, in most of the earthquake loss scenario applications the liquefaction susceptibility have been identified on the basis of geotechnic/geomorphic criteria (Youd *et al.*, 1979; Youd and Perkins, 1978 and Youd, 1991). The investigations on the quantification of the consequences of liquefaction are limited to few studies. Youd and Perkins (1978) have developed a so-called Liquefaction Severity parameter that measures the amount of differential ground displacement.

Techniques for the site-specific assessment of landslide susceptibility based on engineering parameters are developed (EERI, 1986; ISSMFE, 1986). In earthquake loss scenario developments, however, the most commonly used indicators of susceptibility have been based on geomorphic criteria (Wilson and Keefer, 1985). The probability that a landslide will be triggered on a particular slope during a particular earthquake is a function of both the pre-earthquake stability of the slope and the severity of the earthquake ground motion . As such, for future applications, the simple geomorphic criteria of landslide susceptibility will need to be refined with incorporation of methodologies from geotechnical engineering.

The future developments will be oriented towards the assessment of permanent and differential ground displacements associated with ground failure under various geomorphologic conditions described with extensive GIS database of surface geology and morphology. This will facilitate the definition of realistic vulnerability functions for displacement sensitive urban physical systems.

VULNERABILITY ANALYSIS

Vulnerability is defined as the degree of loss to a given element at risk, or a set of such elements, resulting from the occurrence of a hazard. The vulnerabilities of lives, structures, systems, and the socioeconomic structure are the main factors influencing the earthquake risk and losses in urban areas. Vulnerability analysis involves the elements at risk (physical, social and economic) and the type of associated risk (such as damage to structures and systems and human casualties). Vulnerability assessments are usually based on past earthquake damages (observed vulnerability) and, to a lesser degree, on analytical investigations (predicted vulnerability). Primary physical vulnerabilities are associated with buildings, infrastructure and lifelines. These vulnerabilities are agent- and site-specific. Furthermore they also depend on design, construction and maintenance particularities. Secondary physical vulnerabilities are associated with consequential damages and losses. Socioeconomic vulnerabilities include casualties, social disruption and traumas and economic impacts.

Primary Physical Vulnerabilities

Almost all of the earthquake loss scenario developments have used building vulnerability matrices that relate descriptive damage classes to earthquake motion intensities. Coburn and Spence (1992) provide observed vulnerability functions (percent of buildings damaged) for common building types. ATC-13 (1985) provides loss estimates for 78 different building and facility classes for California. To overcome the data limitations, the damage probability matrices and time estimates for restoration of damaged facilities were obtained by aggregating the expert opinions. Anagnos *et al.* (1994) have compared the data presented in ATC-13 (1985) with the findings from recent earthquakes and expressed the results in terms of log-normal fragility relationships. Intensity-based vulnerability matrices also exist for different parts of the world, and for indigenous building typologies. In these vulnerability functions the distinction between damage and loss is not explicit, since only very limited data exist on the cost of repairs. There is only limited experience with the earthquake performance of flexible structures such as moment resisting open frame structures and the base isolated buildings. These structures are responsive to ground displacements, which we currently do not have much information. Future vulnerability of buildings, especially steel structures, who might have developed undetected weaknesses in past earthquakes remains an issue that needs to be addressed.

I believe that the future developments in this field will be oriented towards the use of spectral parameters for the estimation of damage. The damage states will be formulated to incorporate variability of construction practices and the differentiation of damage to structural and architectural elements and the building contents. The relationship between the damage state and the monetary loss will also need to be defined in an explicit manner.

In addition to buildings, many other engineered urban structures, infrastructures, lifelines and services are vulnerable to the effects of earthquakes. Direct damage to lifeline facilities exacerbates damage to socioeconomic fabric by interrupting business. These secondary losses may exceed the direct loss. The earthquake vulnerability of lifelines are critical in the control of induced losses and socioeconomic losses. Kawashima *et al.* (1994) have shown that seismic damage propagates from primary lifeline damage to secondary functional damage to production, commerce and service sectors. If physical damage to transportation lines can be prevented 36% of all propagation paths, leading to secondary damage, can be interrupted.

