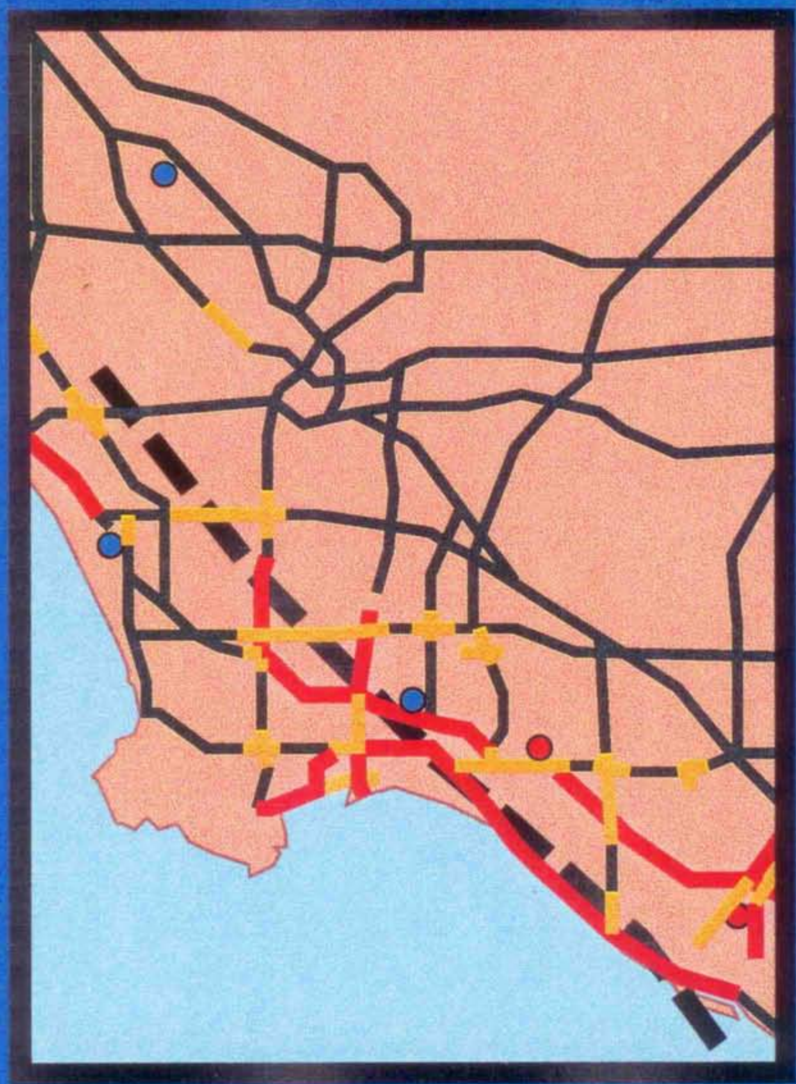

USES OF EARTHQUAKE DAMAGE SCENARIOS

Proceedings and Transcriptions of Special Theme Session Number 10 of the Tenth World Conference on Earthquake Engineering

Editor:
Brian E. Tucker

A GEOHAZARDS INTERNATIONAL PUBLICATION

Uses of Earthquake Damage Scenarios

Brian E. Tucker, editor

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A GeoHazards International Publication

Proceedings of Special Theme Session Number 10 of the Tenth World Conference on Earthquake Engineering entitled *Earthquake Damage Scenarios for Cities of the 21st Century* Madrid, Spain, July 23, 1992

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FOREWORD

On July 23, 1992, a colloquium was held in Madrid, Spain, entitled "Uses of Earthquake Damage Scenarios for Cities of the 21st Century." It was organized as a Special Theme Session of the Tenth World Conference on Earthquake Engineering (10WCEE), sponsored by the International Association of Earthquake Engineers. The proceedings of that colloquium form the basis of this Sourcebook.

The Sourcebook focuses on, and provides a multifaceted introduction to, earthquake damage scenarios (EDSs). An EDS is a description of the anticipated effects that a large but likely future earthquake could have on facilities that are critical to an urban area. By tracing the complex series of social and economic events likely to be triggered by an earthquake, the EDS can raise awareness of earthquake risk among citizens, elected officials, and leaders of the private sector. It can also help administrators to define appropriate earthquake-hazard-reduction strategies, set funding priorities, and direct future research. The EDS is neither a new idea nor a panacea, and it cannot replace detailed technical analyses. EDSs can, however, help to create the social and political context in which such technical analyses become meaningful.

EDS production is a multidisciplinary task, involving such diverse fields as seismology, soils mechanics, structural engineering, urban planning, social studies, economics, and emergency response. Because few people have expertise that spans these fields, the EDS presents special challenges: scientists and engineers must strive to make their work useful to the public; and government officials and business leaders must endeavor to take advantage of recent advances in science and technology. This volume therefore attempts to address a broad audience. It explores several of the technical and social issues involved in earthquake-hazard estimation in terms that we believe are both technically accurate and understandable to the layperson.

If this endeavor has been successful, the Sourcebook will be useful to a wide range of people. Mayors of earthquake-threatened cities might learn about techniques used in other cities to reduce earthquake hazards and gain insight into how those techniques might be applied in their cities. Managers in the private sector might learn about ways their businesses are vulnerable to earthquakes and how that vulnerability could be evaluated and reduced. Seismologists and engineers might devise new ways for EDSs to meet the needs of insurance companies, development banks, and emergency response agencies.

We would like to highlight five themes emphasized by colloquium participants.

1. A standardized procedure or set of guidelines for preparing a scenario is needed, and the time seems ripe to engage international cooperation in such a project.

2. EDS procedures developed in California and Japan should be made appropriate to the needs, budgets, and technical resources of developing countries.

3. Past applications of EDSs--for example, raising public awareness and training emergency response agencies--might be expanded to include: recommending countermeasures; estimating broader financial and political consequences of an earthquake, including international consequences; estimating earthquake consequences beyond the immediate range of ground shaking, including international financial and political consequences; advising land-use planners; and influencing development policy (for instance by linking construction loans with mitigation measures).

4. Geographic information systems (GISs), or computer mapping software, could contribute significantly to EDS production. GIS use allows for efficient updating of data bases and easy generation of new scenarios for different hypothetical earthquakes. Potentially, a GIS could permit rapid estimation of damage after an actual earthquake, for the purpose of guiding emergency response activities.

5. EDSs could be valuable to the insurance industry, particularly if they were available through a GIS. Though the capability of individual companies to use technical information is highly variable, it is clearly underused by the industry as a whole.

The Madrid colloquium assembled leading specialists from several fields to exchange ideas about the production and use of EDSs. Their provocative, informed discussions raised questions and problems but also suggested opportunities. This Sourcebook brings together the broad sampling of current ideas about EDSs raised that day.

The colloquium consisted of four sessions. Approximately half of each session was devoted to the presentation of invited papers (three papers per session) and the other half to open discussion. Transcriptions of these presentations and the discussion periods following them make up the first four parts of the Sourcebook. Each of these four parts closes with a section of written comments submitted by participants after the colloquium. The Sourcebook contains a final, fifth part, consisting of four papers not presented at the colloquium that were solicited to supply technical details for the interested reader.

Part I, "Urban Earthquake Risk," chaired by Julio Kuroiwa, presents an overview of expected risk to cities of the future. In "Global Urbanization," Barclay Jones summarizes how the growth of cities can be expected to increase the vulnerability of a growing proportion of the world's population. In "Earthquakes and Megacities," Roger Bilham points out that many of tomorrow's megacities (cities with more than 10 million inhabitants) will be located in earthquake-prone areas. We should therefore expect greater numbers of earthquake-caused deaths, he concludes. In "Trends in Earthquake Costs," Daniel Bitran summarizes the economic effects of recent earthquakes in Latin America and concludes that the costs of earthquakes, in both human and economic terms, are likely to rise in the future. One reason cited by all three speakers for the increase in earthquake-caused economic loss is the expected increase in the proportion of poor construction in cities of the future.

Part II, "Earthquake Damage Scenarios for Los Angeles and Tokyo," chaired by Alain Le Saux, examines two similar methods used to reduce earthquake risk in two earthquake-prone cities.

In their papers "The Technique of Making Earthquake Damage Scenarios in California" and "The Use of Earthquake Damage Scenarios by the City of Los Angeles," Glenn Borchardt and Shirley Mattingly discuss earthquake-hazard-mitigation efforts in California. Mr. Borchardt tells how, in California, emphasis has been placed on estimating the effects of earthquakes on lifelines such as airports, freeways, ports, water and gas pipelines, electrical networks, and railways. Ms. Mattingly summarizes lessons about the effective use of EDSs, describes current efforts in Los Angeles to develop interactive scenarios, and suggests that cities should share successful earthquake-hazard-reduction techniques.

In "The Technique and Use of Earthquake Damage Scenarios in the Tokyo Metropolitan Area," Tsuneo Katayama summarizes how EDSs have been produced and used in Tokyo over the last 30 years. We learn that Japanese scenarios attempt to estimate a broader scope of earthquake consequences than do Californian scenarios. They focus not only on damage due to shaking, as in California, but also on spread of fire, number of displaced persons, and loss of life; they take into account not only lifelines, but also typical dwellings. These more elaborate scenarios, however, also require more resources to complete: one study lasted nearly 15 years, while another took five years and cost approximately U.S.$4 million. Dr. Katayama feels that for all countries--developing and developed alike--it may be most cost-effective to produce scenarios in only one year.

Participants in the Part II discussion section develop the idea that the effects of future earthquakes will extend far beyond the precise area of occurrence. With the increasing internationalization of national economies, a disaster in one country will increasingly affect other countries. One positive effect of this ever-widening scope is a heightened level of international concern and response to these problems.

Part III, "Earthquake Damage Scenarios for Disaster Management," chaired by David Dowrick, examines some of the possible applications of EDSs to natural-disaster management. In "UNDRO's Work with Earthquake Hazard Mitigation," Dusan Zupka explains the emphasis that the United Nations Disaster Relief Organization now places on natural disasters in assessing development programs. He describes how different types of earthquake scenarios, emphasizing different goals, can be used to evaluate hazards and identify mitigation measures. In "Application of Geographic Information Systems to Earthquake Damage

Estimation," Mario Ordaz describes the interactive computer system now used in Mexico City to produce earthquake scenarios. Government authorities use scenarios thus produced for land-use planning and refinement of building codes. In "Guiding Emergency Response Activities Using Damage Scenarios: A Promising Prospect," Frederick Krimgold describes how a system such as the one described by Mr. Ordaz could be used to improve response immediately after earthquakes.

Part IV, "Earthquake Damage Scenarios for International Insurance Companies," chaired by Åke Munkhammar, highlights needs of insurance companies that could be met by EDSs. Mr. Munkhammar provides an introduction to this session in "The Insurance Industry's Concern with Earthquakes." In "Earthquake Hazard Estimation by the Insurance Industry," Herbert Tiedemann describes the data that insurance companies most value: risk assessment uncertainty figures, earthquake return periods, maps of seismicity, and the area expected to be affected by strong shaking as a function of earthquake magnitude. In "Trends of Worldwide Earthquake Risk to Insurance Companies," Anselm Smolka attempts to quantify both increases in insured earthquake losses over the last three decades and expectations of future increases in these losses. He stresses two uses of EDSs to the insurance industry: presenting earthquake risk data in an easily comprehensible form and illuminating needed mitigation measures. If the data used in making an EDS are stored on a GIS, individual insurance companies could use those data to update their vulnerability estimates.

Part V, "Earthquake Damage Scenario Methods," presents several alternative methods of preparing scenarios. Glenn Borchardt outlines the California Division of Mines and Geology method and Michael Reichle describes a scenario produced by this method for the San Diego-Tijuana area. Fumio Kaneko and Toshihiro Yamada describe the method that has been followed in several urban areas in Japan. Tsuneo Katayama and Shigeru Nagata introduce a newer, more experimental Japanese approach.

ACKNOWLEDGMENTS

We are grateful to paper authors not only for preparing and submitting their papers in a timely manner, but also for agreeing to the editorial changes needed to produce a unified text. Their presentations formed the foundation without which there could be neither colloquium nor Sourcebook, and their promptness allowed the other colloquium participants to come to Madrid prepared for fruitful discussion.

The Chairmen of the four sessions, Julio Kuroiwa, Alain Le Saux, David Dowrick, and Åke Munkhammar, made helpful suggestions concerning the colloquium's organization, reviewed preliminary drafts of session papers, moderated the sessions during the colloquium, and checked final versions of papers.

We would like to thank all colloquium participants. Their focused attention helped to create the stimulating, expectant atmosphere that motivated everyone present. Participants in the discussion periods raised many of the important questions, problems, and opportunities discussed in this Sourcebook. The thoughtful, written comments submitted after the colloquium also raised numerous valuable points.

The Steering Committee of the Tenth World Conference on Earthquake Engineering provided us with invaluable support. Committee Director Rafael Blázquez invited us to organize the Madrid colloquium, and he and other committee members continued their support as we proposed significant modifications to the colloquium's focus. With their help, we were able to reserve the Europa Room of the conference convention center. The room's excellent facilities allowed conference staff to make the quality tape recordings on which much of this text was based.

We gratefully acknowledge Professor Belén Benito, who served as our local coordinator. She helped us to secure the meeting room and handled such varied and essential logistical details as international money transfers, refreshments, and translation services. She maintained contact with us by fax and telephone for the six months prior to the colloquium during both working and nonworking hours, and throughout this long process she buoyed us with her humor and efficiency.

Finally, we are indebted to OYO Corporation of Japan. OYO provided funding for travel and accommodation of several key speakers, as well as logistical assistance and financial support for the publication of this volume. The support for this effort expressed by OYO personnel from the start is a reflection of their company's philosophy that knowledge about earthquakes should be shared worldwide.

The colloquium was conceived and organized by Brian Tucker with the assistance of Gunnar Trumbull. Jules Siedenburg and Gunnar Trumbull handled the day-to-day work of shaping the disparate parts of the colloquium into a coordinated text; Sarah Wyss did the final lay-out and editing; Brian Tucker oversaw this effort and wrote these introductory remarks. Carlos Villacis provided invaluable assistance by editing the two Japanese method papers appearing in Part V.

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INTRODUCTION

In recent years, major financial and human losses due to devastating earthquakes have been increasingly concentrated in densely populated urban areas. This trend holds true in both the industrialized and developing worlds. Recent major earthquakes, such as the Mexico City (1985) and Loma Prieta (1989) earthquakes, remind locals and others of the high vulnerability of certain urban areas to earthquake hazard and of the consequent need to enforce and improve upon current seismic codes.

Thanks to this increasing awareness of seismic hazard, urbanization patterns and technological sites are being reassessed throughout the world to take earthquake threat into account. Japan and the United States lead this process, due to a combination of the heightened awareness of seismic hazard—engraved in the memories of the Japanese and Californian populations as a result of the Great Kanto (1923) and San Francisco (1906) earthquakes—and the commitment of their governments to earthquake hazard mitigation. Enhancing disaster preparedness and response capacity—for example, securing and equipping evacuation routes, assessing and upgrading buildings and lifelines, revising building and land-use codes, stockpiling emergency supplies, and establishing special television and radio networks—is increasingly recognized as a priority political and socioeconomic issue by policy makers.

The colloquium on earthquake damage scenarios, on which this volume is based, examined the growing threat that earthquake catastrophes pose worldwide and the corresponding need for earthquake-mitigation work in large cities. The one-day colloquium emphasized the ways in which international emergency-response agencies and financial institutions might benefit from scenarios as well as the ways in which future scenario projects could use existing scenarios as models.

The goals and spirit of the colloquium match those of two major initiatives already underway: the International Decade for Natural Disaster Reduction and the International Association for Earthquake Engineering's World Seismic Safety Initiative.

The contributions of the colloquium participants have been gathered together into a valuable educational volume, rich with contrasting viewpoints. This book can reasonably be expected to inform and stimulate earthquake-hazard-mitigation efforts worldwide.

Rafael Blázquez, Steering Committee Director
Tenth World Conference on Earthquake Engineering
Madrid, Spain
July 1992

PART I: URBAN EARTHQUAKE RISK

Julio Kuroiwa, Chairman

Dr. Kuroiwa is a professor of Civil and Earthquake Engineering at Peru's National University of Engineering in Lima and works as a consultant in disaster mitigation. He has worked extensively with United Nations organizations, including the U.N. Center for Human Settlement (HABITAT), the U.N. Office of the Disaster Relief Coordinator, and the U.N. Center for Regional Development.

GLOBAL URBANIZATION

Barclay Jones, Cornell University, USA

The population of the world has grown to unprecedented size and continues to grow rapidly. In 1900 it reached 1 billion people. By 1950 it was 2.5 billion. World population will be 6.2 billion in the year 2000.

This population is both dispersed, or rural, and concentrated, or urban. Figure I.1 shows the growth of urban and total world population. Urban population in the year 2000 will be greater than the total population of the planet in 1950. In addition, as total population grows, the percentage that is concentrated increases (Figure I.2).

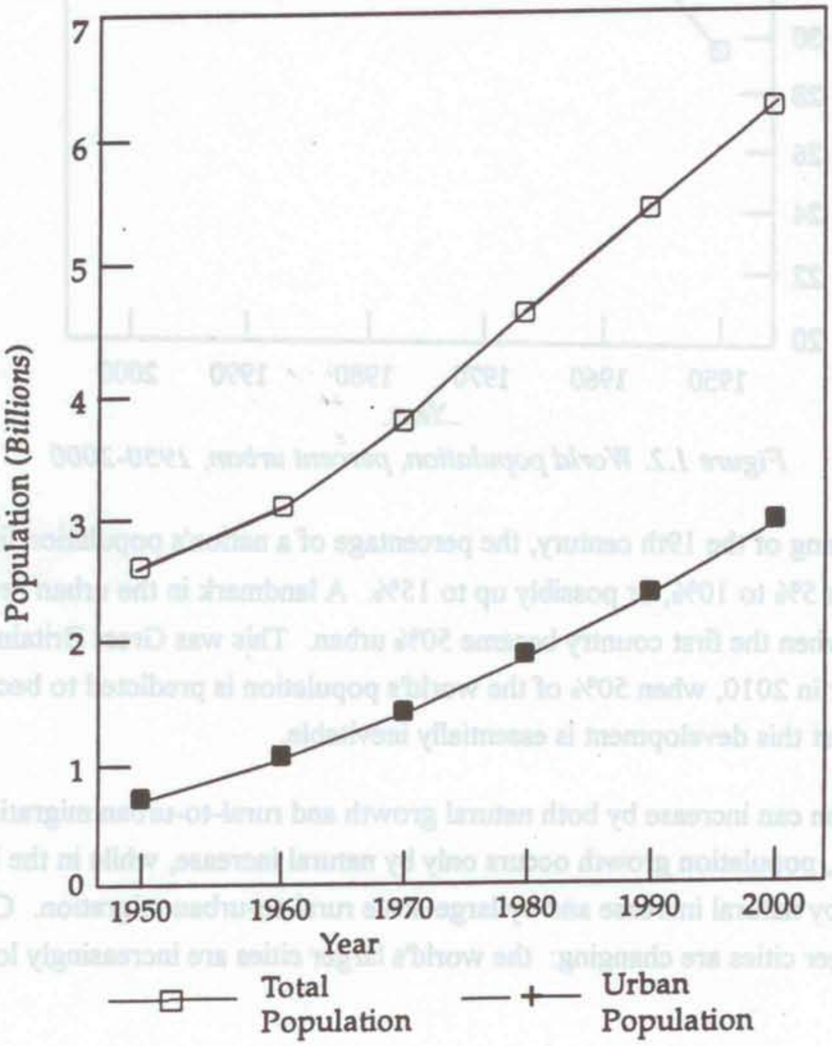

Figure I.1. World population, total and urban, 1950-2000

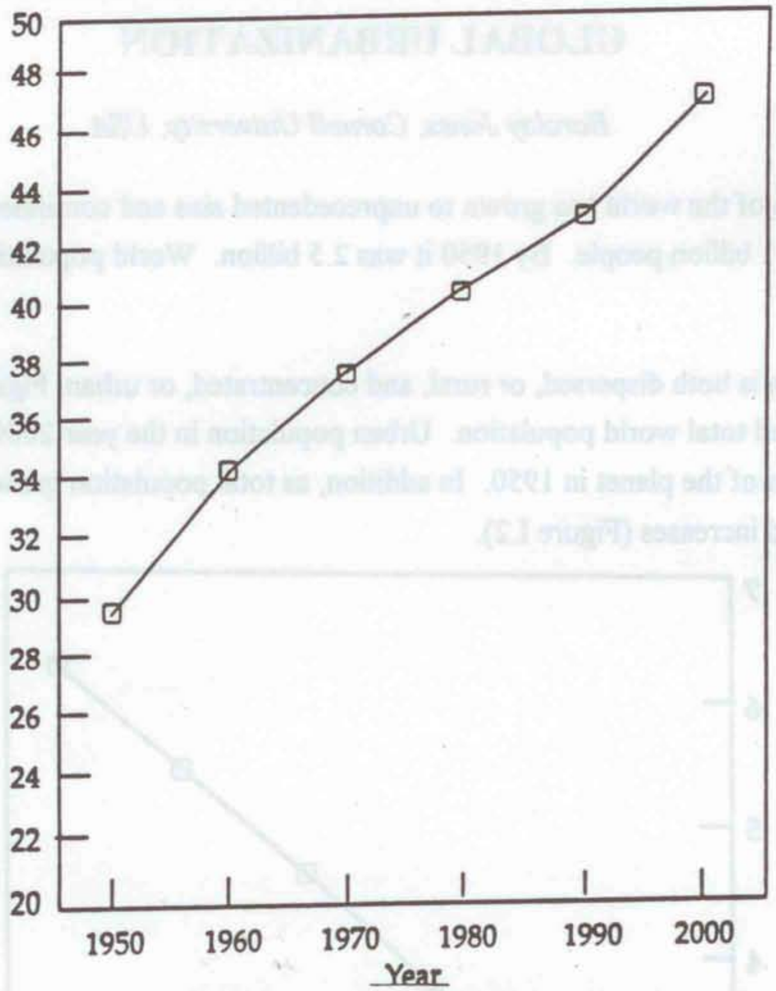

Figure 1.2. World population, percent urban, 1950-2000

Until the beginning of the 19th century, the percentage of a nation's population living in urban centers ranged from 5% to 10%, or possibly up to 15%. A landmark in the urban revolution occurred in 1850, when the first country became 50% urban. This was Great Britain. Another landmark will occur in 2010, when 50% of the world's population is predicted to become urban. Figure I.2 shows that this development is essentially inevitable.

Urban population can increase by both natural growth and rural-to-urban migration. In most urbanized countries, population growth occurs only by natural increase, while in the least urbanized countries it occurs by natural increase and by large-scale rural-to-urban migration. Consequently, the locations of larger cities are changing: the world's larger cities are increasingly located in the developing world.

In 1960, the 25 most urbanized countries accounted for nearly half (48%) of world urban population and less than a quarter (24%) of total world population (Table I.1). By 2000, both of these figures will be halved. The new set of 25 most urbanized countries will represent less than a quarter of the world's urban population and about an eighth of the total population.

In contrast, the 25 countries with the largest urban populations account for four-fifths of the total world population and as much or more of the world's urban population, in both 1960 and 2000 (Table I.2). Consider the situation in 1960. Shaded countries were also on the list of most urbanized countries at that time. The others were not. Notice that three of the first five were not among the most urbanized countries. In the year 2000, what is startling is that the list includes so many unshaded countries, which were not among the top 25 in 1960, while so many shaded

		TOTAL POP. (000) 1960	URBAN POP. (000) 1960	PERCENT URBAN 1960			TOTAL POP. (000) 2000	URBAN POP. (000) 2000	PERCENT URBAN 2000
1	Singapore	1,634	1,634	100.00%	1	Singapore	2,950	2,950	100.00%
2	Belgium	9,153	8,463	92.46%	2	Belgium	10,034	9,807	97.74%
3	Hong Kong	3,075	2,739	89.07%	3	Kuwait	2,782	2,704	97.20%
4	UK	52,372	44,874	85.68%	4	UK	57,509	53,898	97.20%
5	Netherlands	11,480	9,759	85.01%	5	Israel	5,280	4,934	93.45%
6	Australia	10,315	8,315	80.61%	6	Hong Kong	6,612	6,088	92.08%
7	Uruguay	2,114	1,627	76.96%	7	Netherlands	15,207	13,484	88.67%
8	Germany, FR	55,433	42,883	77.36%	8	Denmark	5,139	4,552	88.58%
9	Israel	2,114	1,627	76.96%	9	Germany, FR	59,818	52,418	87.63%
10	New Zealand	2,372	1,803	76.01%	10	Australia	18,610	15,990	85.92%
11	Denmark	4,581	3,375	73.67%	11	Sweden	8,322	7,125	85.62%
12	Argentina	20,616	15,176	73.61%	12	New Zealand	3,632	3,093	85.16%
13	Sweden	7,480	5,429	72.58%	13	Venezuela	27,322	23,151	84.73%
14	Kuwait	278	201	72.30%	14	Uruguay	3,475	2,937	85.16%
15	Germany, DR	17,240	12,340	68.90%	15	Argentina	38,235	32,162	84.73%
16	US	180,671	126,470	70.00%	16	Chile	16,245	13,924	83.34%
17	Canada	17,909	12,340	68.90%	17	Spain	40,812	33,693	82.56%
18	Chile	7,614	5,165	67.84%	18	Saudi Arabia	20,686	16,924	81.81%
19	Venezuela	7,502	4,996	66.60%	19	Germany, DR	16,618	13,380	80.52%
20	Japan	94,096	58,810	62.50%	20	UAE	1,950	1,517	77.79%
21	France	45,684	28,501	62.39%	21	Korea, Rep.	49,989	38,661	77.34%
22	Italy	50,200	29,799	59.36%	22	Norway	193,603	148,397	76.65%
23	Spain	30,455	17,228	56.57%	23	Brazil	193,603	148,397	76.65%
24	Switzerland	5,362	2,736	51.03%	24	Japan	131,101	100,276	76.49%
25	Mexico	38,019	19,296	50.75%	25	France	58,196	44,469	76.41%
	TOTAL 112 COUNTRIES	2,870,123	973,586	33.92%		TOTAL 112 COUNTRIES	5,985,155	2,737,565	45.74%
	MOST URBANIZED 25	678,193	466,109	68.73%		MOST URBANIZED 25	798,458	649,488	81.34%
	PERCENT OF TOTAL	23.63%	47.88%			PERCENT OF TOTAL	13.34%	23.73%	

Source: United Nations, *Prospects of World Urbanization* 1988.

Table I.1. Twenty-five most urbanized countries, 1960 and 2000

		TOTAL POP. (000) 1960	URBAN POP. (000) 1960	PERCENT URBAN 1960			TOTAL POP. (000) 2000	URBAN POP. (000) 2000	PERCENT URBAN 2000
1	UNITED STATES	180,671	126,470	70.00%	1	India	1,042,530	356,875	34.23%
2	China	657,492	124,892	19.00%	2	China	1,341,412	322,125	24.01%
3	Soviet Union	214,335	86,114	40.18%	3	Soviet Union	307,737	217,447	70.66%
4	India	442,346	79,414	17.95%	4	United States	273,664	198,687	72.60%
5	JAPAN	94,096	58,810	62.50%	5	BRAZIL	193,683	148,397	76.65%
6	UNITED KINGDOM	52,372	44,874	85.68%	6	JAPAN	131,101	100,276	76.49%
7	GERMANY, FR	55,433	42,883	77.36%	7	Mexico	116,302	82,985	71.35%
8	Brazil	72,595	32,627	44.94%	8	Indonesia	208,329	75,960	36.46%
9	ITALY	50,200	29,799	59.39%	9	Nigeria	159,149	68,893	43.29%
10	FRANCE	45,684	28,501	62.39%	10	Pakistan	162,467	61,438	37.82%
11	MEXICO	38,019	19,296	50.75%	11	UNITED KINGDOM	57,509	53,898	93.72%
12	SPAIN	30,455	17,228	56.57%	12	GERMANY, FR	59,818	52,418	87.63%
13	ARGENTINA	20,616	15,176	73.61%	13	FRANCE	58,196	44,469	76.41%
14	Poland	29,561	14,160	47.90%	14	Italy	57,881	41,667	71.99%
15	Indonesia	96,194	14,032	14.59%	15	KOREA, REP.	49,989	38,661	77.34%
16	GERMANY, DR	17,240	12,456	72.25%	16	Philippines	77,447	37,953	49.01%
17	CANADA	17,909	12,340	68.90%	17	Egypt, AR	66,710	36,547	54.79%
18	Pakistan	49,955	11,042	22.10%	18	Turkey	66,622	36,188	54.32%
19	Egypt, AR	25,922	9,815	37.86%	19	SPAIN	40,812	33,693	82.56%
20	NETHERLANDS	11,480	9,759	85.01%	20	ARGENTINA	38,235	32,163	84.12%
21	BELGIUM	9,153	8,463	92.46%	21	Colombia	40,962	28,557	69.72%
22	Philippines	27,561	8,350	30.30%	22	South Africa	43,332	298,123	64.90%
23	AUSTRALIA	10,315	8,315	80.61%	23	Bangladesh	150,589	27,491	18.26%
24	Turkey	27,509	8,182	29.74%	24	Poland	40,366	26,944	66.75%
25	South Africa	17,396	8,113	46.64%	25	VENEZUELA	27,322	23,151	84.73%
	TOTAL 112 COUNTRIES	2,870,123	973,586	34.60%		TOTAL 112 COUNTRIES	5,985,155	2,737,565	55.42%
	25 LARGEST URBAN POP.	2,294,509	831,111	53.95%		25 LARGEST URBAN POP.	4,812,084	2,175,006	63.19%
	PERCENT OF TOTAL	79.94%	85.37%			PERCENT OF TOTAL	80.40%	79.45%	

Source: United Nations, *Prospects of World Urbanization* 1988.

Table I.2. Twenty-five countries with largest urban population, 1960 and 2000

countries, the previously most urbanized nations, disappear. In the year 2000, the 25 countries with the largest urban populations, accounting for almost 80% of the world urban population, will for the most part be countries that were not among the most urbanized nations in 1960.

Nearly one-third of the countries with huge urban populations in the year 2000 projection will be less than 50% urban. These countries have considerable potential for continued urbanization. The primary mechanism for this urbanization will be rural-to-urban migration.

Because the first phase of the urban revolution started in Western Europe and North America during the 19th century, most of the largest cities have, until recently, been located in these regions. The current phase of the urban revolution, however, is marked by the urbanization of less developed and less urban regions. The largest cities in the future will be in East Asia, Southeast Asia, and Latin America.

On the left of Table I.3 are the 35 largest urban agglomerations in 1950; on the right are the 35 largest in the year 2000. Cities in the left column that are shaded are those that are not present in

RANK 1950	AGGLOMERATION	COUNTRY	POP. 1950	RANK 2000	AGGLOMERATION	COUNTRY	POP. 2000
1	NEW YORK	US	12.34	1	Mexico City	Mexico	24.44
2	Shanghai	China	10.26	2	Sao Paulo	Brazil	23.60
3	LONDON	UK	10.25	3	Tokyo/Yokohama	Japan	21.32
4	Tokyo-Yokohama	Japan	6.74	4	NEW YORK	US	16.10
5	Beijing	China	6.64	5	Calcutta	India	15.94
6	PARIS	FRANCE	5.44	6	Greater Bombay	India	15.43
7	Tianjin	China	5.36	7	Shanghai	China	14.69
8	Buenos Aires	Argentina	5.13	8	Teheran	Iran	13.73
9	CHICAGO	US	4.94	9	Jakarta	Indonesia	13.23
10	MOSCOW	USSR	4.84	10	Buenos Aires	Argentina	13.05
11	Calcutta	India	4.45	11	Rio de Janeiro	Brazil	13.00
12	LOS ANGELES	US	4.05	12	Seoul	Korea	12.97
13	Osaka/Kobe	Japan	3.83	13	Delhi	India	12.77
14	MILAN	ITALY	3.63	14	Lagos	Nigeria	12.45
15	Rio de Janeiro	Brazil	3.45	15	Cairo/Giza	Egypt	11.77
16	PHILADELPHIA	US	2.94	16	Karachi	Pakistan	11.57
17	Greater Bombay	India	2.90	17	Manila/Quezon	Philippines	11.48
18	Mexico City	Mexico	2.88	18	Beijing	China	11.47
19	DETROIT	US	2.77	19	Dacca	Bangladesh	11.26
20	Sao Paulo	Brazil	2.75	20	Osaka/Kobe	Japan	11.18
21	NAPLES	ITALY	2.75	21	LOS ANGELES	US	10.91
22	LENINGRAD	USSR	2.62	22	LONDON	UK	10.79
23	MANCHESTER	UK	2.51	23	Bangkok	Thailand	10.26
24	BIRMINGHAM	UK	2.50	24	MOSCOW	USSR	10.11
25	Cairo/Giza	Egypt	2.41	25	Tianjin	China	9.96
26	BOSTON	US	2.24	26	Lima-Calio	Peru	8.78
27	Shenyang	China	2.22	27	PARIS	FRANCE	8.76
28	WEST BERLIN	GERMANY	2.15	28	MILAN	ITALY	8.74
29	SAN FRANCISCO	US	2.03	29	Madras	India	7.85
30	LEEDS-BRADFORD	UK	1.91	30	Bangalore	India	7.67
31	HAMBURG	GERMANY	1.79	31	Baghdad	Iraq	7.66
32	Hong Kong	Hong Kong	1.75	32	CHICAGO	US	6.98
33	Jakarta	Indonesia	1.73	33	Bogota	Colombia	6.94
34	Sydney	Australia	1.70	34	Hong Kong	Hong Kong	6.09
35	KATOWICE	POLAND	1.69	35	Lahore	PAKISTAN	5.93

Source: United Nations. *Prospects of World Urbanization* 1988.

Table I.3. Thirty-five largest world agglomeration, 1950 and 2000

the right column. Cities in the right column that are shaded are those that are new entries. It is interesting to note that the shaded cities on the left, those that disappear, are all from Western Europe or North America (with the exception of Osaka), while none of the shaded cities on the right, the new large cities, are from Western Europe or North America.

Urban populations occupy systems of cities the size of which conforms to a skewed distribution, such as the lognormal or the rank size rule. Four properties define the rank size distribution: (1) total urban population, (2) the number of urban places, (3) the size of the largest urban place, and (4) the slope of the line describing the distribution. A change in any one property requires a change in at least two other properties.

Figure I.3 shows an idealized system of cities. In the lower curve, an urban population of 4.3 million is distributed across 40 cities larger than 25,000, the largest of which is 1 million. The log of rank is on the horizontal axis and the log of population on the vertical axis. In the upper curve, the urban population has increased--slightly more than doubled--to 9.9 million and is now distributed over 80 cities, the largest of which is 2 million. From this diagram, one can see what will happen to cities as urban populations continue to grow. As the growing world population becomes more urban, urban agglomerations will reach unprecedented sizes, and, at the same time, the number of cities above any given size will increase.

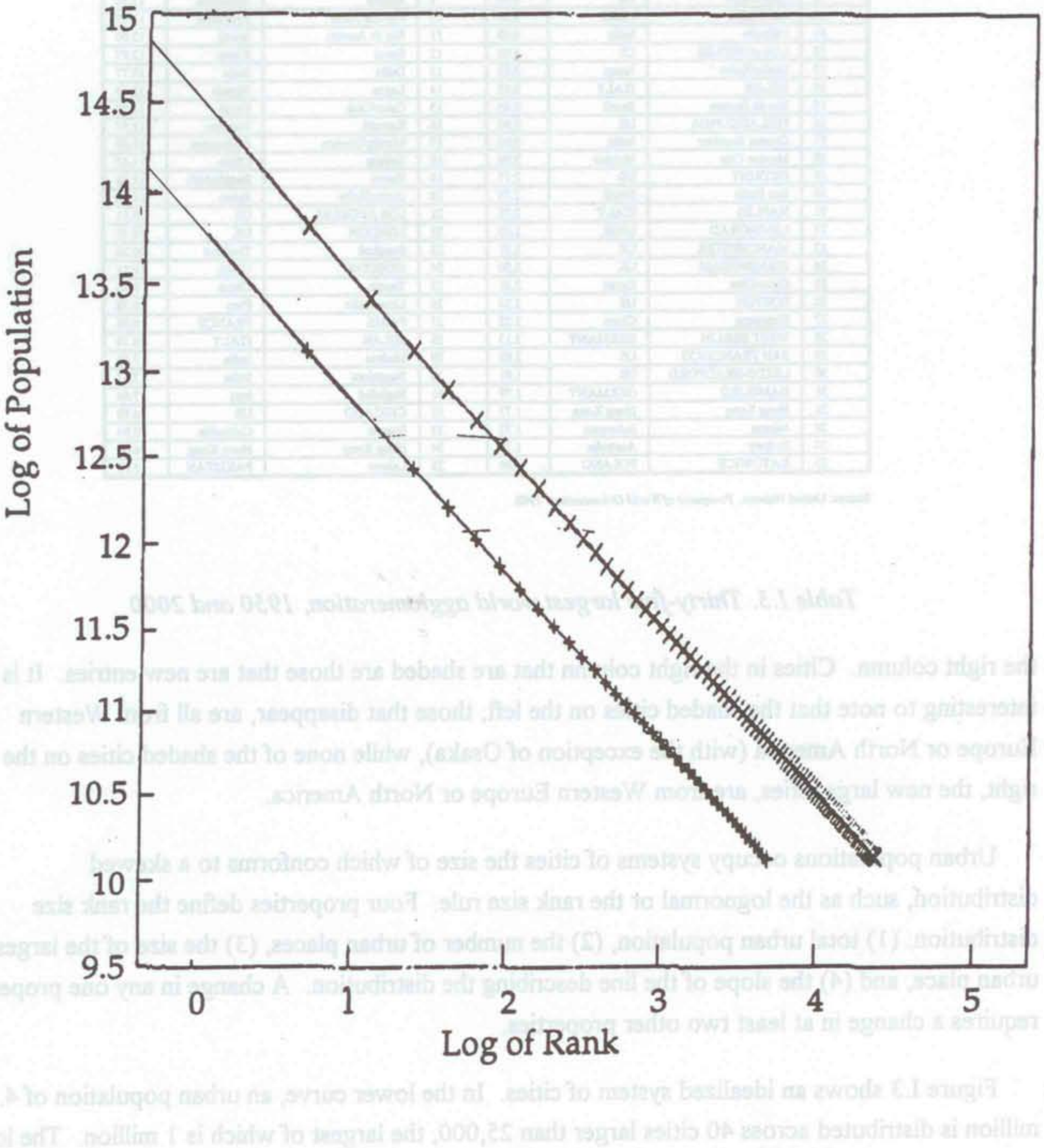

Figure I.3. Rank size distribution of cities

In 1800, only one city, Beijing, had a population of one million (Table I.4). In 1850, there were three cities that large. In 1900, there were 16. In 2000, there will be 410. In 1900, four cities had populations over 2 million. In 2000, one hundred cities will be larger than that--I can no longer name them. In 1900, two cities had populations over 4 million. In 2000, sixty cities will be that large or larger.

Population	1800	1900	2000
1 million	1	16	410
2 million	0	4	100
4 million	0	2	60

Table I.4. Number of large agglomerations

As total world population and the extent of empires fluctuated between A.D. 800 and 1800, the size of the largest city ranged from as large as 1 million to as small as 250,000. Since 1800, the size of the largest cities in the world has grown rapidly to unprecedented sizes and will continue to grow (Figure I.4). Megacities--those cities with populations of 10 million or greater--are an inevitable outgrowth of world urbanization.

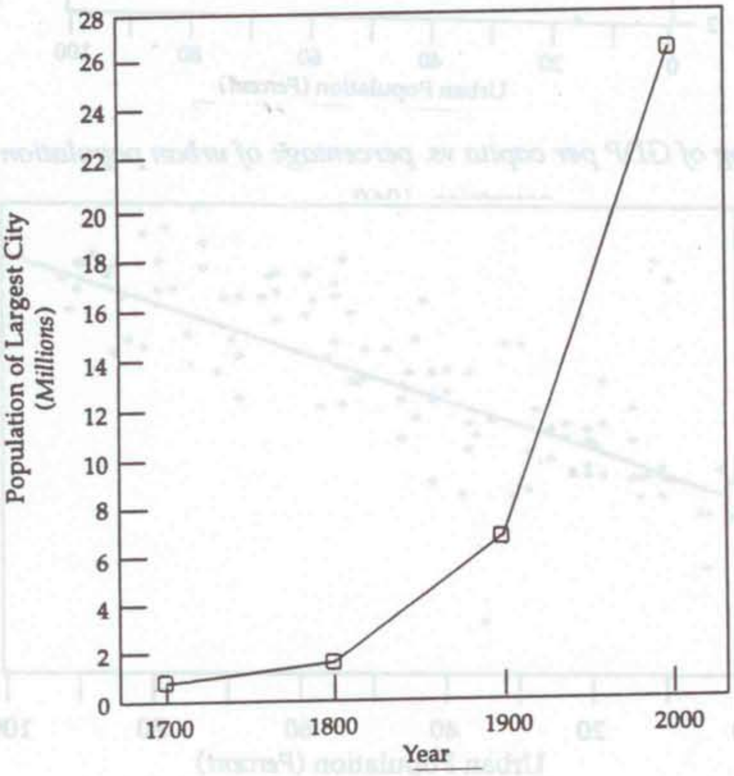

Figure I.4. Size of largest world city, 1700-2000

Since urban economic activities generally have higher levels of productivity than do rural ones, degree of urbanization is related to per capita gross national product. As the world has urbanized, per capita incomes have increased. Figures I.5 and I.6 show the percentage of population that is urban (on the horizontal axis) and the log of per capita gross national product (on the vertical axis) for 113 countries. As levels of urbanization increase from 1960 to 1980, the scatter shifts upwards and to the right. While the scatter moves in this direction, the line remains roughly constant. The relationship is strong for both years ($r^2 = 0.76$), when outlying and unreliable observations are removed. The greatest potential for urban growth is in the least urban and the lowest-income countries.

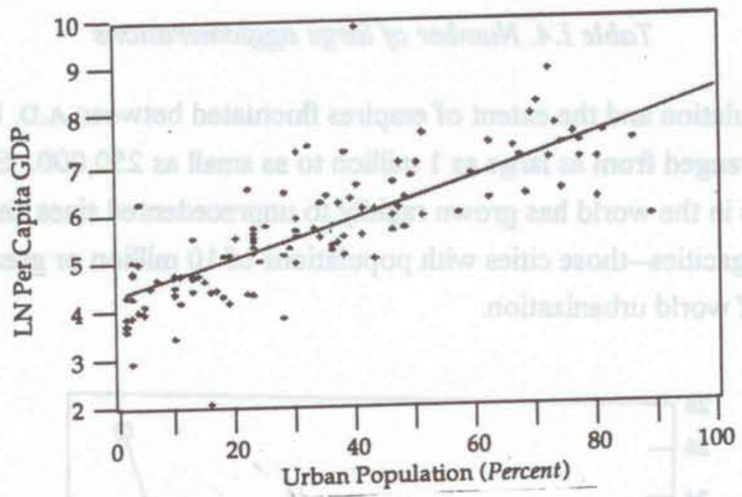

Figure I.5. Natural log of GDP per capita vs. percentage of urban population for 113 countries, 1960

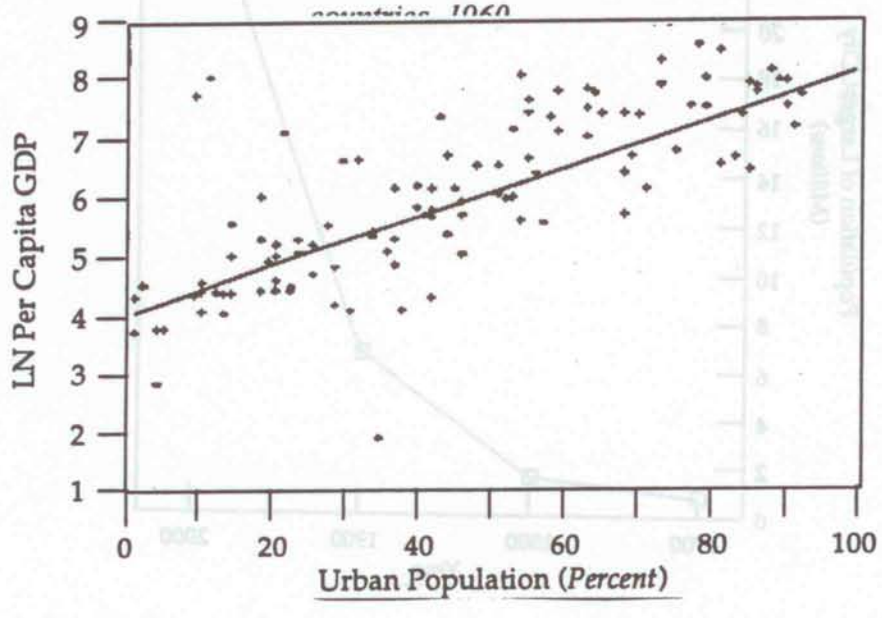

Figure I.6. Natural log of GDP per capita vs. percentage of urban population for 113 countries, 1980

The built physical environment (BPE) of buildings, other structures, and infrastructure that shelter and support human activities is accumulated over time. Its cost greatly exceeds income in any given period. Given this fact, it is virtually inevitable that physical facilities will be at inadequate levels in the early stages of urban growth and will increase with income.