Observations acquired from past urban earthquakes (EERI, 1986), supplemented by the worldwide experience has been used as a guide to assess their physical vulnerabilities. A compilation of lifeline vulnerability functions and estimates of time required to restore damaged facilities are provided in ATC-25 (1991). The vulnerability functions are based on the review of existing models and the expert opinion in ATC-13 (1985) supplemented by an expert technical advisory group.

Recent work on lifeline vulnerability is focused on pipelines, transportation and electricity networks. For example, Bendimerad and Bouabid (1995) have related the ground failure, water pipeline and nodal facility damages to respectively peak ground displacement, velocity and acceleration, obtained fragility functions for each component and assessed the system performance via a network analysis. Basöz and Kiremidjian (1994) have classified bridges on the basis of foundation, structure, material and geometric attributes and developed a relational database management system for the determination of their vulnerabilities corresponding to PGA levels. Werner et al. (1995), have utilized a GIS data base that incorporates data, models and methodologies for: Characterizing the system; estimating the seismic and geologic hazards; developing the component vulnerability models; incorporating the effects of post-earthquake emergency traffic management procedures for alleviating traffic congestion; and Assessing the impacts of each scenario earthquake on traffic flows throughout the system. Eidinger et al. (1995) have examined the empirical performance of components at high voltage substations in past earthquakes and derived fragility and restoration functions.

These models and network analysis need time and observational verification for future incorporation in the earthquake loss scenarios. In the future practical vulnerability models will be developed to yield damage, restoration time and cost as a function of appropriate ground motion descriptors such as PGD.

Secondary Physical Vulnerabilities

Only limited vulnerability models exist for secondary damages for secondary hazards, such as: post-earthquake fire, hazardous material release, explosions and water inundation.

Recent developments in fire following earthquake models (e.g. Dong *et al.*, 1995) include three stages: ignition, spread and suppression, and provide first-order estimates of total losses as functions of intensity, wind, building density and fire engine number. There does not exist any practical method for modeling hazardous material release and/or explosions. Tsunamis, seiches and dam failures may immediately proceed an earthquake in many urban centers and contribute significantly to the losses. High resolution mapping of areas susceptible to inundation necessitates accurate prediction of water run-up heights and water velocities affected by the interaction of onshore structures and topography (Sanchez *et al.*, 1991).

Focused reassert will be needed to develop practical secondary physical vulnerability models for their incorporation in urban seismic loss assessments. Hazardous material release associated with large scale industries and water inundation due to a dam failure will likely remain as highly source- and site-specific problems and defy generalizations.

Socioeconomic Vulnerabilities

In addition to the physical vulnerabilities, the socioeconomic vulnerability of the urban system also need to be assessed in terms of casualties, social disruption and economic loss for a comprehensive earthquake damage and loss scenario.

Casualties in earthquakes arise mostly from structural collapses and from collateral hazards. Lethality per collapsed building for a given class of buildings can be estimated by the combination of factors representing the population per building, occupancy at the time of the earthquake, occupants trapped by collapse, mortality at collapse and mortality post-collapse (Coburn and Spence, 1992). Future research and data acquisition will be needed to decrease the large uncertainties involved with casualty estimates. Social disruption needs to be measured in both quantitative (e.g. number of displaced families) and qualitative terms. The ethno-cultural context of the social disruption should also be considered.

Bulk of the current urban seismic loss studies have considered only the direct physical losses. However, it is generally known that losses due to collateral hazards and the indirect economic losses constitute a major portion of the total earthquake loss in an urban system. Indirect economic losses arise from discontinued service of damaged facilities and include: Production and/or sales lost by firms in damaged buildings; Production and/or sales lost by firms unable to receive supplies from other damaged facilities; Production and/or sales lost by firms due to damaged lifelines; Losses arising from tax revenues and increased unemployment compensations. Partial quantification of these indirect economic losses can be found in ATC-25 (1991). More than detailed economic models, practical rules need to be incorporated in the loss assessments for the evaluation of complex economic impacts.