The replacement cost of the BPE is some multiple, k, of gross regional product (GRP), as shown in Formula I.1.

$$BPE = k\ GRP \qquad (I.1)$$

In a baseline inventory that I have been making for one medium-size metropolitan area in the United States--Wichita, Kansas--I have found that the replacement cost of Wichita's BPE for 1983 was more than $22 billion, while the GRP was only approximately $6 billion per year. The multiplier k, for Wichita, is therefore 3.7. The gross product of the construction industry in that region was less than $650 million per year. This means that the replacement time for the BPE in Wichita, if no new construction were undertaken, would be 35 years. More realistically, if half of all construction resources were spent on maintenance, repair, and renovation, the replacement time would be 70 years.

Cities grow by accretionary processes, expanding on the fringes and retaining large percentages of built physical stock from each period, so that most older structures will be near the center. Table I.5 shows the growth in population and the accumulation of building stock for a hypothetical city over the course of a century, from 1890 to 1990. Buildings survive from each period. Since growth takes place largely at the periphery, the area of urban agglomerations increases more rapidly than population does, and density declines.

YEAR	POP.	BLDGS.	1ST	2ND	3RD	4TH	5TH	6TH	SQ. MILES	DENSITY	ACRES /PC
1890	4,000	1,000	1,000						0.5	8000	0.08
1910	16,000	4,211	750	3,461					2.5	6500	0.10
1930	32,000	8,889	638	2,595	5,656				6.2	5200	0.12
1950	64,000	18,824	574	2,206	4,242	14,008			15.2	4200	0.15
1970	128,000	40,000	545	1,985	3,606	10,506	23,358		37.9	3375	0.19
1990	256,000	85,333	518	1,886	3,245	8,930	17,518	53,236	94.8	2700	0.24

Table I.5. Hypothetical city: change in population, building stock, and density, 1890-1990

Figure I.7 shows the hypothetical city's building stock for each period described in Table I.5. The death rates of these buildings are, in my opinion, exaggerated. We are still working on means of accurately determining death rates. So far, we have found that rates of demolition seem to vary from two-tenths to five-tenths of a percent. This means that it would take between 200 and 500 years to replace the existing building stock in a city under the current rates of demolition / reconstruction. The life expectancies of buildings probably range from 150 to 250 years.

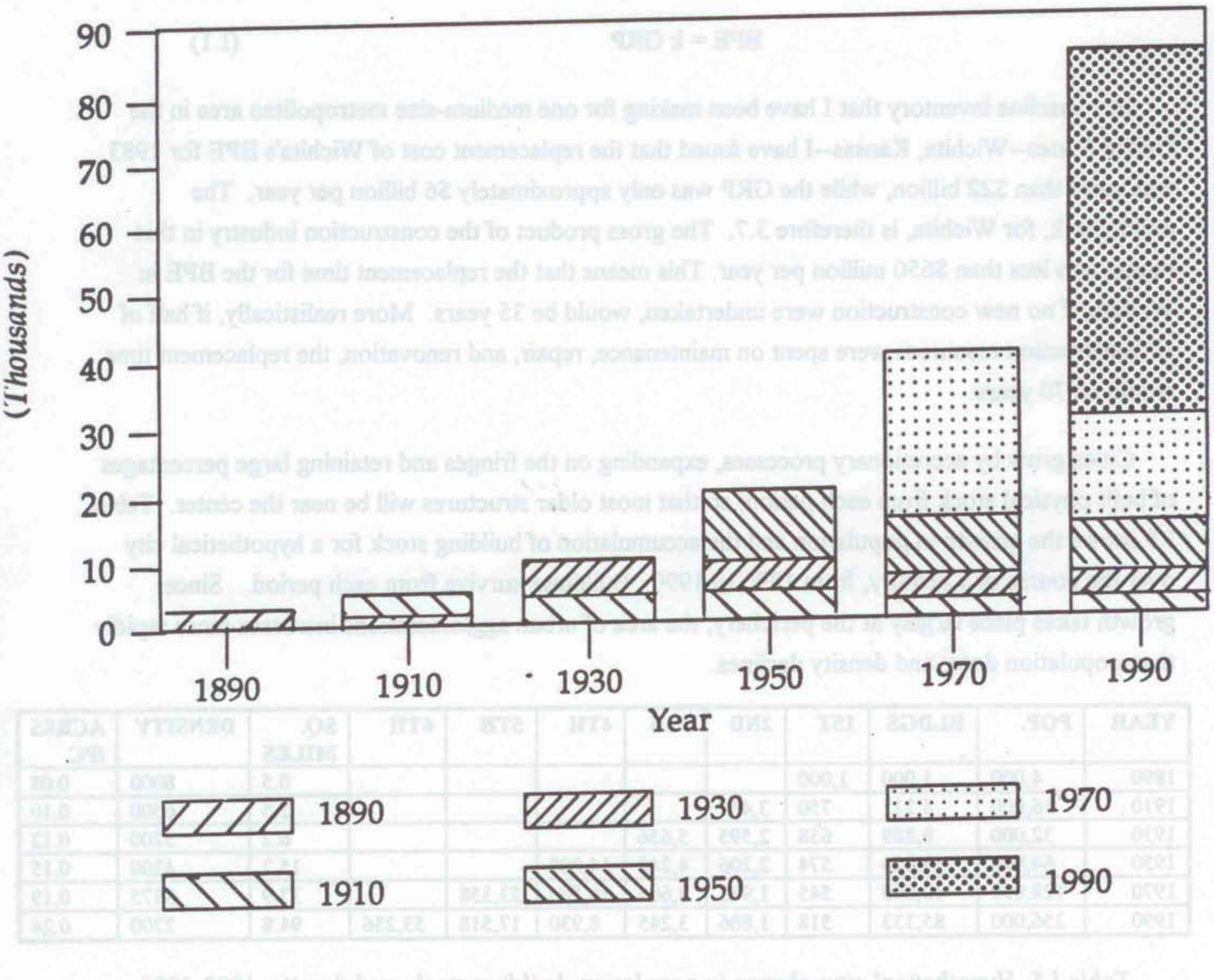

Figure I.7. Hypothetical city: age strata of building stock, 1890-1990

To meet the urgent needs of rapid urban growth, buildings and other structures will at first be inexpensive and less durable than those built later, when the pace of accumulation processes has matched pace of growth. In other words, the stock of buildings and other structures that will be built to accommodate the enormous urban expansion over the next two decades will be more fragile and more vulnerable to disasters such as earthquakes than are existing building stocks.

Dr. Jones is a professor of City and Regional Planning and Regional Science at Cornell University in Ithaca, New York. He also directs the Urban and Regional Studies Program at Cornell's Institute for Social and Economic Research. His current research includes developing indirect methods for estimating building stocks in order to assess earthquake risk and reduce vulnerability.

EARTHQUAKES AND MEGACITIES

Roger Bilham, University of Colorado, USA

It is sometimes difficult for people in the developed nations to appreciate the effects of earthquakes. I often show the graph in Figure I.8 to my students to highlight this problem. Of the various ways that people can die in the United States, earthquakes figure very insignificantly compared, for instance, to driving into and shooting one another. Even terrorists seem to win over earthquakes. This is not the situation, however, in the developing nations of the world.

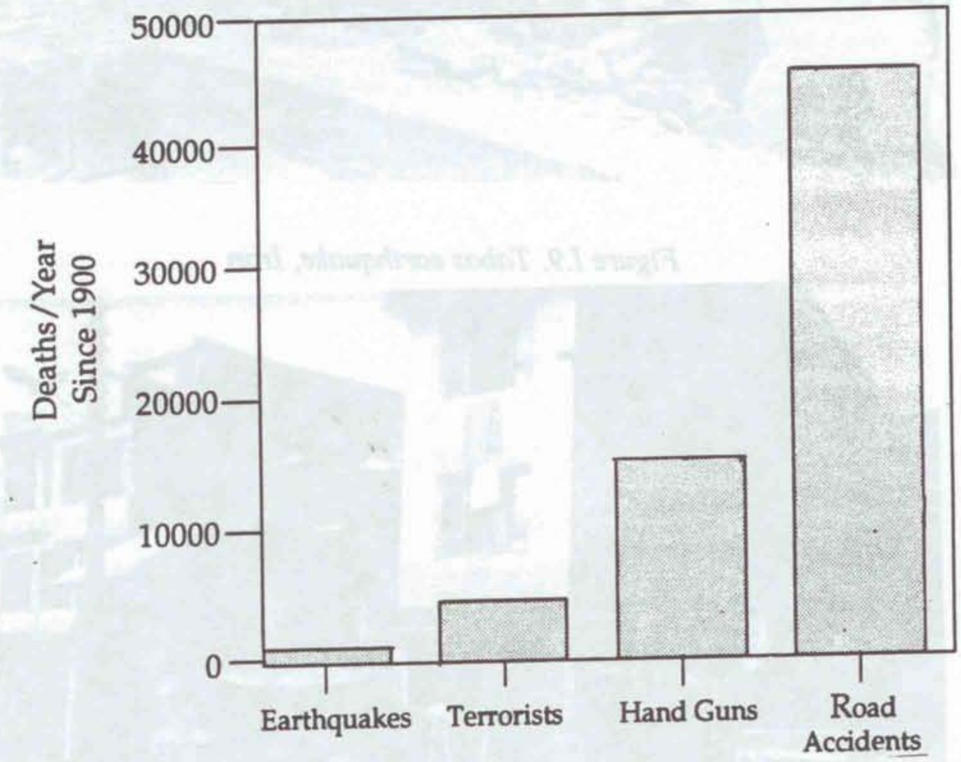

Figure I.8. Ways to die in the United States

Figure I.9 shows destruction caused by the 1990 Tabas Earthquake in Iran. The city of Tabas began with a population of approximately 30,000; only 3,000 inhabitants were alive after the earthquake. This disaster teaches us that in many developing nations, an earthquake lasting only a few seconds can destroy an entire city. The Tabas Earthquake had a magnitude of 7, comparable in severity to the earthquake that hit California in July 1992, in which only one person was killed. California has to be congratulated on both its building codes and its good fortune.

Figure I.9. Tabas earthquake, Iran

Figure I.10. Kathmandu construction

The situation is of course not the same in the developing nations. Figure I.10 shows central Kathmandu. We can be assured that when the next earthquake occurs here, as it almost certainly will within the next 100 years, this particular street will be just a heap of rubble, and many people will be killed.

Figure I.11. Mexico City

I hope the same is not true of Mexico City (Figure I.11). It is the largest city in the world and lies close to the seismic gap on the coast of Mexico that caused the 1985 earthquake. A second seismic gap that has not yet released is closer to Mexico City than is the gap that caused the 1985 event and is expected to cause a larger earthquake than the 1985 event. I am afraid we will see more collapsed buildings in Mexico City.

To summarize this discussion of building quality: areas with good buildings tend to sustain expensive damage, while areas with poor buildings tend to lose large numbers of people (Table I.6). Loss of life and facilities due to earthquakes in developing nations will be particularly tragic because these nations usually concentrate administrative infrastructures in their capital cities.

Los Angeles 1987	M 5.9
$358M	3 dead

Mexico 1985	M 7.9
$30M	9,500 dead

Tangshan 1976	M 7.9
$?	300,000 dead

Table I.6. Building quality as it affects impact

The root of the problem of poor building quality is the incredible increase in population taking place in much of the developing world. Figure I.12 summarizes growth trends in the world's population, which now seems likely to reach 12 billion in the 21st century. This number is, of course, not certain. Nonetheless, all historical attempts to pinpoint future populations for the planet have erred on the low side. We are only at the beginning of an unprecedented rise in population.

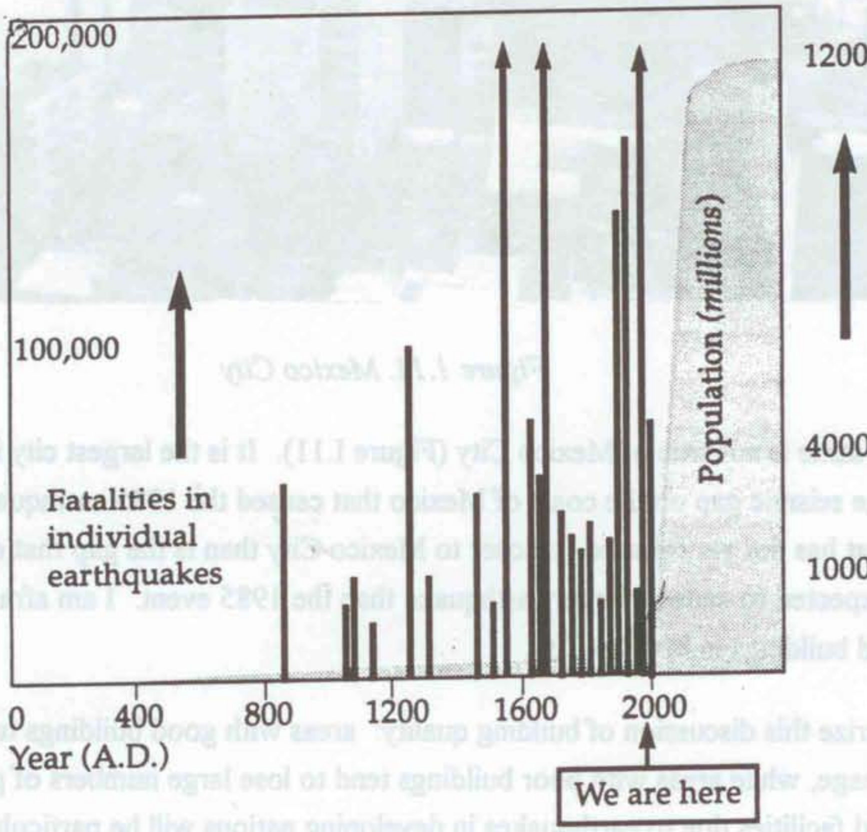

Figure I.12. Population increase and earthquakes

Figure I.12 also depicts the number of people killed in large earthquakes over the past thousand years. There are earthquakes of comparable magnitudes throughout this period, but they have tended to do increasingly greater damage over time. The casualty figures of several hundred thousand we have for the three earthquakes that exceed the scale in Figure I.12 (two of them in China) are hopelessly inaccurate. We do not really know the number of people killed in the 1976 Tangshan, China, Earthquake, for example, because whole families were lost. These devastating earthquakes may well be the shape of things to come in terms of earthquake damage, however.

The population of the developed nations is not increasing substantially, and world population growth is occurring almost entirely in the less developed nations (Figure I.13). It is as though a space station holding the current population of the earth were circling the earth and preparing to land. In other words, the population of the earth will double or triple over the next 25 years. Unfortunately, we have very little control over where these people will be born and live. Despite the dangers associated with living near a major fault, many will most likely do so.

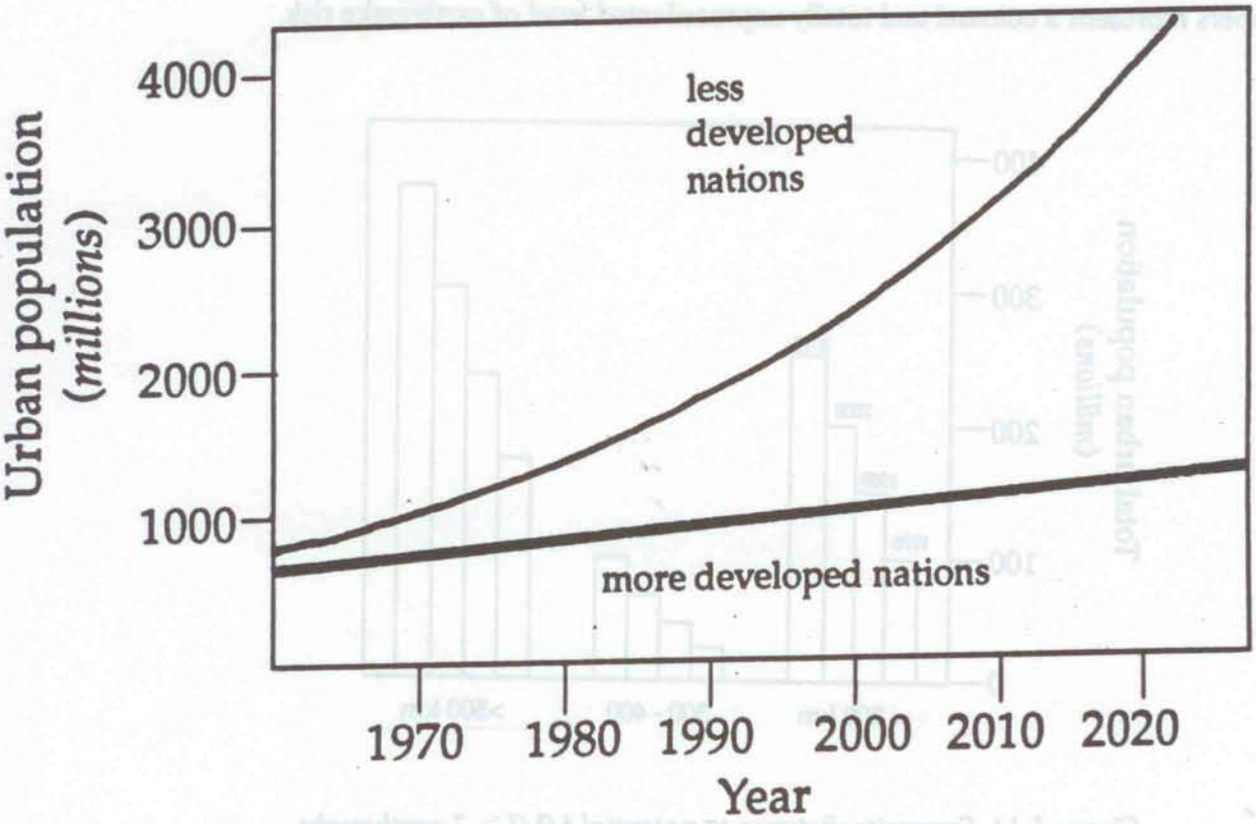

Figure I.13. World urban population, 1970-2025 (Source: U.N.)

Figure I.14 shows those populations that will be living within 200 kilometers of a magnitude 7 earthquake and those that will be living farther than 200 kilometers from one. Although these predictions are based on solid data, they still involve a good measure of guesswork, and earthquakes sometimes occur where one would not expect them. We do not expect very great earthquakes to hit New York City, for example. Although an educated guess designates New York as an essentially earthquake-safe zone, historical precedents do exist. Several large earthquakes have occurred on the East Coast of the United States. In fact, East Coast earthquakes have generally been larger than the more common California earthquakes.

Even though the graph of earthquake-associated death shown in Figure I.14 excludes these unpredicted earthquakes, the numbers are shockingly large. Within 25 years, we will be dealing with urban populations that approach 250 million. If we include a few unexpected events in places like the East Coast, or a repeat, for instance, of the Lisbon Earthquake in Portugal, the number of people at risk from great earthquakes in urban centers could exceed 500 million within 25 years. These numbers represent a colossal and totally unprecedented level of earthquake risk.

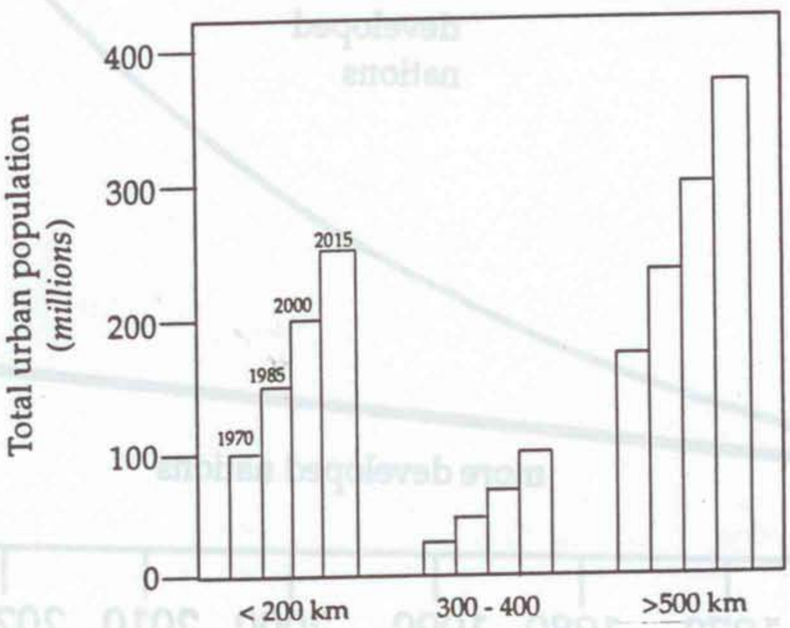

Figure I.14. Supercity distance to potential MMI > 7 earthquake

I liken earthquakes to bombs (Figure I.15). Wars have given us a clear sense of what bombs can do. It is estimated that a magnitude 7 earthquake has equivalent energy to a 30 megaton nuclear explosion. The kind of earthquakes that we are considering have magnitudes between 7 and 10. Magnitude 10 earthquakes exceed the limits of the Richter scale to accurately measure intensity. The Chilean and the Alaskan earthquakes are two examples of magnitude 10 events. A magnitude 9 earthquake is 1,000 times more powerful than the magnitude 7 depicted here. This is a vast amount of energy.

Although it may look as though earthquakes are becoming more numerous, earthquakes are steady-state. The growing population of the earth is causing an increase in the number of fatalities due to earthquakes, while earthquake magnitude and frequency remain roughly constant. Stated in terms of the bomb metaphor, bombs have struck the earth at a constant rate over the course of history (Figure I.16) while humans have gradually made more targets for these bombs (Figure I.17). We have made not only more targets but larger targets. We have thus given earthquakes a greater chance to do damage to civilization (Figure I.18).

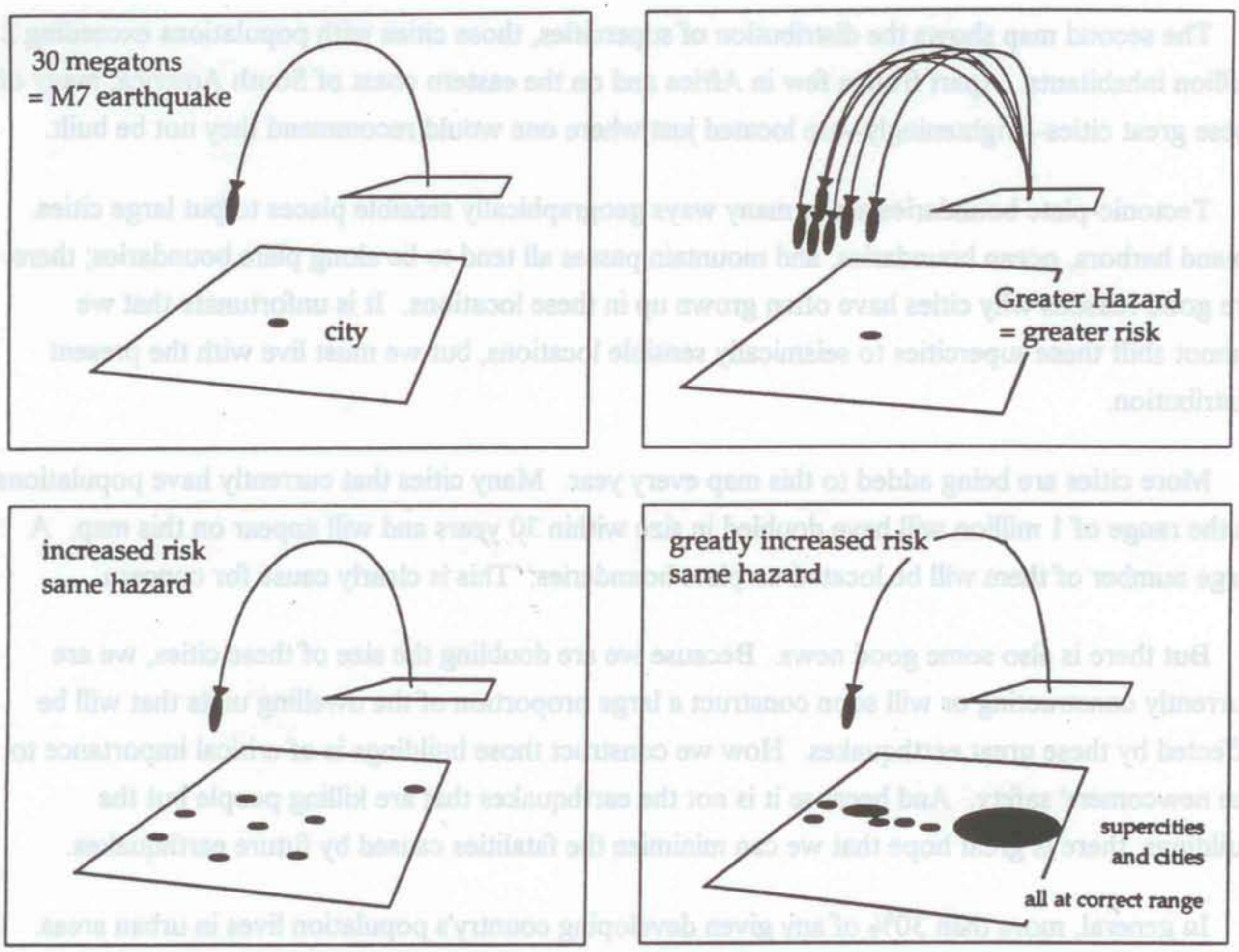

Figure I.15 - I.18. Earthquake likened to bombs

Of these larger targets, only one has been hit: the city of Tangshan, China, in 1976. The death toll may have been as low as 300,000 or as high as 700,000. But this level of loss, as a virtually inevitable phenomenon, is unprecedented in human history. China has an enormous population. To lose one of its cities is tragic, but not a complete catastrophe for the national economy. For other developing countries, however, losing a large fraction of the people in a city of 2 million or more could have disastrous consequences for the entire nation.

The maps on page 207 look the same but are in fact slightly different. The first shows the number of people killed by earthquakes in the last thousand years. Large dots indicate where more than 300,000 people were killed: the smallest dots, where more than 10,000 were killed. Lines represent the planetary plate boundaries that are responsible for the world's great earthquakes, those of magnitude 7 or greater. Rifting-type plate boundaries, responsible for swarms of relatively small earthquakes, have been omitted. In general, the dots fall on the planet's transform boundaries and thrust-type boundaries.

The second map shows the distribution of supercities, those cities with populations exceeding 2 million inhabitants. Apart from a few in Africa and on the eastern coast of South America, many of these great cities--frighteningly--are located just where one would recommend they not be built.

Tectonic-plate boundaries are in many ways geographically sensible places to put large cities. Inland harbors, ocean boundaries, and mountain passes all tend to lie along plate boundaries; there are good reasons why cities have often grown up in these locations. It is unfortunate that we cannot shift these supercities to seismically sensible locations, but we must live with the present distribution.

More cities are being added to this map every year. Many cities that currently have populations in the range of 1 million will have doubled in size within 30 years and will appear on this map. A large number of them will be located on plate boundaries. This is clearly cause for concern.

But there is also some good news. Because we are doubling the size of these cities, we are currently constructing or will soon construct a large proportion of the dwelling units that will be affected by these great earthquakes. How we construct those buildings is of critical importance to the newcomers' safety. And because it is not the earthquakes that are killing people but the buildings, there is great hope that we can minimize the fatalities caused by future earthquakes.

In general, more than 30% of any given developing country's population lives in urban areas. Figure I.19 shows the present populations of four countries and their capital cities, with a projection for 2025. In each country, there is a comparable growth in the size of the capital city and in the growth of the country as a whole. That is, the fraction of the total population living in the capital tends to remain the same. The population of Mexico City (currently 12 million) continues to increase rapidly and is expected to reach 30 million in the next century.

All other larger cities in a given developing country, taken together, are often equivalent in size to the nation's largest city. The dark sections in Figure I.19 represent the largest cities, while the shaded regions represent the other urban areas, and the white regions represent the rural population. In general, most of the developing world follows this pattern, with expansion not only in the size of the population but also in the size of the largest city.

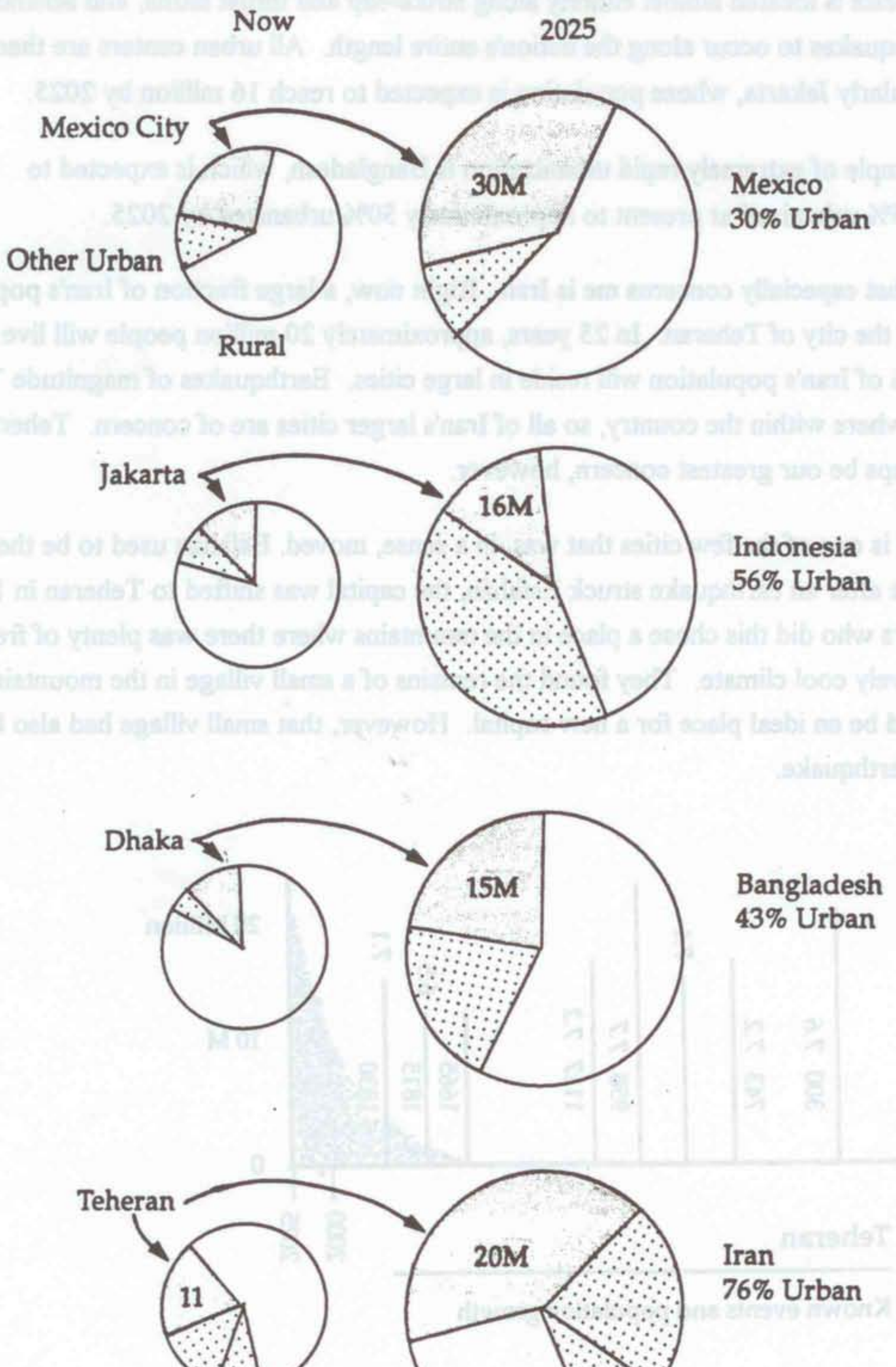

Figure I.19. Distribution of developing country populations

The rate of urbanization in Indonesia is tremendous. The country is presently only approximately 15% urbanized, but this figure is expected to increase to approximately 60% by the year 2025. Indonesia is located almost entirely along strike-slip and thrust faults, and seismologists expect great earthquakes to occur along the nation's entire length. All urban centers are therefore at risk, but particularly Jakarta, whose population is expected to reach 16 million by 2025.

A second example of extremely rapid urbanization is Bangladesh, which is expected to transform from 15% urbanized at present to approximately 50% urbanized by 2025.

The country that especially concerns me is Iran. Right now, a large fraction of Iran's population is concentrated in the city of Teheran. In 25 years, approximately 20 million people will live in Teheran, and 75% of Iran's population will reside in large cities. Earthquakes of magnitude 7 can occur almost anywhere within the country, so all of Iran's larger cities are of concern. Teheran itself should perhaps be our greatest concern, however.

First, Teheran is one of the few cities that was, in a sense, moved. Esfahán used to be the capital of Iran, but after an earthquake struck Esfahán, the capital was shifted to Teheran in 1788. The urban planners who did this chose a place in the mountains where there was plenty of fresh water and a relatively cool climate. They found the remains of a small village in the mountains and thought this would be an ideal place for a new capital. However, that small village had also been destroyed by an earthquake.

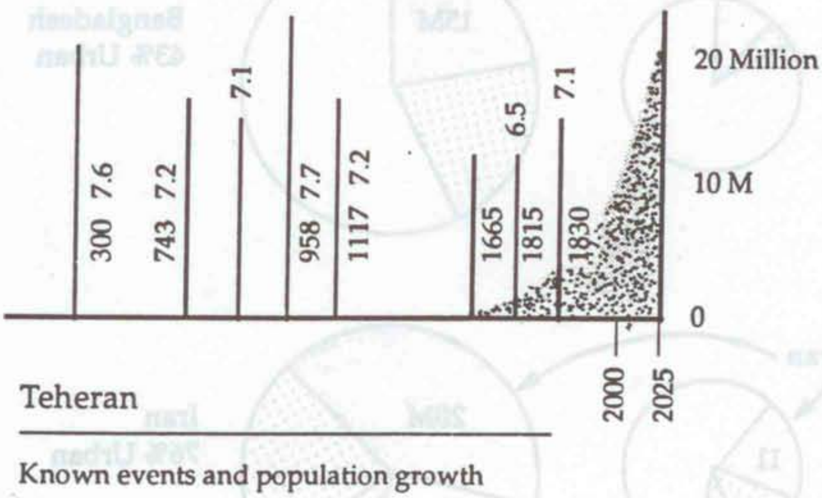

Figure I.20. Seismic History of Tehran and environs (Source: Ghafory-Ashtiany et al., 1992)

Figure I.20 shows the history of earthquakes since the year 300 that are thought to have occurred on faults within 20 kilometers of Teheran. The repeat time for these earthquakes is approximately 160 years, similar to that for major earthquakes along the San Andreas Fault near Los Angeles. The last event was in 1830, similar to the last event on the San Andreas. The probability of a magnitude 7 earthquake occurring here within a decade has been calculated to be 70%.

The predicted tragedy of Teheran is a horrendous story. Of all the city's buildings, 45% were constructed in the last 15 years, and were built to withstand shaking of 0.1g. New calculations show that the predicted magnitude 7 earthquake will have a minimum shaking amplitude of approximately 0.4g. If this estimate proves to be accurate, 60% of all existing buildings will collapse. The airport will certainly be closed for weeks due to rupturing of the runway, so no relief will be able to arrive except by road from great distances. Electric power is expected to be totally lost for between one week and one month. The water supply will be almost obliterated, with 6,600 kilometers of underwater pipes ruptured. Of the 145 hospitals in Teheran, most were built to the recent lower code levels, and many will likely be destroyed. It is expected that approximately 400,000 people will be killed in this one city.

This massive scale of earthquake-related destruction and death is a new phenomenon on this planet. The only precedents we have are times of great war and the bubonic plague, both of which debilitated or destroyed large fractions of whole nations. I fear that without vigorous measures, it will take decades for an affected country to recover from the consequences of a severe earthquake striking its capital city.

Dr. Bilham is a professor of Geology at the University of Colorado in Boulder. He is also a fellow of the Cooperative Institute for Research in Environmental Sciences and the adjunct senior research scientist at Lamont Doherty Geological Observatory. His current research projects include studies of fault afterslip, Ethiopian rift zone development, crustal deformation in Southern California, and the relationship of global sea levels to major earthquakes.

TRENDS IN EARTHQUAKE COSTS

Daniel Bitran, National Water Commission, Mexico

This paper deals with the concrete experience that we have had in Latin America in evaluating the economic effects of earthquakes and other natural disasters.

The governments of various Latin American countries have requested that the United Nations Economic Commission for Latin America (UNECLA) design post-earthquake reconstruction and rehabilitation programs. Using a methodology developed by UNECLA, we calculated the real impact of major Latin American earthquakes in the last 20 years. Three categories of economic impact were measured: (1) direct effects, including destruction of physical assets and inventories; (2) indirect effects, including reduced production of goods and services; and (3) secondary effects, including impact on economic variables such as GNP, balance of payments, employment, and inflationary pressures.

Earthquakes and volcanic eruptions cause frequent disasters in Latin American and Caribbean countries. Most occur along the so-called Ring of Fire on the continent's Pacific coast and along other lines of contact between tectonic plates.

Indeed, earthquakes tend to cause more casualties in Latin America than do meteorological phenomena such as floods. Earthquake-related loss of physical and social infrastructure generally also exceeds the damage caused by meteorological phenomena. These trends are particularly clear when earthquakes occur in urban areas. The impact of earthquakes on agricultural production, on the other hand, tends to be smaller than the impact of meteorological phenomena.

The impact of an earthquake on a nation varies according to three factors: (1) the magnitude of the earthquake, (2) the area affected, and (3) the level of economic development of the country.

During the last two decades, economic losses due to major earthquakes in Latin America have ranged from 3% to 83% of the affected nation's GNP (Table I.7). The Nicaragua Earthquake of 1972 caused the greatest economic impact, costing approximately 83% of Nicaragua's expected GNP for that year (direct losses 67%, indirect losses 16%). Mexico, by contrast, suffered much greater absolute loss (total losses, $4.3 billion), but lost only 3.2% of its GNP for that year (Table I.8). The fact that Nicaragua suffered colossal damage was due, at least in part, to the concentration of national population and economic activity in Managua.

	Nicaragua 1972	Guatemala 1976	Mexico 1985	El Salvador 1986	Ecuador 1987 *
TOTAL LOSSES	82.9	16.5	3.2	22.8	12.3
DIRECT LOSSES	66.6	16.1	2.8	17.2	2.3
INDIRECT LOSSES	16.3	.4	.4	5.5	10.0

* Includes floods and mud flows, which accounted for a high proportion of the damages.

Table I.7. Economic losses caused by earthquakes in Latin America, as percentage of GNP

	NICARAGUA 1972	GUATEMALA 1976	MEXICO 1985	EL SALVADOR 1986	ECUADOR 1987 *
TOTAL LOSSES	1,967	1,437	4,337	937	1,001
DIRECT LOSSES	1,580	1,402	3,793	710	186
INDIRECT LOSSES	387	35	544	227	815
GROSS DOMESTIC PRODUCT	2,372	8,731	134,211	4,117	8,160

* Includes floods and mud flows, which accounted for a high proportion of the damages.

Table I.8. Economic losses caused by earthquakes in Latin America, in millions of U.S. dollars at 1987 prices

The Guatemala Earthquake of 1976 produced 23,000 recorded casualties. Accumulated economic losses amounted to 16.5% of the GNP. The impact of damage on the national economy might have been much greater given the number of people killed, but the area affected was inhabited by a very poor stratum of the population, whose economic activities had a relatively small impact on the GNP.

In El Salvador, damage caused by the 1986 earthquake accounted for 22.8% of the GNP.

In Nicaragua, Guatemala, Mexico, and El Salvador, direct losses were greater than indirect losses, mainly because housing stocks and social infrastructure were destroyed. In Ecuador, indirect losses were greater than direct losses because of difficulties that the country faced in recovering its productive capacity.

There is not much empirical evidence, as only 20 years of records are available for most Latin

American countries. Though it is impossible to draw firm conclusions, it seems clear that the socioeconomic dislocation caused by natural disasters in general and earthquakes in particular will continue to rise for decades.

Natural phenomena--earthquakes, in particular--tend to cause greater casualties and economic impact in developing countries than in industrialized countries. This greater vulnerability is due mainly to the urbanization processes in the developing countries. Rates of urban population increase are much higher in developing countries than in industrialized countries, while the quality of buildings, houses, and safety standards tends to be lower. Rapid population growth and inadequate quality standards for urban infrastructure combine to produce increased risk.

Large urban concentrations magnified the consequences of earthquakes in both Nicaragua and Mexico. The 1972 Nicaragua and the 1985 Mexico earthquakes, which affected urban areas, produced human and material losses much greater than those resulting from the Ecuador Earthquake, which affected mainly rural areas. As explosive population growth in developing countries increases population densities, casualties and material losses caused by earthquakes are bound to increase.

Education and mitigation measures help to reduce earthquake-related casualties and damage in developing counties. Two phenomena, however, work against this, tending to increase vulnerability. On one hand, these countries tend to incorporate large-scale modern technologies that demand high levels of capital investment. On the other hand, the process of urban demographic agglomeration continues unabated. Both phenomena devour scarce city government resources that might otherwise be used on disaster-preparedness measures.

Increasing use of new technologies--including nuclear technology, biotechnology, genetic engineering, and computer science--brings with it a new class of risks unknown in previous decades. Such technological developments increase the destructive potential of earthquakes: industrial accidents can leak toxic or radioactive waste, and damage to computer systems can impair the functions of the national economy. The effects of these new dangers tend to be more adverse in developing countries, where advanced technological complexes are often installed without suitable safety measures. These technological advances also increase the geographic extent of an earthquake's impact, spreading damage to regions remote from the event's epicenter.

Poverty may magnify the effects of earthquakes in Latin American countries. The decade of the 1980s, sometimes called the "Lost Decade," saw an increase, in absolute terms, in the poverty level of Latin Americans. This increase has brought deficiencies in living conditions, the quality of housing, and safety measures, leaving populations more vulnerable to natural disasters.

In summary, the impact of earthquakes on Latin American nations, and on developing countries in general, is likely to increase due to three factors: (1) the rapid pace of urbanization, which tends to create large, densely populated cities; (2) the risks of utilizing new technologies without access to proper damage-prevention mechanisms; and (3) the high levels of poverty that make populations more vulnerable to earthquakes.