INVENTORY OF EXPOSED VALUES (ELEMENTS AT RISK)

In urban areas the population, structures, utilities, systems, and socioeconomic activities constitute the "Elements at Risk". Preparation of urban earthquake damage/loss scenarios encompass compilation of information on: Demographic structure for different times of the day; Building stock and its typification; Lifeline and infrastructure (major roads, railroads, bridges, overpasses, public transportation, power distribution, water, sewage, telephone, and natural gas distribution systems) including their nodal points (stations, pumps, switchyards, storage systems, transmission towers, treatment plants, airports, marine ports etc.); Major and critical facilities (dams, power plants, major chemical and fuel storage tanks) in the form of GIS databases. Unfortunately the general incompleteness, if not unavailability, of these information creates a serious bottleneck for the urban earthquake loss assessments. The building classification systems used in inventories (and eventually in vulnerability matrices) are country-, even region-, specific and cannot have uniform applicability in all major urban centers. The inter-regional difference in building architecture and construction practices necessitate region-specific building classifications for the development of inventories and vulnerability information. For urban centers where building inventories are unavailable or unreliable practical surveying methods, such as: aerial imagery and rapid visual screening (sidewalk survey), needs to be developed. The information on the lifelines and major facilities are easier to obtain and the related design and construction practices may have more international conformity.

RISK ASSESSMENT: EARTHQUAKE DAMAGE AND LOSS SCENARIOS

In the context of damage scenarios risk can be defined as the losses to the elements at risk that can result from the occurrence of scenario earthquake(s). Damage scenarios are the vehicles to portray these risks. Following is a brief review of current developments in earthquake damage and loss scenarios:

Oyo Corporation have produced earthquake damage scenarios for several localities (e.g. Kawasaki City, Saitama Prefecture and Kanagawa Prefecture) in Japan (Oyo, 1988; Kaneko and Yamada, 1992; Kaneko, 1994; Komaru *et al*., 1995). These scenario analysis consists of several steps in which natural sciences, social sciences and government have certain roles. The main procedure of the analysis encompasses: Identification of disaster prevention problems in the objective area; Postulation of the kinds of earthquakes that may affect the area; mapping the distribution of their seismic intensities and assessing the probable effects of their seismic motion; Estimation of damage to structures, lifeline facilities; Estimation of fires, casualties and time to restoration of normal conditions. The Seismic Intensity Distribution (SID) estimation constitutes a basic part of the earthquake damage scenario. Several earthquakes are generally hypothesized for the scenario including the historical earthquakes. The geological conditions in the region is divided into representative soil profiles, and the amplification characteristics of seismic motion were calculated for each profile. The basement motions are obtained by using a semi-empirical method that considers the fault model. Seismic intensity values are converted from calculated surface motion. The assessment of a comprehensive earthquake damage scenario for Quito, Equator (Fernandez *et.al*, 1994) is based on a similar methodology. The methodology used by Oyo Corporation in earthquake loss scenario developments for Kawasaki City, Saitama Prefecture and Kanagawa Prefecture is elaborated by Komaru *et al.* (1995). The methodology, called “Seismic Damage Estimation System”, has four major entities: Precise Damage Estimation; Quick Damage Estimation; Data Management and Demonstration.

Under the general title of "Planning Scenario", California Department of Conservation-Division of Mines and Geology has prepared earthquake damage scenarios for several areas in California (Toppozada *et al*., 1988, 1993 and 1994). The seismic shaking intensity maps were developed on the basis of an Evernden *et al.* (1981) type model where various geologic units are assigned adjustment factors, ranging up to 2 intensity units, relative to the bedrock. Assessment of the building damage was limited to public high schools and hospitals. Damage, loss of service to highways, airports, marine facilities, railroads, electric power (plants and facilities), natural gas (storage, transmission and distribution pipelines), water supply (source, transmission, treatment, distribution), dams and reservoirs, waste water (collection, treatment, discharge), telephone systems have been assessed and the restoration periods have been estimated by treating these elements as parts of a network as well as on nodal point basis.