Mr. Bitran is a consultant to the Mexican Water Commission and has worked as an economist for the United Nations Economic Commission for Latin America in a variety of posts throughout Latin America. He is currently responsible for drafting Mexico's National Hydraulic Program for the period 1991-1994 and has recently completed a manual on evaluating natural disaster damage.

DISCUSSION

Robin Spence, Cambridge University, UK

There is an apparent discrepancy between the remarks made by Roger Bilham and the concluding remarks of Professor Barclay Jones. Professor Bilham said that there is some hope of minimizing the negative effects of earthquakes on the urban populations of developing countries because many of the buildings in which these populations will be living have not yet been built. Professor Jones said that the trends toward poverty and poor construction in urban areas would inevitably increase for some years to come. Could you, Dr. Jones, enlarge on your final remark and tell us if you think the dwellings of the future will inevitably be more vulnerable or if this trend of increasing vulnerability could possibly be reversed?

Barclay Jones, Cornell University, USA

When urban populations are growing rapidly, new facilities to accommodate them must also be built rapidly. These dwellings are frequently discarded within 25 years, as urban growth catches up and as more resources become available. Building stocks show a high child-mortality rate, and there is a greater probability that a building will be torn down or demolished in the first 25 years of its existence than after that. If it survives 25 years, it is likely to remain standing for a long time. Young buildings found in developing nations experiencing rapid population growth are typically relatively flimsy and poorly constructed. They have what could be called a built-in obsolescence.

After China's Tangshan Earthquake, an enormous retrofit program took place in Beijing. Although Beijing itself experienced little actual destruction, the shaking felt there and news about Tangshan were sufficient to spur this effort. As a result, the visitor to Beijing today sees thousands of buildings, most of them less than 30 years old, that have been retrofitted, redeveloped, and strengthened to withstand future shocks. These strengthened buildings will likely remain standing for many years.

John Tomblin, DHA-UNDRO, Switzerland

I was in Teheran immediately after the 1990 earthquake that hit some towns in northwestern Iran. Near the United Nations office a six-story steel-framed building had also collapsed, although Teheran was more than 200 kilometers from the earthquake's epicenter. I later learned that this building had collapsed several days before the earthquake simply because an older structure had been removed from a site adjacent to it. The steel frames of many Iranian buildings have been spot-welded in such a way that only about 10% of the surfaces in contact were actually welded. Money had been spent to purchase steel frames, but only 10% of the potential benefit was realized, and the resulting buildings were quite vulnerable. Given the performance of the same style of building and the same low-quality welding in these three towns, perhaps 400,000 is a highly conservative figure for the potential population loss resulting from a major earthquake in Teheran.

I was also in China two years ago studying the Tangshan Earthquake. The authorities told me that the event had claimed 242,000 lives. I was able to tour Tangshan and observe the population for which the city has been rebuilt. It looked as if approximately one quarter of the city's population had lost its life. The figure of 242,000, which falls toward the low end of the published estimates, therefore seems realistic.

Herbert Tiedemann, Swiss Reinsurance Company, Switzerland

It is a fact too often overlooked that the more complex human society becomes, the more vulnerable it becomes. This is a law of nature. We are less resilient than our forefathers.

I do not share the wishful thinking of structural engineers about reducing earthquake losses, for the simple reason that more than 80% of all earthquake losses are nonstructural. All too often, structural engineers calculate the vibrational behavior of structures, working like lunatics without knowing the essential parameters of earthquake risk for these structures. Given this irresponsible behavior, losses are bound to stay where they are. Over the last 30 years, there has been almost no progress toward effective mitigation, particularly in the poorer parts of the world.

David Dowrick, Institute of Geological & Nuclear Sciences, Ltd, New Zealand

In studies conducted over the last five years, or since New Zealand's major 1987 earthquake, average damage to buildings of different ages in New Zealand has been found to be stable. In other words, building vulnerability has changed little since the first codes were introduced in 1935, although heavy damage within high-intensity zones has decreased. Our construction codes, however, aim to reduce loss of life rather than to reduce damage.

Roger Bilham, University of Colorado, USA

Professor Nicholas Ambraseys of Imperial College, London, has pointed out that many people think of earthquakes as acts of God, or events that simply happen and that people can do little to influence. Of course, we cannot stop earthquakes themselves. But the destruction resulting from an earthquake is by no means inevitable. We sometimes think of this destruction as an act of God, too, but actually it is our fault.

Professor Ambraseys points out that in the 4,000 to 5,000 years of recorded history, supercities and megacities have emerged only in the last hundred years. While humanity can doubtless survive a few Tangshan-like events, people can also take action to mitigate future disasters. The people who need to get this message are the urban planners and architects in these large cities. They must be made to understand that something can be done to minimize earthquake damage. Though the remarks we have heard here to the effect that the situation may well be more ominous than I made it out to be are no doubt valid, there is nevertheless room for hope. There is room, for example, for retrofitting older buildings and for redesigning many of the structures that will be built in the next few years. There is no room, however, for complacency in this matter. Events that have in the past been taken as acts of God may well in the future be taken as studies in criminal negligence.

Brian Tucker, GeoHazards International, USA

Professor Jones mentioned that he is studying Wichita, Kansas, and as a professor at an American university, most of his experience has been with U.S. cities. To what extent, Dr. Jones, can the experience of cities in the industrialized world be helpful to non-U.S., non-Western cities, which are often quite fast-growing and fragile?

Barclay Jones, Cornell University, USA

My guesses about the applicability of our experience to developing nations are based on personal experience working in developing countries and close contact with the many students from developing countries who have worked under me on the problems of their home countries. Applicability varies tremendously from place to place. In Indonesia--to mention one example of an area where our experience applies poorly--the historical vernacular building has been a wood-framed, wood-walled structure well designed to withstand earthquake shocks. Over the last 25 to 30 years, however, construction in Indonesia has been similar to recent construction in the West. These newer buildings will not withstand earthquakes as well as the traditional buildings.

Michio Hashizume, United Nations Educational, Scientific, and Cultural Organization (UNESCO), France

The list of major natural disasters from 1960 to 1987 shown in Table I.9 is drawn from a list compiled by the Munich Reinsurance Company (Munich Re). The original list contains 111 events. Selecting from this list all events whose damage exceeded 1% of the affected nation's Gross National Product, the new list shows three phenomena: (1) the most significant disaster events are earthquakes, although only 30% of the events in the original Munich Re list are earthquakes; (2) approximately 60% of the original list were developed countries--in the list of most-impacted nations, the majority are developing countries; and (3) there are almost no African countries on the list. One conclusion of this analysis is that disaster impact to a nation needs to be considered in conjunction with the nation's stage of development.

COUNTRY	EVENT	DATE	DEATH	LOSSES (US$ MIL)	GNP (US$ BIL)
Morocco	Earthq	29/02/60	13,100	120	12
Chile	Earthq	21/05/60	3,000	800	17
Yugoslavia	Earthq	26/07/63	1,070	600	45
Philippines	Typhoon	11/64	58	600	32
Italy	Earthq	06/05/76	978	3,600	352
Peru	Earthq	31/05/70	67,000	500	17
Nicaragua	Earthq	23/12/72	5,000	800	3
Honduras	Hurricane	09/74	8,000	540	3
Guatemala	Earthq	04/02/76	22,778	1,100	9
Italy	Earthq	06/05/76	978	3,600	352
China	Earthq	27/07/76	242,000	5,600	280
Romania	Earthq	04/03/77	1,581	800	51
Yugoslavia	Earthq	15/04/79	131	2,700	45
Caribbean/US	Hurricane	08/79	1,400	2,000	
Algeria	Earthq	10/10/80	2,590	3,000	47
Italy	Earthq	23/11/80	3,114	10,000	352
Greece	Earthq	24/02/81	25	920	33
Yemen	Earthq	13/12/82	3,000	90	4
Peru/Ecuador	Floods	01/04/83	500	700	27
Fiji	Cyclone	04/03/83	7	85	1
Colombia	Earthq	31/03/83	250	380	35
Chile	Earthq	03/03/85	20	1,200	17
Bangladesh	Cyclone	05/85	11,000		
Mexico	Earthq	19/09/85	10,000	4,000	136
Colombia	Volcano	13/11/85	23,000	230	35
El Salvador	Earthq	10/10/86	1,000	1,500	4
Iran	Floods	12/86	424	1,560	90
Vanuatu	Typhoon	02/87	50	200	0.1
Ecuador	Earthq	05/03/87	1,000	700	10
Bangladesh	Floods	09/87	1,600	1,300	12

Sources: Modified after G. Berz, *Natural Disasters Vol. 1*, 1988 and *Atlas Eco*, Air France, 1985

Table I.9. Major natural disasters, 1960-1987

Tsuneo Katayama, University of Tokyo, Japan

Dr. Bilham said that the urban planners of today are responsible for safety in cities. He also said, in unequivocal terms, that seismologists of this decade must make a concerted effort to characterize future seismic hazard. But in his comments about Teheran, he used the report of the engineers to highlight the need for assessments. What then are his definitions of planner, engineer, geologist, and architect?

Roger Bilham, University of Colorado, USA

Essentially, the seismologists and geologists of the world are interested in earthquakes as an esoteric study. The people who build buildings like constructing buildings and making a profit. Urban planners send out requests and take the lowest bids simply to get houses built, because the demand in these large, fast-growing cities is intense. These pressures on the various professions are understandable. Perhaps the problem is the lack of forums where experts from a variety of relevant disciplines gather to consider a given problem as a unified whole.

SUBMITTED COMMENTS

Thomas Anderson, Fluor Daniel, Inc., USA

Barclay Jones gave the figures of 150 to 250 years for the life expectancy of buildings. This may be accurate as an average range, but it does not hold true in Southern California, where building life expectancy is less than 50 years.

Anand Arya, University of Roorkee, India

It would be useful to consider such questions as why urbanization is growing, whether the trend toward urbanization could be arrested, and how this might be possible. Another useful approach would be to consider what could be done to draw the attention of city planners to earthquake risks so that they might become proactive in reducing future risks.

Mustafa Erdik, Bogaziçi University/Kandilli Observatory & Earthquake Research Institute, Turkey

It would be interesting to consider discrepancies between predicted and observed scenarios to date.

Sudhir Jain, Indian Institute of Technology, Kanpur, India

Procedures for developing quick, perhaps crude scenarios would be extremely useful, especially in developing countries. It is unlikely that many vulnerable megacities will have both the will and the resources necessary to develop sophisticated procedures like those used in Los Angeles and Tokyo.

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

It would be interesting to analyze the observed trends of damage in megacities of the First and Third Worlds. Apparently, economic losses are huge in the First World and moderate in the Third World, while casualty figures show precisely the opposite trend.

Antonios Pomonis, Cambridge University, UK

The world has experienced 1,106 fatal earthquakes in the 1900-1991 period, with an estimated total loss of 153 million lives in 75 countries. (The 1976 Tangshan Earthquake alone is considered to have caused 243,000 deaths.) Despite an increase in world population from approximately 2 billion to more than 5 billion people over this period, loss of life due to earthquakes has dropped by an estimated 20% to 25% between the first and second halves of the century (Figure I.21).

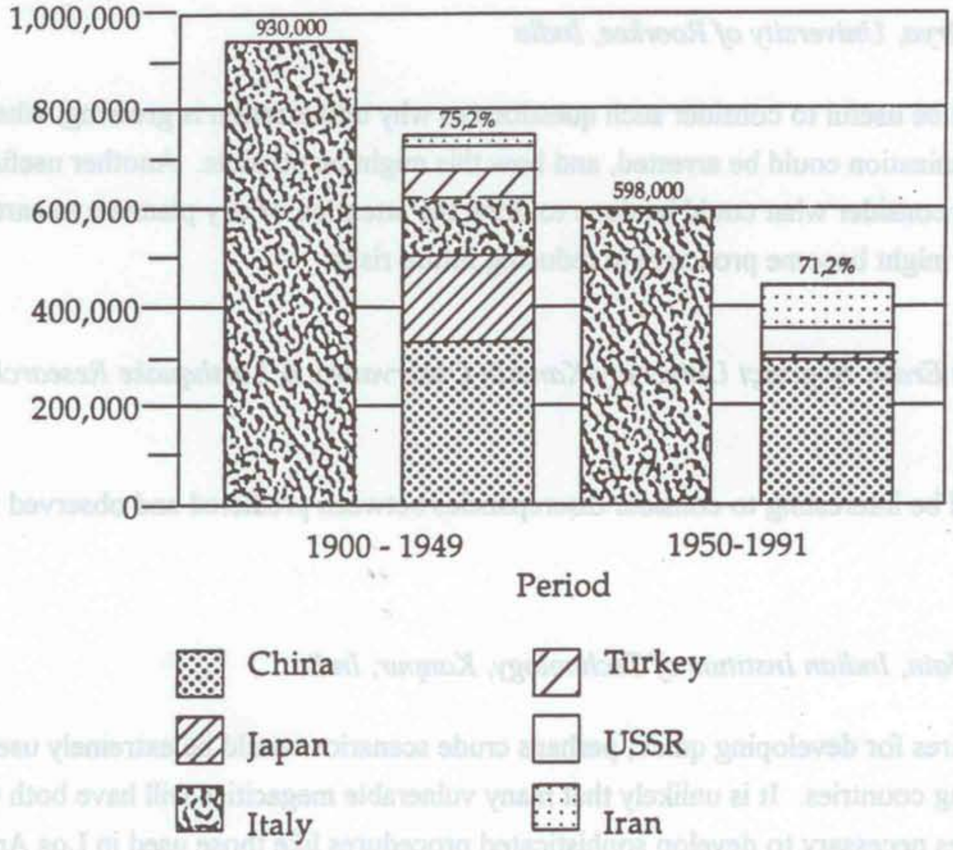

Figure I.21. Loss of life due to earthquakes in the 20th century

Approximately 75% of the loss of life occurred in only six countries. Of these, only Iran has experienced a significant increase in loss of life in the post-1950 period, while loss of life in the other five countries (especially Japan and Italy) has decreased considerably.

In the 38 countries most affected by earthquakes, there are 832 cities with 200,000 or more inhabitants. The total population of these cities in 1985 was 676 million people, or 14% of the world's population at that time (Figure I.22). Almost 70% of the world's population now lives in these 38 countries.

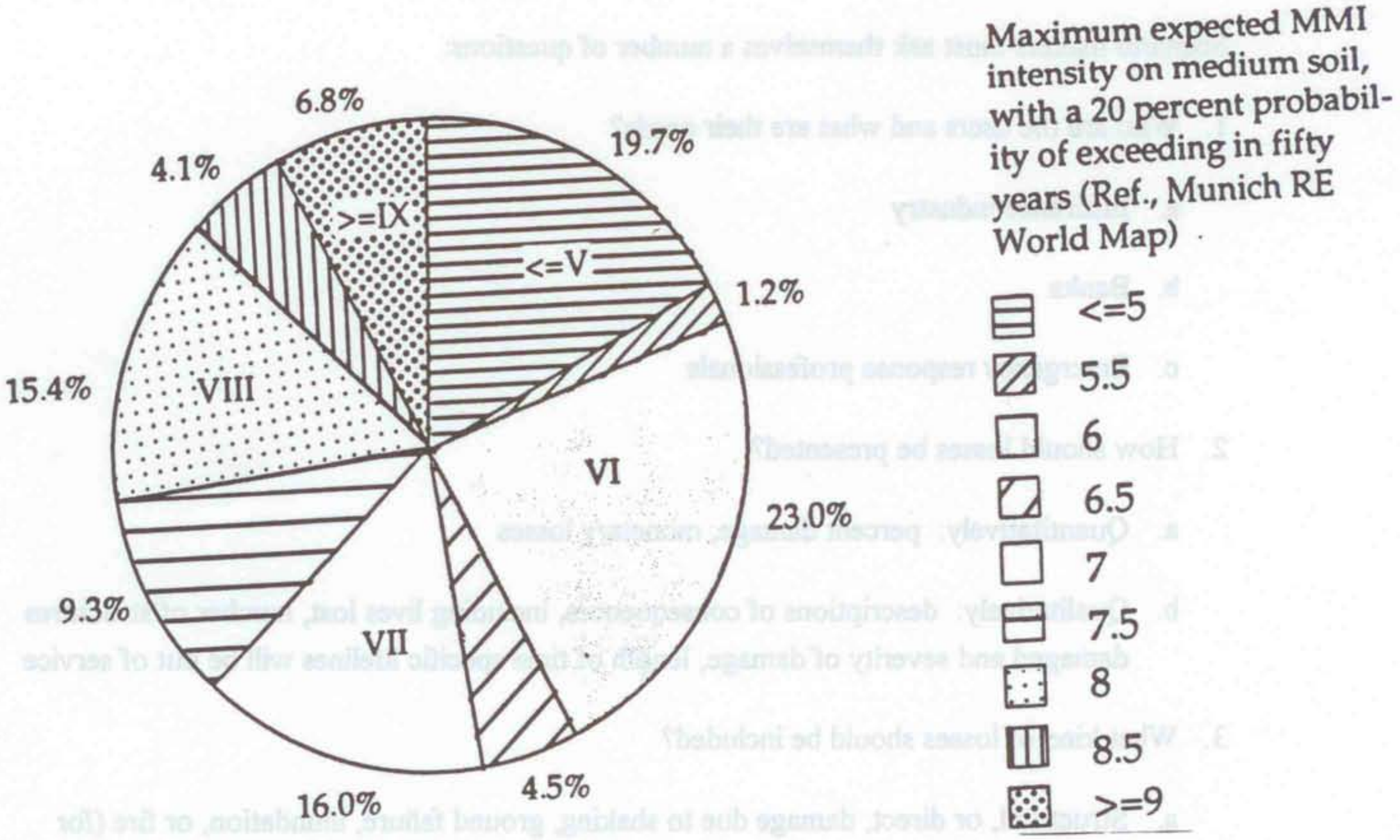

Figure I.22. Large-city populations located in seismic hazard zones (39 most earthquake-prone countries, cities with over 200,000 inhabitants)

Approximately 52% of the urban population shown in Figure I.22 is located in areas of Modified Mercalli Intensity (MMI) VII or higher (using Munich Re's world hazard map). Approximately 26% (178 million people or 4% of the world's population) is located in areas of MMI VIII or higher.

Many people living in these cities are exposed to unacceptably high risk. The world community clearly has an obligation to target the most vulnerable of these cities and attempt to reduce their seismic risk. Teheran is a striking example of a population living with an unacceptably high level of seismic risk.

Christopher Rojahn, Applied Technology Council, USA

Scenario makers must ask themselves a number of questions:

1. Who are the users and what are their needs?

   a. Insurance industry

   b. Banks

   c. Emergency response professionals

2. How should losses be presented?

   a. Quantitatively: percent damage, monetary losses

   b. Qualitatively: descriptions of consequences, including lives lost, number of structures damaged and severity of damage, length of time specific lifelines will be out of service

3. What kind of losses should be included?

   a. Structural, or direct, damage due to shaking, ground failure, inundation, or fire (for either selected types or all types of facilities)

   b. Indirect economic losses

   c. Deaths and injuries

4. How will ground shaking be characterized? (This decision may be dictated by the motion-damage relationships selected for the project.)

5. What model will they adopt?

   a. Japanese

   b. Peruvian

   c. Mexican

   d. California Division of Mines and Geology

   e. ATC-13 (Applied Technology Council)

PART II: EARTHQUAKE DAMAGE SCENARIOS FOR LOS ANGELES AND TOKYO

Alain Le Saux, Chairman

Mr. Le Saux is project chief for prevention of development-related environmental emergencies and pollution at the Institut d'Aménagement et d'Urbanisme de la Région d'Ile de France. He is also scientific director for the committee on major emergencies at the Association Mondiale des Grandes Métropoles (METROPOLIS).

THE TECHNIQUE OF MAKING EARTHQUAKE DAMAGE SCENARIOS IN CALIFORNIA

Glenn Borchardt, California Division of Mines and Geology, USA

Since 1982, the State of California has been developing and publishing earthquake scenarios that delineate the effects of hypothetical earthquakes on the most populated areas of the state. Designed to give a realistic image of anticipated disasters, scenarios teach us an important scientific lesson about the affected resources: some will be usable and some will be unusable. By pinpointing the areas where extensive damage is likely, California's scenarios highlight both where search and rescue will be needed and where alternative lifeline facilities need to be developed for search and rescue efforts.

Preparation of earthquake planning scenarios is divided into two phases: preparation of a seismic intensity distribution (SID) map (which includes corrections for fault locations, liquefaction, and landslides) and preparation of lifeline maps. Once completed, these maps are used to educate emergency planners and the general public and to stimulate geotechnical studies and better construction.

The factors that describe ground motion--acceleration, frequency, and duration--are like the three dimensions of an object; we cannot assess seismic intensity without considering all three factors. Unfortunately, computer programs used to predict seismic intensity often use only acceleration as an indirect gauge of duration. This method, although essentially inadequate, gives a rough approximation only because large-magnitude earthquakes typically show not only high accelerations but also long periods of shaking. And obviously, the more something shakes, the more likely it is to get damaged. The effect of frequency is a subject of current research where much more work needs to be done.

Figure II.1 shows a computer-generated isoseismal map for a magnitude 7 earthquake. Modified Mercalli Intensity (MMI) VII shaking occurs within 8 kilometers of the fault, and MMI VI shaking occurs out to 30 kilometers. These figures show bedrock acceleration.

The generalized geologic map on page 209 shows various geologic units. The most vulnerable areas generally are Quaternary sediments (shown in yellow) in flat-lying areas. Two intensity units are added to the shaking estimates for these areas (Table II.1). If an area's bedrock is experiencing MMI VII shaking, for instance, Holocene sediments will exhibit MMI IX shaking, while Plutonic or metamorphic rocks will exhibit MMI VII shaking. The Holocene sediment areas are, not surprisingly, where much of the damage occurs.

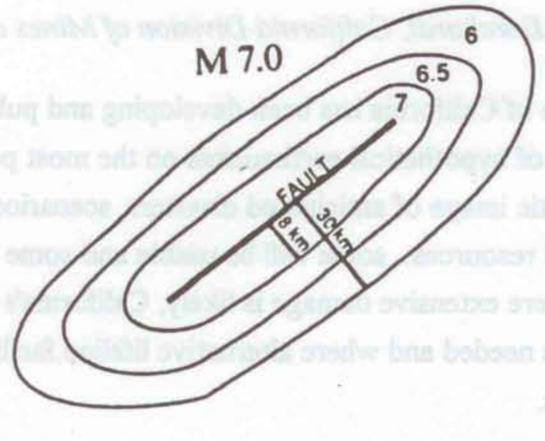

Figure II.1. Computer-generated isoseismal map

GEOLOGIC MAP UNITS	INTENSITY FACTOR TO BE ADDED
• Plutonic and Metamorphic	0
Volcanic	0.3
Miocene Nonmarine	1.3
Miocene Marine	1.5
Pliocene and Pleistocene	1.8
Holocene	2.0

Table II.1. Intensity factor to be added, by soil type

Sediments that magnify shaking are slightly different in different parts of the world. One challenge in developing earthquake damage scenarios is to characterize both the expected bedrock shaking and the geologic materials that will influence that shaking.

The first step is to know the geology, so geology maps are terribly important. One reason it takes so long to prepare a scenario is that most available geology maps are at different scales. In California, we typically prepare our maps at a 1:100,000 scale and then reduce them to 1:200,000 to publish them. All maps generally have to be converted to the 1:100,000 scale to produce a usable working map for an area.

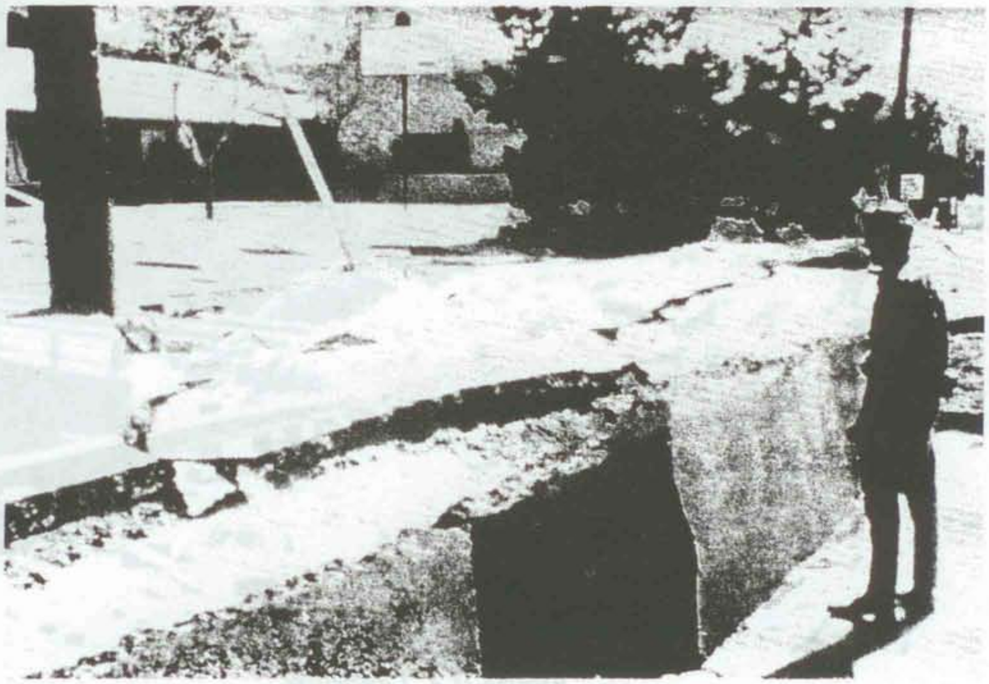

Figure II.2. Fault rupture

Figure II.2 shows fault rupture, which obviously should be noted on the map. Liquefaction in 1933 caused damage to roads (Figure II.3). The third type of ground failure is landslides, or rock fall, which can close roads (Figure II.4).

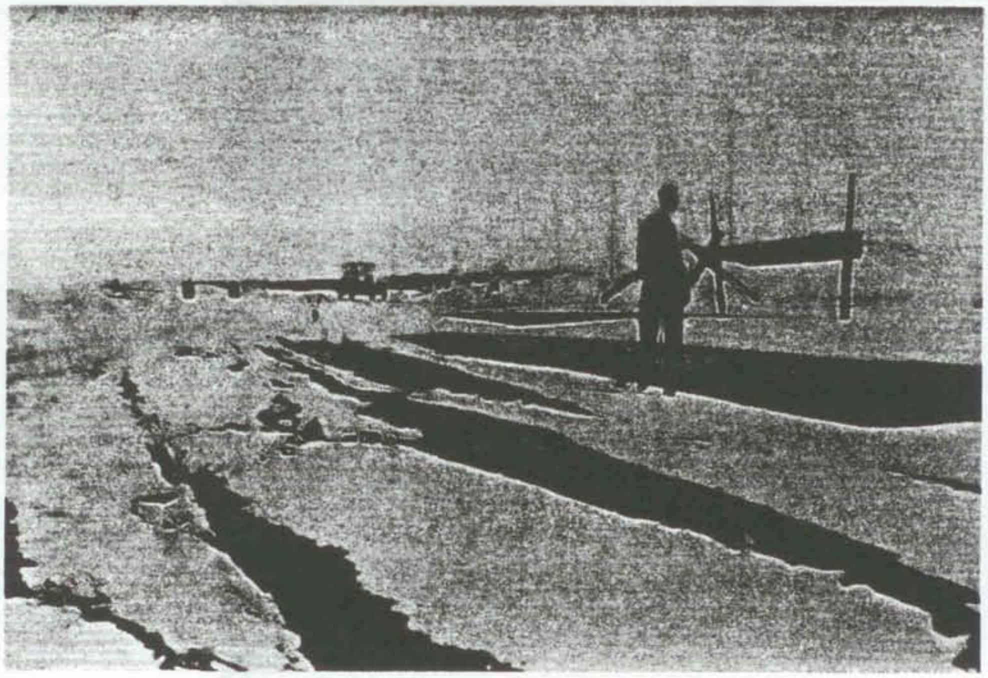

Figure II.3 Liquefaction damage

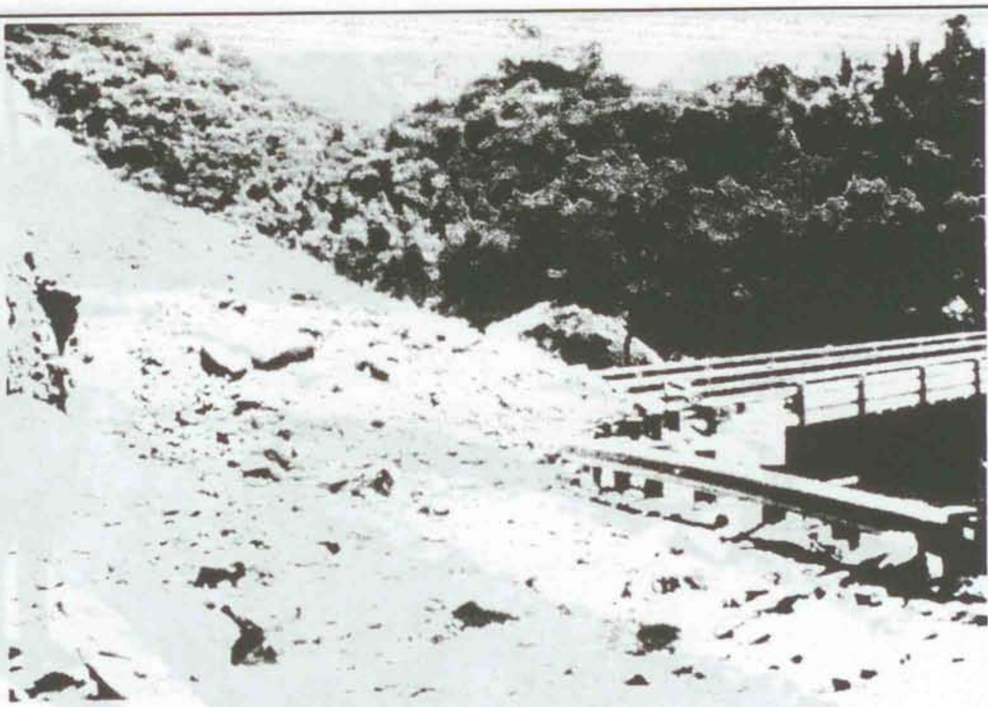

Figure II.4. Landslide

The map of Los Angeles in Figure II.5 shows the Newport-Inglewood Fault running through the metropolitan area. The San Andreas Fault, which receives attention in the press, actually poses much less of a threat to Los Angeles (see page 211). Given its location, Los Angeles will be affected probably 10 or 100 times more strongly by the Newport-Inglewood Fault than it will by the San Andreas Fault.

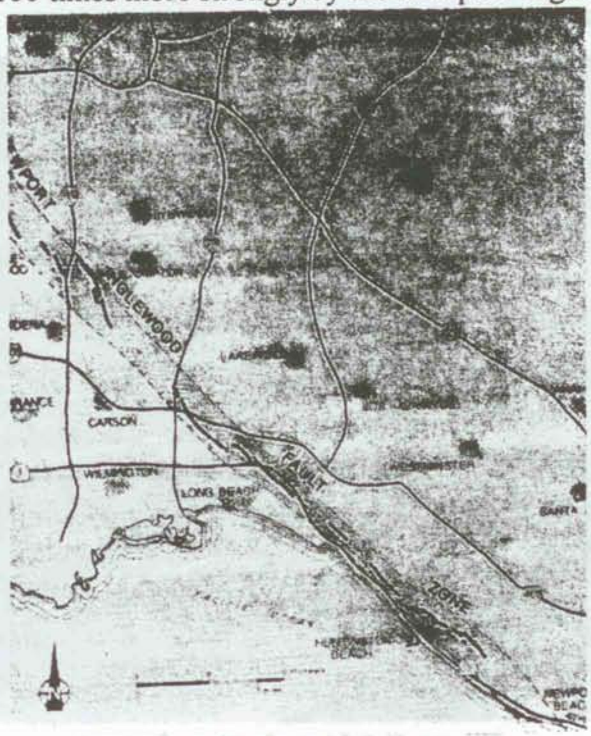

Figure II.5. Newport-Inglewood Fault (Source: CDMG)

On page 209 there is a map of the Hayward Fault in the San Francisco Bay Area. The blue-lined regions are the areas in which we might have liquefaction--that is, areas where soils could possibly turn to quicksand during an earthquake. The water table in these areas is within 10 meters of the surface. This area is not adequately mapped. Nonetheless, we have indicated all the areas of possible liquefaction until further work is done to delineate the actual risk. Dotted sections designate hilly areas, defined as having slopes of 30% or greater. We can expect to have landslides in these areas but must do more scientific work to determine specifically where landslides will occur in any particular event.

The SID map on page 211 shows the seismic intensity distribution for a given hypothetical earthquake. This SID map is for a magnitude 8 earthquake on the San Andreas Fault, one of the two specific scenarios that I will discuss. It includes some information on liquefaction, but none on landslides.

The phenomenon of liquefaction is largely independent of baseline ground shaking and can occur up to 500 kilometers from the fault. The 1964 Alaska Earthquake showed this. We do not, however, have a good understanding of the dependence of liquefaction on distance from an earthquake's epicenter. More research needs to be done in this area.

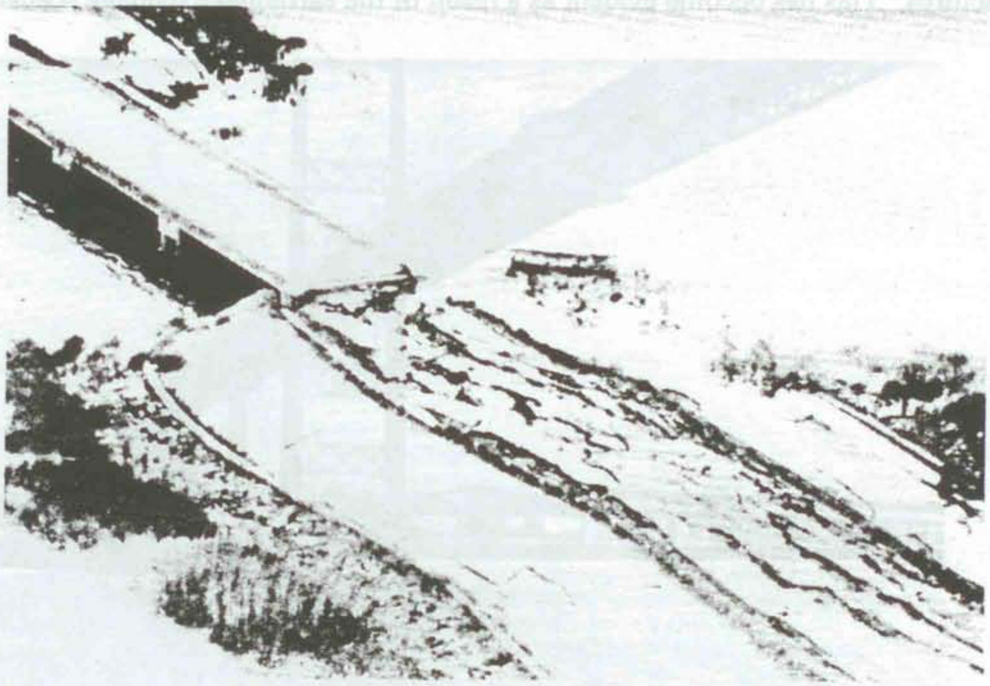

Figure II.6. Liquefaction-caused subsidence

It is even more difficult to gauge the effects of disasters on lifelines. In areas having a high water table, we typically find liquefaction-caused subsidence (Figure II.6). Notice that the bridge is standing nicely, but that the approaches have failed. This is typical and can be analyzed. We need only know the depth of the water table and something about the kind of soil. In this case, the soil was sandy, so the slump was probably due to liquefaction.

Certain structures do well in earthquakes. Suspension bridges, in particular, have characteristics that usually allow them to withstand earthquakes. Figure II.7 shows the Thomas Bridge in Los Angeles. In the 1989 Loma Prieta Earthquake, while the suspension bridge over San Francisco Bay did fine, the bridge's cantilevered section did not. Structural engineers are involved in generating earthquake damage scenarios to predict damage to lifelines and provide a needed engineering component.

Figure II.8 shows damage to an electrical substation in 1986. This particular section of the 500,000-volt substation is a rather new construction, built in 1982. Figure II.9 shows this substation in 1967, when it carried only 50,000 volts. As we have increased the voltage to supply electricity to a growing population, we have actually compounded the problem of electricity-lifeline vulnerability to earthquakes. Some newly erected structures are not better, but actually worse, than older structures. This has become evident as a result of the earthquake damage scenario analyses.

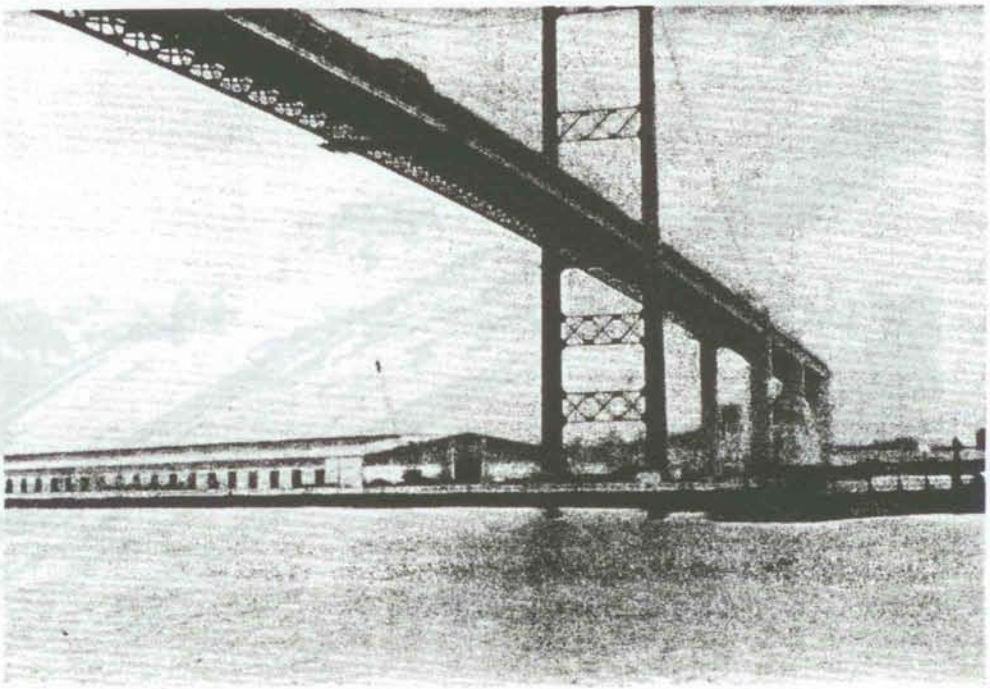

Figure II.7. Thomas Bridge, Los Angeles

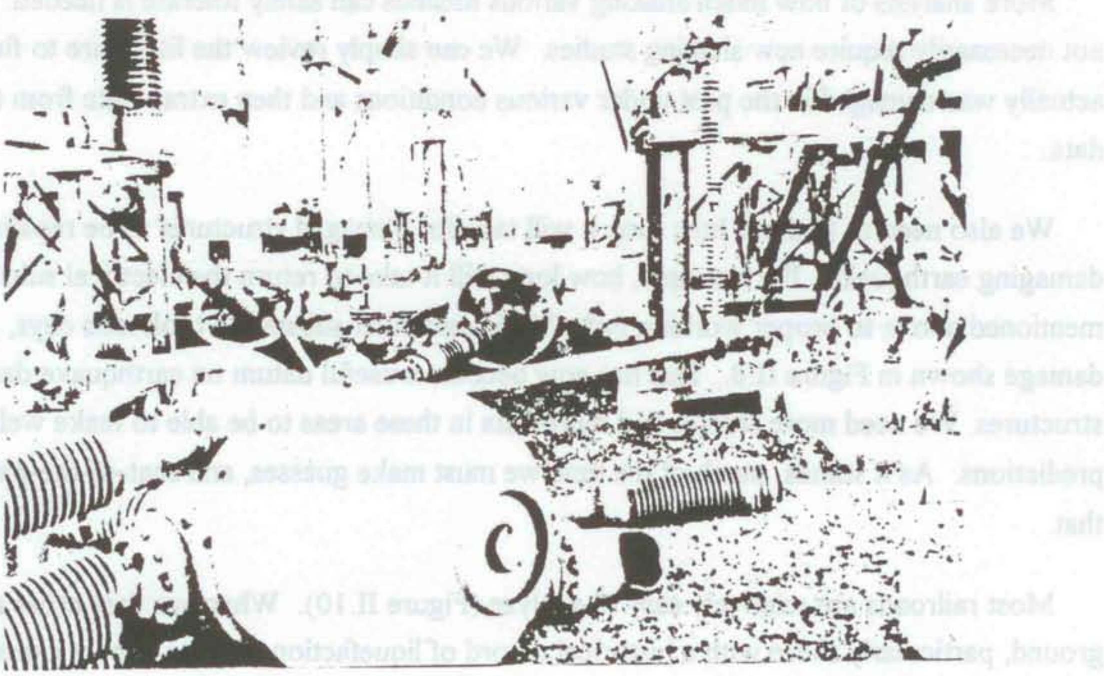

Figure II.8. Electrical substation damage, 1986

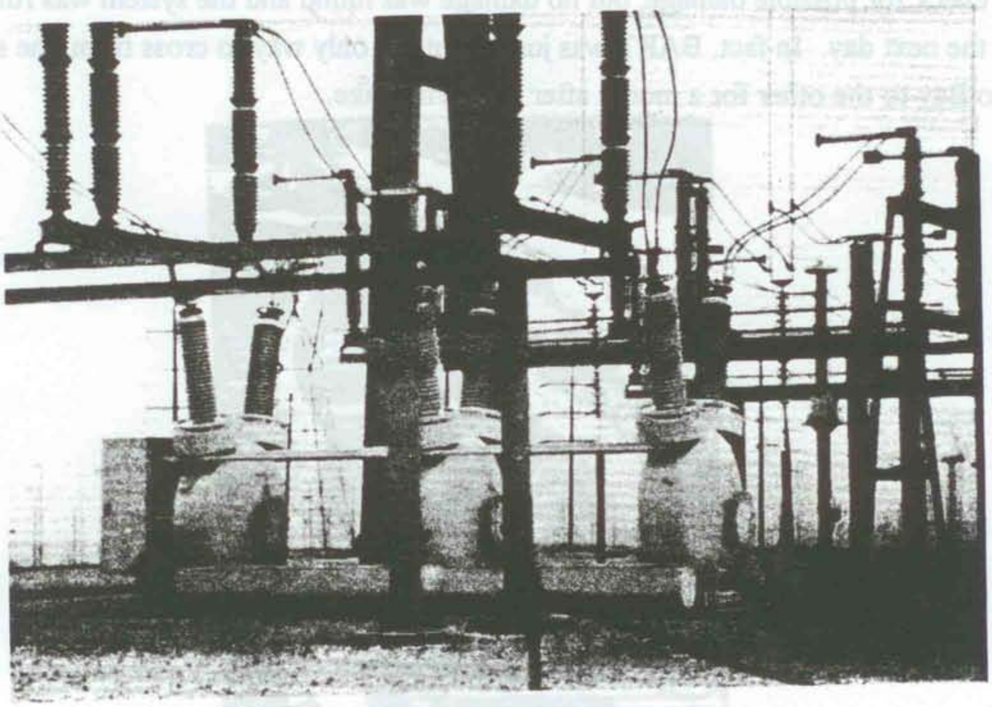

Figure II.9. Same electrical substation in 1967

More analysis of how much shaking various lifelines can safely tolerate is needed. This does not necessarily require new shaking studies. We can simply review the literature to find out what actually was damaged in the past under various conditions and then extrapolate from these hard data.