An application of the state-of-the-art methodologies involving property, business interruption, lifeline, toxic release, casualty and general liability models for earthquake loss estimations are presented in RMS (1995).

COMMENTS ON FUTURE APPLICATIONS

The largest earthquakes that recently hit modern urban environments are M6.7 Northridge and M6.9 Kobe earthquakes. Both events have shown that urban earthquakes can be highly damaging with the potential of disrupting our lifeline systems, socioeconomic structure and cause economic losses reaching 100 Billion US Dollars. Yet, the loss figure estimated for a future Tokyo earthquake is in the vicinity of 1 Trillion US Dollars (Berz and Smolka, 1995). Such a disaster can obviously have, not only national, but severe global repercussions.

Future earthquakes will have more urban centers and exposed values to target. The industrialization will create more sources of disaster in the form of dangerous spills, explosions and fires. Increased dependence on computers will bring also complexities into the earthquake risks. However, we will also be better armed in assessing the physical and socioeconomic impact of urban earthquakes and in proper allocation of resources towards mitigation of these impacts. We will increase our efforts for the assessment of earthquake risk in urban centers and widely disseminate the results. Several international institutions, programs and initiatives in this regard, such as: WORLDBANK, IDNDR, GSHAP and WSSI will serve as a catalysts.

The extensive research being carried out on the development of earthquake risk assessment methodologies guide our expectations for the future. The initial findings on the development of an GIS-based method for earthquake damage and loss estimation "Methodologies for Evaluating the Socioeconomic Consequences of Large Earthquakes" are reported in King *et al.* (1995 a, b). This methodology is essentially based on three components linked to a GIS. These components are: Relational Database Management Systems to process information on surface geology and built environment; External Computational Programs to model earthquake ground shaking and secondary hazards and; Knowledge-Based Expert Systems to identify high risk facilities and to model socioeconomic effects. The GIS provides for the management, analysis and display of data and models for earthquake loss assessment. The development of another GIS-based comprehensive earthquake loss assessment methodology is presented by Lawson *et al.* (1995). The framework of the methodology encompasses the following interlinked components: Potential Earth Science Hazard Module to estimate ground motion and ground failure potential; Inventory Module for data management; Direct Physical Damage Module to estimate damage to buildings and lifelines; Induced Damage Module for assessment of secondary damages; Direct Losses Module for determining socioeconomic losses and; Indirect Losses Module. The scenario event can be selected on the basis of deterministic or probabilistic methodologies or can be supplied by the user. The ground motion is defined by site-specific response spectral amplitudes at eight specific periods. Ground failure is quantified in terms of permanent ground displacements (PGD) with associated probabilities. Building damage is assessed on the basis of simplified inelastic response and expressed in terms of the probability of being in one the damage states.

To recap what has been elaborated for the future of urban earthquake risk assessments, the following can be stated. In the future, earthquake hazard assessments will be more of an predictive effort than a probabilistic one. Future descriptions of the ground motion severity will no longer use earthquake intensity but will incorporate more rational descriptors such as spectral amplitudes (or parameters) and permanent ground displacements. Future developments of vulnerability functions will relate these ground motion descriptors to loss-related damage classes. Risk analysis methodologies will be improved and standardized to handle relational GIS databases. GIS computer software and applications will be developed to capture, manage and display spatially referenced data, and to facilitate analysis and simulation. . With such credible long range loss predictions the societal efforts will be concentrated and prioritized in a rational manner to assist in mitigating these disasters.

What will be needed in the future is the dissemination of urban earthquake loss information in understandable formats to increase the awareness of the general public and to sensitize the top level decision makers. Unless this activity is coupled with future risk assessments the return of the benefits will only academic and marginal.

In the past every urban earthquake seemed to be a surprise. Our objective is not to be surprised by future earthquakes. Current rate of developments in earthquake engineering indicate that this objective will be met as we enter the new century.

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