We also need to find out how long it will take for damaged structures to be repaired after a damaging earthquake. For example, how long will it take to return the electrical substation mentioned above to proper working order? This particular substation took nine days, given the damage shown in Figure II.8. This has now become a useful datum on earthquake damage to structures. We need more studies and more data in these areas to be able to make well-informed predictions. As it stands, much of the time we must make guesses, and seat-of-the-pants guesses at that.

Most railroads are relatively easy to analyze (Figure II.10). Wherever they cross areas of poor ground, particularly those with a historical record of liquefaction, we can expect damage and closure.

The Bay Area Rapid Transit (BART) in the San Francisco Bay Area is a modern train that performed well in the 1989 earthquake. The system was shut down for one day after the event in order to check for possible damage, but no damage was found and the system was running at full capacity the next day. In fact, BART was just about the only way to cross from one side of San Francisco Bay to the other for a month after the earthquake.

Figure II.10. Railroad damage

There is a typical lifeline map on page 213. Green indicates automobile routes that will be open, yellow the routes that might be open or partly open, and red the routes that will be closed.

Our scenarios apply to the three days following an earthquake. After that, they become less useful, as more of the actual damage and appropriate relief strategies are determined.

We include estimates of earthquake effects on airports. Airports indicated in blue will be closed for 6 hours. A few airports (red) will be closed for 24 hours. Unfortunately, our central planning area for earthquakes is located at Los Alamitos. Los Alamitos is a problematic site because it is located over a high water table and thus may be susceptible to liquefaction. We make similar assessments for electrical power, water, petroleum fuels, and other lifelines.

To date, California has produced four earthquake damage scenarios. In the few years since their introduction, scenarios have become important in California. My office, which publishes California's scenarios, has had to make a new printing run of these scenarios several times. Even the public is buying them now.

We provide scenario maps to planners so that they will know two things: what will be damaged and what will not be damaged--that is, what to depend on and what not to depend on. We also have the gray area in between that we cannot easily predict. Despite their imperfection, these maps are sorely needed by planners.

There are two possible methods of writing a scenario: deterministic and probabilistic. I am personally biased in favor of the deterministic method. In my view, the scenario should convey the situation that would exist a few minutes after the earthquake, assuming the earthquake occurred where we had said it was going to occur and was of the magnitude we had assumed. Statements used in deterministic scenarios employ deterministic language. They say, "This will be damaged, that will be damaged," and so on. The other--perhaps the more scientific--method is to write, "'Possibly' this will be damaged, 'maybe' that will be." Conditional terms are sprinkled throughout in the second method.

I have found that the planners who use the scenarios to guide their work want something specific for planning purposes. Probability statements may be exact, but it is important to have a document from which people can work. I prefer the deterministic method for this reason.

Figure II.11 shows a water pipe that crosses the Hayward Fault, which shifts approximately 5 millimeters a year. The section of the pipe that spans the fault has been put aboveground so that minor shifts will not damage it, and it will be easy to repair if it sustains damage during a serious earthquake. This particular preparedness measure was actually taken before earthquake damage scenarios were developed in California. Scenarios can help stimulate more measures of this kind.

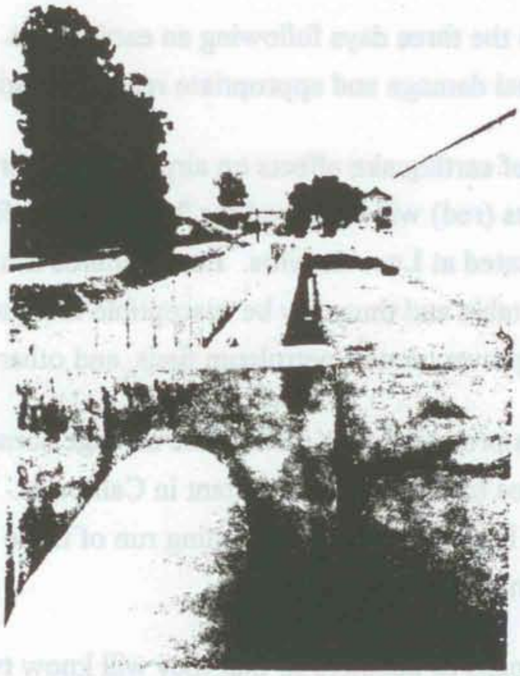

Figure II.11. Water pipe spanning Hayward Fault

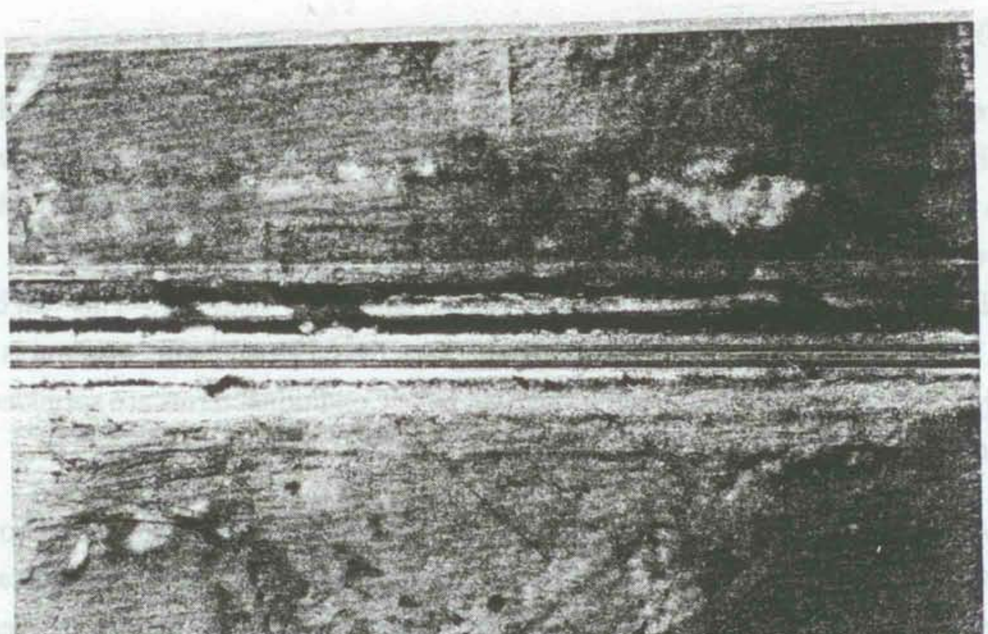

Figure II.12. Oil pipeline and railroad spanning Hayward Fault

Figure II.12 is an example of an earthquake-mitigation effort in the absence of earthquake damage scenarios. This aerial photograph looks down on a railroad track. The parallel fill-settlement lines indicate the location of a buried oil pipeline. This particular pipeline is buried in a 12-foot cement conduit for a distance of 500 feet, which means that it is basically suspended across the fault. This is a very expensive type of installation. We now know much more about this fault than we did when this pipeline was built. Even 5 feet of offset would produce a negligible distortion in the pipe. We are now confident that the offset will be less than that. Cheaper installations are available that would have been sufficient. Thus, more money was spent here than necessary.

Earthquake planning scenarios attempt to give people accurate answers to such key questions as, "How large will the offset be?"; "What will the shaking be like?"; "What is the risk?"; and "What do we need to do?" This information can be extremely useful, and it is the kind of information that we try to provide.

Although it was a rather new building, the Olive View Hospital failed in 1971 because of a weak first floor (Figure II.13). The building's replacement may not be as beautiful, but it is certainly much safer (Figure II.14).

Figure II.13. Damage to Olive View Hospital, 1971

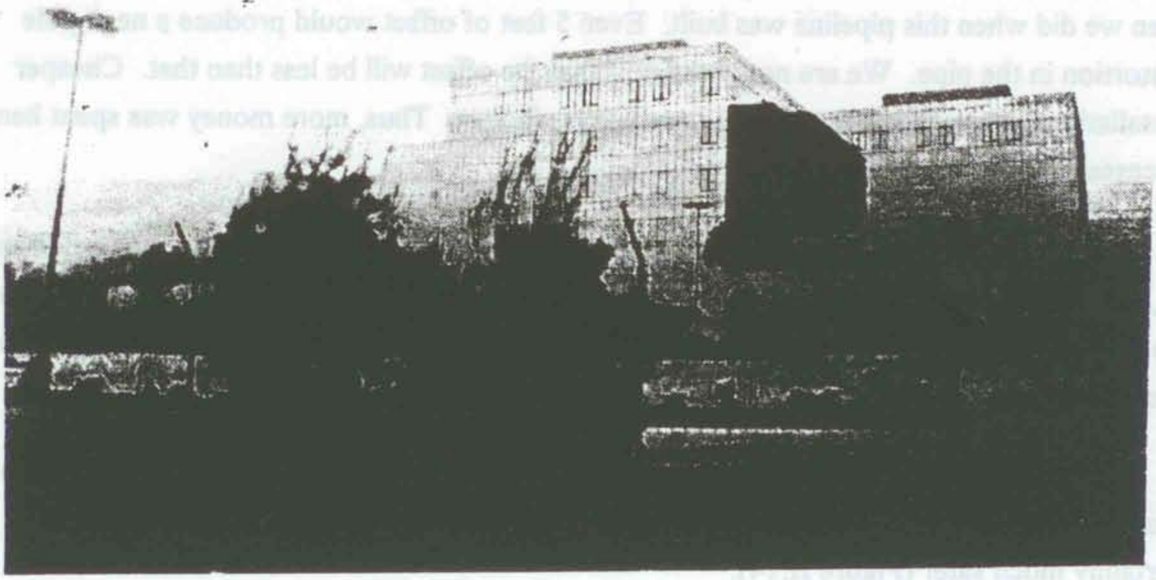

Figure II.14. New Olive View Hospital building, 1988

The map on page 213 highlights a political problem we have in the United States. Blue dots indicate hospital sites within 5 miles of the Newport-Inglewood Fault. This map could not really be called a scenario, as it shows locations of hospitals but says nothing about relative vulnerability. This vagueness is intentional. In the United States, hospitals are mostly privately owned. For the state government to say that a particular hospital will be damaged in the event of a major earthquake would involve thorny legal problems.

Such political peculiarities must be addressed. We must simply ask ourselves whether we want to publish a scenario or not, and if the answer is yes, we must work with the political issues that arise. I suspect, for example, that within 10 years we will have a list of the local hospitals most vulnerable to seismic damage.

I will close by reiterating some basic points regarding the preparation of earthquake damage scenarios: SID maps show the isoseismal contours of an area, as corrected for local geology. SID maps also delineate areas of fault rupture, liquefaction, and landslides. Next, lifeline maps are prepared, then combined with the SID map for the analysis of damage. One basic purpose of preparing earthquake damage scenarios is to educate urban and emergency planners and the general public. A second purpose is to stimulate geotechnical studies and better construction.

As a result of this work and the awareness it has prompted, the local newspapers have distributed pamphlets on earthquake preparedness to more than a million people in the San Francisco Bay Area alone. These pamphlets, in turn, have helped people in the area to make informed decisions about personal preparedness méasures. They have also helped to win public support for the continued development and application of earthquake planning scenarios by local and regional governments.

Dr. Borchardt is a soil scientist at the California Division of Mines and Geology (CDMG), a consultant at Soil Tectonics, and a lecturer in Soil Mineralogy at the University of California, Berkeley. He has been involved in all of CDMG's scenario projects and has developed soil mineralogical techniques to investigate fault activity.

THE USE OF EARTHQUAKE DAMAGE SCENARIOS BY THE CITY OF LOS ANGELES

Shirley Mattingly, City of Los Angeles, USA

Technical solutions to seismic-hazard problems exist. Hazards can be mapped, earthquake effects can be predicted, and structures can be designed and constructed, or retrofitted, to withstand collapse. In spite of this technical ability, however, the vulnerability of people and structures continues to increase rather than decrease. This occurs either because the capacity and commitment to take action are lacking or, alternatively, because sound risk-assessment data are unavailable.

Without sound risk-assessment data, even the best-intentioned local government officials are handicapped in trying to make risk-management decisions. Earthquake damage scenarios can fill this void by providing critical information and motivation. I speak from experience in saying that scenarios have been very helpful to us in Los Angeles.

I would like to give a brief introduction to the Los Angeles environment, where one of the scenarios described previously by Glenn Borchardt was applied. I will then explain why we were receptive to the scenarios, what their policy relevance was, and why and how the scenarios have been used, rather than left to gather dust on a bookshelf. I will conclude with a brief comment on some other work to which the scenarios have led and some lessons from our experience in Los Angeles that might be useful to others.

In evaluating potential uses of earthquake damage scenarios, we ask two questions: what goal are they designed to accomplish, and in what context or environment are they developed and applied?

Our goals in Los Angeles were straightforward: to reduce vulnerability to earthquakes, to mitigate impacts, and to reduce losses. We aimed to effect changes in official decision making and public behavior that would reduce future losses.

Inhabitants of Los Angeles have fairly constant reminders of the seismic risk with which they live because they experience moderate earthquakes every few years. Typically, these awaken us at 5:00 in the morning with a jolt, but do not cause widespread destruction.

We have not had a destructive earthquake for 21 years. The last one killed 64 people and caused two hospitals to collapse. We have to work to keep earthquake-hazard mitigation alive on the public policy agenda during these intervening decades. One of the most valuable tools we have in this endeavor is the earthquake damage scenario.

Los Angeles is a large and growing city. It is currently undergoing significant demographic changes, particularly in terms of increased ethnic diversity and a growing group of unemployed people. A recent survey showed that 94 different languages are spoken in the Los Angeles school district.

In terms of our physical environment, the city is sprawling into all available space, including the mountains and canyons that cut across it. We have problems with air and water pollution. In addition, elements of our infrastructure, for instance our sewers, are inadequate. At the same time that our city is sprawling into these marginal areas, older, more central areas of the city remain. These areas tend to be more densely populated and characterized by a high proportion of seismically unsafe buildings.

These changes in our demography and physical environment impact our vulnerability to hazards. Assessing our risks is like trying to hit a moving target. Los Angeles, like other earthquake-prone megacities and supercities, faces special seismic risks due to the vast scale of people, building, and investment at risk. The many interdependencies in the socioeconomic systems, physical infrastructure, and lifelines in large cities also contribute to making earthquake response and recovery especially complex processes in these areas.

In recognition of these problems, the City established an organization 12 years ago for emergency planning, response, recovery, and mitigation. This is the Emergency Operations Organization. Largely because of this organization's efforts and the leadership of its key players, Los Angeles has spawned an organizational culture that was receptive to the kind of information that earthquake damage scenarios offered. We were not only willing but eager to use the information that they provided about the impacts of major earthquakes.

Before the age of scenarios, we had known for generations that we lived with seismic risk. Our understanding of that risk was limited, however. Scenarios gave substance to the threat and made potential impacts real and compelling. They provided the data needed by emergency planners to convince audiences that they could not face the horrendous problems following a major earthquake unless they took measures to mitigate impacts.

Thus, scenarios gave Los Angeles an invaluable tool for emergency response planning and training programs. They also provided a marketing tool for us to promote mitigation and preparedness measures among government officials, businesses, and the public. Moreover, they paved the way for future problem-focused research.

The City responded to the studies with several different actions. Armed with insight into the expected patterns of damage to our lifeline systems, we formulated new planning partnerships with utility companies, the business community, and other governmental agencies whose cooperation would be needed in responding to and recovering from the destructive earthquakes described in the scenarios. A business-government coalition named the Business and Industry Council for Emergency Planning and Preparedness (BICEPP) was formed to facilitate and promote these joint efforts between government and business and to share information across corporate boundaries. The specific damage projections in the scenarios were used to test our emergency plans through drills and exercises. Also, we initiated public awareness events and media campaigns that were later adopted by the State of California. And now, thanks to our efforts, the entire month of April is Earthquake Preparedness Month throughout the state. It features drills in schools, businesses, and government offices, and a public information blitz. These initiatives grew out of the Emergency Operations Organization's desire to motivate the public to become involved in preparedness actions.

Elected officials in Los Angeles found the scientific basis of loss predictions very convincing. The credibility of scenarios has helped to motivate officials to incorporate mitigation into the everyday business of government. Every year they adopt budgets and dedicate staff to efforts to enhance the City's readiness for response and capacity for recovery.

Overall, scenarios have played a major role in improving the City's capability to respond not just to earthquakes but also to disasters generally, including the civil disturbance in April 1992. Scenarios gave us a realistic basis for our response and recovery planning efforts.

Earthquake scenarios have also led to other studies, which have further defined the city's problems and suggested appropriate solutions. For instance, scenarios were the basis for a landmark study conducted by an urban planning consultant entitled "Pre-Earthquake Planning for Post-Earthquake Rebuilding," also known as the PEPPER Report. This report delineated likely damage to private structures throughout the city, based on various scenario earthquakes. The PEPPER Report, in turn, engendered an innovative project by the City government to develop a plan, or blueprint, for recovery and reconstruction from a major earthquake.

This recovery plan, the first of its kind in our country, can also be useful in non-earthquake disasters. It has, for instance, formed the basis for policies and strategies of recovery from the destructive civil disturbance surrounding the Rodney King case in April 1992. Although the plan was designed for earthquake recovery, the policies and actions we contemplated in putting the plan together were sound. They have proved very useful in riot recovery.

This is how earthquake scenarios have been used--fairly effectively--in Los Angeles for 10 years.

In Los Angeles, we were fortunate to have an existing organization involved in mitigation and emergency planning within the City government. This organization needed and wanted the information that the scenarios could provide. Political players were receptive to the information and ready to use it to tackle tough problems, and both the organization and the politicians showed a genuine concern for the good of the community. This concern was strong enough to stand up to pressures from, and to steer a middle course between, conflicting interests--building owners and developers, for example--at least part of the time. City officials consulted with the people who were preparing the scenarios.

Timing can be important, and our timing was good. In the case of Los Angeles, at the time the scenarios were being developed, the city had just made a commitment to seismically retrofit some 8,000 of its hazardous unreinforced masonry structures. The city pushed for the retrofitting of both privately owned and publicly owned structures by adopting a local regulation requiring seismic strengthening or demolition of structures deemed at risk of collapse during a major earthquake. So the political climate to receive and use the information was very good.

Generalizing from experiences in Los Angeles, we can identify some generic constraints on successful utilization of earthquake damage scenarios. Clearly, utility and success will be constrained if (1) there is a lack of receptivity to the information or a lack of willingness on the part of decision makers to take on the challenge; (2) the study is too technical or does not reflect the language or values of the community it describes; (3) there is no structure or organization set up to process and use the information; and (4) there is inadequate cooperation or consultation between the people preparing the scenarios and the various potential users of the information. It is crucial to understand the scenario's function and fit it to the environment in which it will be used.

For any city, assessing hazards is a constantly evolving process, moving from a base study--in this case the basic scenario--to greater levels of accuracy and specificity. In Los Angeles, for example, we are looking beyond what we now have toward developing an interactive model. This model would combine earthquake-related data bases, such as projected strong ground motion and projected ground failure, with data bases on lifelines, building types, housing stocks, and the populations that live in those housing stocks. The model would then tie these various databases to real-time information about an actual earthquake's epicenter and intensity. In my view, our future efforts in earthquake-hazard mitigation will be based on tying real-time earthquake data to geographic information system technology through an interactive system. That will give us the ability to model both theoretical and actual events on computers and to see an actual earthquake's impact on roads, lifelines, and structures as, or immediately after, the actual damage takes place. Once realized, such a system would provide a superior tool for response and planning activities and for promoting adoption of risk-reduction measures.

Los Angeles has started developing such a system. We already have a system of real-time monitoring that gives us relevant scientific information within seconds of an earthquake, although it is not tied to the City's geographic information data bases. The systems and data bases must be integrated in the future.

In conclusion, earthquake damage scenarios are the key to looking systematically at seismic hazards, mitigating their effects, and being prepared to deal with their impacts. The bottom line is that local governments must incorporate hazard-reduction thinking into the way they go about the day-to-day business of government. To realize the vision of a safer future for their cities, local officials must understand both the hazards confronting them and how to mitigate their impacts.

We are now in the third year of the International Decade for Natural Disaster Reduction. The time is right for cities to share successful hazard-mitigation strategies. Cities facing serious seismic risks can serve as practical sources of knowledge for one another. To this end, Los Angeles is currently engaged in a cooperative agreement with Mexico City for a mutual exchange of information on seismic-hazard reduction. I believe such partnerships can help to protect lives, property, and economic well-being from future earthquakes. We in Los Angeles represent a willing participant in such future efforts.

Ms. Mattingly is director of Emergency Management for the City of Los Angeles. She is responsible for various aspects of emergency planning, policy analysis, and public safety for the city.

THE TECHNIQUE AND USE OF EARTHQUAKE DAMAGE SCENARIOS IN THE TOKYO METROPOLITAN AREA

Tsuneo Katayama, University of Tokyo, Japan

Tokyo has been the most earthquake-conscious city in Japan. This is understandable if one recalls the 1923 disaster, which killed about 140,000 people in and around Tokyo. In addition, the South Kanto area is located in a zone of extremely high seismic activity, where three tectonic plates interact with each other in a complex manner.

The metropolitan government of Tokyo began conducting serious seismic vulnerability studies in the early 1960s. This work accelerated after the 1964 Niigata Earthquake. Around 1970, the city began a systematic investigation of potential seismic damage to the Tokyo metropolitan area, where about 8.65 million people lived on 580 km^2 of land. The investigators hypothesized a recurrence of the 1923 Kanto Earthquake: magnitude 7.9, approximately 100 kilometers from Tokyo. The final report was published in June 1978, the month in which the Miyagi-ken-oki Earthquake inflicted substantial damage on the lifelines of Sendai, population 640,000. This report gave the first comprehensive earthquake-damage projection for a large urban area in Japan. It is difficult to say exactly how many years were required to complete the study because there was a considerable period of preparatory investigations, but it was approximately 15.

The study included estimations of the following factors:

- Ground-motion severity and liquefaction
- Damage to wooden houses
- Failure of slopes and retaining walls
- Collapse of highway bridges
- Effects of fallen objects from buildings
- Damage to buried water and gas pipes
- Spread of toxic gases
- Conflagration following the earthquake

- Tsunami- and earthquake-induced flooding
- Panic and life loss

This 1978 assessment emphasized primary, or structural, damage caused by the hypothetical earthquake. The number of burned-down houses was assumed to be 473,000. Although this figure may sound high, it is understandable if one takes into account the size of Tokyo. The estimated number of deaths, 35,700, was 0.41% of the total population of metropolitan Tokyo.

In the conflagration assessment, a total of 300 fire outbreaks, as well as a specific wind velocity and direction, were assumed. The estimate of burned-down houses applies to the 24 hours after the earthquake's occurrence.

Several years later, a similar assessment was made for the suburban area of Tokyo, where a population of 3.35 million lived on 1,160 km^2. This assessment was published as a report in 1985. The estimated damage was less than that estimated for the metropolitan area. Total deaths were estimated at 1,660 (0.05%), and the death rate was one-eighth of that calculated for the metropolitan area. This difference had been expected, given that the average population density of the suburban area was 2,900 per km^2, while that of the metropolitan area was 14,900 per km^2.

In the suburban area study, a network analysis of water lifelines was performed, and the qualitative effects of primary damage on people in the affected areas were investigated. This second report required a total of 10 years to complete.

A third study, a revised version of damage assessments for the metropolitan, suburban, and island areas of Tokyo, was initiated in 1986 and published in September 1991. This third study required five years, 500 million yen (approximately U.S.$4 million), and about 100 people to complete--including researchers from universities, practicing engineers from consulting firms, and the Tokyo government. It is interesting to note that 15, 10, and 5 years were spent for the three assessment studies, in chronological order.

Progress reports for the third study filled approximately 2,000 pages each year. After five years, we had 10,000 pages of assessment, including annual reports and the final report. The following maps highlight some results of the third scenario.

The map on page 215 shows the peak acceleration distribution. Red indicates high acceleration areas. The bay area of Tokyo is on the lower right. The grid size is 500 by 500 meters.

The map on page 217 shows projected liquefaction. Red indicates the most susceptible areas.

The map on page 219 shows projected building damage. In this case, red indicates the most severe damage.

The map on page 221 shows conflagration. Red indicates fire within 12 hours, green within 24 hours, and dark blue within 48 hours after the earthquake.

Some notes about the third assessment:

1. Comparison of Tokyo's nighttime population with its daytime population showed that about 2.2 million people commute to Tokyo daily from surrounding jurisdictions. Tokyo is not an isolated city.

2. Power was impaired 33% and phones 28%. These results were strongly affected by fire, which burned 26% of the area.

3. A precautionary service shutdown caused an 87% loss of city gas.

4. Conflagration estimates assumed a particular time of day, weather condition, and season. Consequently, the final result took into account only one particular set of assumptions. These were informed assumptions, but assumptions all the same.

5. Evacuation simulations were also incorporated and seem to have reduced the estimated number of deaths. This trend becomes clear if we compare the 9,000 casualties predicted by the third scenario with the 30,000 predicted by the first scenario.

We also made estimates for lifeline recovery. A 15-minute educational video entitled "Tokyo at Risk" was made based on this assessment.

Dr. Katayama is director of the International Center for Disaster-Mitigation Engineering (INCEDE) at the University of Tokyo's Institute of Industrial Science. He is also a professor of Civil Engineering at the university and the secretary general of the International Association for Earthquake Engineering.

DISCUSSION

Anselm Smolka, Munich Reinsurance Company, Germany

In view of the large number of burned and collapsed buildings resulting from the hypothetical Tokyo earthquake, I am extremely surprised by the small number of deaths Dr. Katayama has predicted. The low numbers make me wonder if these scenarios do not actually make too many optimistic assumptions.

As far as I understand, the scenarios he described are solely for metropolitan Tokyo. But metropolitan Tokyo is only one part of a larger urban complex that includes Yokohama and Chiba prefectures. To what extent, Dr. Katayama, would damage in these prefectures influence metropolitan Tokyo, and to what extent has this possibility been considered in the damage projections made for the metropolitan area?

Tsuneo Katayama, University of Tokyo, Japan

There is a magic of numbers that includes magically making the number of deaths smaller. The problem is that the Tokyo scenario is only a case study of an assumed event. Event characteristics such as wind velocity and direction, and evacuation strategy have been assumed. While there may prove to be a case in which these numbers are realized, there also may not. I do not think, however, that the casualty figures cited are overly optimistic. If the situation proves to be quite bad, the number could be 3 times greater than our estimate. If we have rain, or if an earthquake occurs at night, on the other hand, then we may have one-third the estimated number of deaths. This exercise simply gives us a rough but fair estimate. We do not believe that tens of thousands of people are likely to die, even if a big earthquake strikes.

In answer to the second question, similar studies have, in fact, been done for other jurisdictions. Unfortunately, however, they have been done independently of one another, and no standardized, common format has been established. Tokyo has done its own study, and Chiba, Kanagawa, and Saitama prefectures have each done an independent study. Nobody has bothered to check whether these different studies are compatible or not, but we will have to do that.

John Tomblin, DHA-UNDRO, Switzerland

Our constant concern at the United Nations is to simplify or otherwise alter programs and methods to make them applicable to the less developed parts of the world. Consequently, I hope the discussion here today will focus on how we can scale down earthquake damage scenarios to bring them within the capacities of less developed countries. Two examples of inappropriate mitigation measures being applied in developing countries come to mind.

During Peru's famous earthquake prediction and preparedness effort in 1982, the Peruvian authorities, in their enthusiasm and anxiety to have public education materials available for disaster preparedness, published and widely circulated a set of earthquake-preparedness brochures to the public. These brochures were simply adaptations of brochures that had been designed for a developed state, namely California, and were grossly inappropriate for Peru. The brochures said, among other things, that people should store cans of water and stock their refrigerators. This level of preparation, however, was only relevant to the small minority of Lima's population whose houses were sufficiently well-built that they were unlikely to collapse and who could afford extra food and appropriate storage facilities. Because of its obvious inappropriateness, this public education campaign made most Peruvians cynical about earthquake-preparedness measures and dampened interest instead of stimulating it.

Erzincan, Turkey, was unprepared for the earthquake that struck there in March 1992. The same city was devastated by an earthquake in 1939 and lost almost half its population. Despite the city's obvious vulnerability, during my visit soon after the event, I found that supervision of building quality and code controls had declined appreciably over the previous 15 or 20 years. Although memory of major disasters stretches from 1923 in Tokyo and from 1906 in California, memories tend to be much shorter in less developed countries. This fact must be addressed by disaster-mitigation schemes for less developed countries.

Dusan Zupka, DHA-UNDRO, Switzerland

Do earthquake damage scenarios only describe the anticipated damage of a potential earthquake or do they also prescribe mitigation countermeasures, public information programs, and other types of follow-up activities?

Barclay Jones, Cornell University, USA

The numbers of collapsed buildings and deaths Dr. Katayama has cited are indeed quite modest given the magnitude of the assumed earthquake. Although lower than previous scenarios have predicted, these damage and death rates nonetheless seem realistic to me, based on what I know about Tokyo's mitigation efforts.

Tsuneo Katayama, University of Tokyo, Japan

In answer to the question raised by Mr. Zupka about whether damage scenarios prescribe mitigation countermeasures, I would ask, "What type of scenario do you have in mind?" Ten different cities will have 10 different varieties of scenario, as will 10 different countries. All that is certain is that scenario makers are concerned with minimizing damage. The definitions of the term "scenario" are likely to be quite different, for example, among the various people attending this session: some think of mitigation countermeasures and response plans; others think that a damage scenario is purely descriptive, like the scenario of a movie.

W. D. Liam Finn, University of British Columbia, Canada

Technical Committee IV of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE), which deals with geotechnical earthquake engineering matters, is currently working to respond to the need for simplification that Mr. Tomblin has highlighted. Under the direction of Professor Ishihara of the University of Tokyo, the committee (of which I am a member) is producing a seismic-hazard and seismic-risk assessment handbook that might be useful to developing countries. The handbook discusses assessments based on the simplest kind of data as well as more sophisticated procedures, allowing user countries to carry out systematic evaluations at their current technological level. After this conference, the committee will meet in Lisbon to review progress to date and to assess the results of studies on preliminary use of the handbook in a number of countries. The committee hopes that the handbook will help developing countries with limited technology and limited data bases to make real progress toward assessing the hazards and risks they face from earthquakes.

A brief remark to Professor Katayama: it seems to me that in the case of earthquake-prone cities of international importance, such as Tokyo or Los Angeles, there is an international aspect to risk assessment that should not be neglected. For example, the impact of Tokyo's post-earthquake chaos on financial markets and business systems in other countries should be considered. Is any group currently looking into this international aspect of disaster planning?

Tsuneo Katayama, University of Tokyo, Japan

Yes, some people are. But I do not care that they are because that to me is not the important issue. When a big earthquake comes, the most important issue is whether we rescue potential survivors or allow them to die. Economists (not all of them!) sometimes argue this point because problems of economic impact are interesting to them. But I believe in the good of the people and simply do not care whether the Japanese market collapses or something along those lines occurs.

W. D. Liam Finn, University of British Columbia, Canada

The impact of a major Tokyo earthquake on the financial markets and business systems of other countries might, however, affect the ability of other countries to respond to chaos in Tokyo.

Julio Kuroiwa, National University of Engineering, Peru

From 1973 to 1978, a group of about 15 graduate students from the National University of Engineering in Lima conducted, under my guidance, an earthquake-impact study for Lima. Three alternative methods were used.

The first statistical method divided the city into uniform sections with respect to expected earthquake intensity, building type, and building age. A random sample of buildings was selected, including 5% of the city's blocks and 10% of the buildings from each of these blocks. Basic data on the selected buildings were divided into general categories--such as adobe, brick masonry, or reinforced concrete--on specially prepared forms. Using data and experience gained in the 1970 Peru Earthquake, the percentage of expected damage to each variety of building for Modified Mercalli Intensity VII, VIII, and IX events was determined. Levels of damage expected in each section were differentiated by color. We found that the areas most vulnerable to earthquakes were the old sections of Lima and of the port city Callao. Callao is also exposed to tsunami risk.

In the second method, aerial photographs (scale 1:2,500) of Lima were used to identify and map the different types of construction materials used in the different areas of the city. The photos showed that the most risky sections were those having a high proportion of adobe buildings. These results agreed closely with the results of the statistical method.

The third method involved studying the historical growth of Lima and taking into consideration building materials and construction techniques used at different periods of the city's history. It was found that the most risky areas were those developed in the 1930s and before. This was due to the fact that adobe construction was prohibited in Lima after the May 31, 1940, earthquake.

These simple methods allowed many students to usefully participate in this earthquake-vulnerability study. A group of architecture students, for instance, spent two years studying Lima block by block with aerial photographs. Similar methods might be useful elsewhere.

In conclusion, the three methods--the statistical method, observing aerial photographs, and studying the historical growth of Lima's infrastructure--gave similar results and permitted positive identification of the most risk-prone areas of metropolitan Lima.

Brian Tucker, GeoHazards International, USA

Dr. Katayama noted that the amount of time and effort spent on the successive scenarios made for the Tokyo area has decreased significantly. If somebody were trying to do a scenario now, what would be the right amount of effort for a large, developed city, such as Tokyo? Can Glenn Borchardt or Shirley Mattingly make a recommendation for Los Angeles? Obviously, it costs more to do more, and while we are interested in the possibility of making inexpensive scenarios, we also want a reasonably accurate product. What would be the right amount of time for a developing city?

Tsuneo Katayama, University of Tokyo, Japan

In the past we have spent too much time, too much money, and too much manpower refining scenarios. And now, a scenario on which we spent 10 years is essentially useless. It would have been possible to get almost 80% of the results within one year. The remaining nine years were spent primarily on improving our assessment to add the final 20%. Small groups of people with modest funding working to achieve as much as they can in a short time might be the most reasonable, cost-effective way to proceed. Scenario developers could then wait for criticisms from users and make improvements on the basis of these. To carry out a five-year project from the beginning without outside criticism is not efficient.

Glenn Borchardt, California Division of Mines and Geology, USA

In California, the minimum cost for developing a scenario is about a quarter of a million U.S. dollars and about three person-years (although we have more than one person working at a time). Scenario preparation teams typically include, among others, a seismologist, a geologist, a soils person, and a structural engineer. Once complete, assessments are reviewed by lifeline operators. Because they do this free of charge, some of the total cost is effectively borne by them. They are often glad to do these reviews because they want to catch any mistakes we might have made. The cost is thus relatively modest, and we have managed to complete scenarios in two years. To finish in one year would be difficult, partly because it takes time to ask many people to review the initial assessment. The local geology can pose difficulties, too, depending on how well geological problems are already worked out for the area.

The idea of using a geographic information system (GIS) to develop scenarios is intriguing. Typically, the first step of scenario making involves blowing up or reducing small sections of maps. However, if the GIS could be implemented as a form of shell, a scenario-developing team could come into an area and begin developing an assessment for a metropolitan area with the map base already laid out. This is an exciting prospect because playing with maps is generally half the work involved in developing a scenario.

In answer to Dusan Zupka's question, damage scenarios do not prescribe remedies to the problems that they highlight. Basically, scenarios say "2 + 2 =" and the various users fill in the blank according to their professions. Disaster-management people, such as Shirley Mattingly, help to coordinate these efforts. The more people involved in a scenario's preparation, the more likely it is to be used by various people in various ways, and the more effective it will prove in the event of an actual earthquake. Simply producing a volume that sits on a shelf, however, does not serve the cause of earthquake-hazard mitigation.

Shirley Mattingly, City of Los Angeles, USA

To determine the necessary complexity of a study, scenario developers must look at the purpose of the study and the environment into which it is being introduced. In any city, but particularly in a developing area with scarce resources, an impact study does not need to be extremely complex, and perhaps simple is better. A certain base of scientific knowledge and engineering knowledge is, of course, necessary, as is a level of collaboration with the potential users. These potential users, particularly in developing countries, must represent a broad spectrum of interests, including the private sector and public utilities as well as local government planners and emergency response. The greater the collaboration, the better the result. Higher levels of complexity can be achieved later, as Professor Katayama has suggested, if that seems desirable and money is available.

In developing regions in particular, great opportunities exist for mitigating hazards through influencing how new areas are developed. Hazards can be mitigated through incorporating mitigation measures into new construction and through regulating land-use, including designating where new construction will occur and perhaps avoiding construction in more seismically hazardous zones.

The issue of relative scenario accuracy goes back to the study's purpose. An extremely accurate study may not be necessary, especially considering that few of our scenarios have even been tested. It is clear, in any event, that core information must be generated, then used to do initial planning. Rudimentary emergency response planning is the critical first step toward effective emergency response planning.

Herbert Tiedemann, Swiss Reinsurance Company, Switzerland

As a matter of principle, the scientist should always be honest. And the scientist who asks himself whether he has the necessary vulnerability functions and parameters to do a simple yet valid assessment must admit that he does not. I say this with some authority, as I personally have hunted desperately for 33 years for ways of making simple, inexpensive assessments. If the necessary details to make a deterministic evaluation, or even the data to make a statistical evaluation, are unavailable, there is no sense in spending computer-years and man-years on a study that does not hold water because it does not take into account these basic parameters. I have done many scenario studies, and it requires time to be certain that key parameters are taken into consideration. The insurance industry worries about key parameters because insurers, in contrast to scientific enterprises, must pay for their mistakes. They risk bankruptcy if their projections are unrealistic.

The scenario maker generally first tries to establish the magnitude of the hypothetical event. This means that a few experts walk through the town and size it up. They look at the subsoil, the structures, and such factors as whether the city has a dangerous industry such as a chlorine plant located in town. Jumping to general conclusions from one earthquake or even a few, however, is idiotic. The Armenian earthquake, for instance, could have had its epicenter under Yerevan, in which case losses would have been 3 or 4 times higher than the losses actually registered.

Disaster studies are badly needed, but they should be based on experience rather than on computer power. More detailed studies of an area should be conducted only once a situation has been determined to be dangerous. The biggest obstacle to earthquake-assessment studies, particularly in the developing world, is the lack of receptivity on the part of politicians to earthquake-mitigation measures. Scientists often make a big mistake in this area by approaching politicians with Monte Carlo functions and elliptical integrals and other technical information that politicians do not understand. Scientists must recognize that they are shooting themselves in the foot when they do this.

Roger Bilham, University of Colorado, USA

In considering how best to stimulate the development of simplified methods, the issue of motivation is critical. What does it take to get a large city in a developing nation to implement programs for retrofitting or for earthquake-resistant design? Three possible responses come to mind.

Aware that earthquakes are a problem, developed nations often have a national policy and simply say, "We are going to do this." Japan and China are examples of the national policy method. Japan spends more on earthquake awareness and preparedness than on national defense. China has an immensely successful earthquake policy that is far ahead of the data on which it is based. Third World nations, operating under a different set of considerations, generally do not have such policies.

Another possible motivation is economic advantage. A businessman wants to build a block of flats and puts in a low bid, which will probably be accepted, although the building may not be of earthquake-resistant design. If it can be pointed out to the businessman, however, that an earthquake will strike during the building's lifetime, particularly if this is likely within the next 10 to 25 years, then he will experience economic pressure to do something about that building's capacity to withstand earthquakes. The time scale of destruction should be routinely incorporated into the mentality of constructing buildings. One could regard this economic motivation as "greed" or simply good business sense.

A third possible motivating factor is ethical guilt felt by the responsible parties. Persuading builders and public officials to feel responsible for ensuring the safety of the building's tenants can be a highly effective means of ensuring that earthquake-hazard mitigation considerations are incorporated into a building's construction. Concerns over litigation can also be raised in conjunction with the responsibility issue. This important motivation can usefully be brought up when buildings are in the design and construction phase or when retrofitting is considered due to policy changes.

In answer to John Tomblin's question, then, it is necessary to provide some motivation, or specific advantage, to the person preparing to construct a building to make that building earthquake resistant.

Robin Spence, Cambridge University, UK

Some recent studies conducted in the United Kingdom speak to the issues of quantification and simplification. These studies considered the effects of uncertainty on the accuracy of damage estimates. They concluded that spending an enormous amount of time getting a highly detailed inventory is not worthwhile because the error remaining in inventory and building vulnerability functions is likely to be much smaller than the error associated with the effects of variations in soil conditions.

SUBMITTED COMMENTS

Anand Arya, University of Roorkee, India

It would be useful to explore how scenario studies could be applied to megacities in the developing world, which typically have low proportions of skilled workers and severely limited funds. Los Angeles and Tokyo are highly developed cities, both seismically and economically. The methods that work for them would have to be altered to be useful to developing world megacities, where simplified, low-cost methodologies are needed.

Pierre-Yves Bard, Université Joseph Fourier, France

In the Californian and Japanese scenario examples, local authorities were willing to take action to maximize earthquake safety, perhaps because of a high level of awareness of earthquake threat in these two areas. I doubt that local and national authorities will always be so willing to accept (much less fund) earthquake damage scenarios in either developing or developed nations. Some years ago in France, for example, a number of city officials did not want to hear about earthquakes because they were afraid that industries would move, or tourists would not come, or their electors would ask for unrealistically high levels of earthquake-safety measures. In another developed nation in Europe, I was told that politicians think that the electoral benefit of post-earthquake reconstruction (short-term) is larger than the electoral benefit of earthquake-hazard mitigation (long-term). This does not mean that seismologists and earthquake engineers should give up trying to mitigate hazards, but simply that they should consider facing squarely the nontechnical issues that can affect their efforts in addition to technical and scientific issues.

I feel that some people are strongly pushing geographic information system (GIS) technology in order to sell their software and data. However, we have to be cautious. GIS may be a wonderful tool, but only if it is, in fact, used as a tool, and if the quality of the presentation is not used to hide the poor quality or enormous uncertainties involved in various components of the scientific studies.

Daniel Bitran, National Water Commission, Mexico

The basic elements that should be included in an earthquake scenario for a developing country have not, to date, been specified. Determining the key elements of such a "minimum" standardized scenario could be quite useful.

Mustafa Erdik, Bogaziçi University/Kandilli Observatory & Earthquake Research Institute, Turkey

Scenarios developed in Los Angeles and Tokyo were made using available data bases. In most cases, tapping existing extensive data bases will not be possible.

PART III: EARTHQUAKE DAMAGE SCENARIOS FOR DISASTER MANAGEMENT

David Dowrick, Chairman

Mr. Dowrick is an earthquake engineer at the Institute of Geological & Nuclear Sciences. His work has focused on hazard assessment, risk management, and earthquake-resistant design in New Zealand.

UNDRO'S WORK WITH EARTHQUAKE HAZARD MITIGATION

Dusan Zupka, DHA-UNDRO, Switzerland

I will address the earthquake-disaster-mitigation activities of my office, the Department of Humanitarian Affairs-Office of the United Nations Disaster Relief Organization (DHA-UNDRO), and touch on the relationship between earthquake disasters and development. Rather than elaborate on the economic impacts of major earthquakes, I hope to highlight some important points to keep in mind during future efforts to prepare earthquake damage scenarios.

The close link between earthquakes and social and economic development has long been ignored. Development programs have traditionally not been assessed with regard to seismic disasters: neither the potential impact of disasters on development programs nor the potential earthquake vulnerability of a given development strategy. Earthquakes were seen in the context of emergency response, not as a part of long-term development planning.

The relationship between earthquakes and development is not only negative. Of course, major earthquakes inflict casualties, economic disruption, property loss, environmental damage, and trauma on the affected society. However, new development activities provide an excellent opportunity for effective mitigation measures, and it is essential that we take full advantage of these. When construction is damaged by a major earthquake, replacement structures are generally built in the same earthquake-prone areas. This is because it can be difficult to convince earthquake survivors, who are often bound by habit and emotional ties, to move to a completely new area. Earthquake-mitigation efforts can, instead, focus on constructing new buildings and reinforcing existing ones to resist major earthquakes.

Also, we need to have tools with which to sensitize politicians and decision makers to potential economic impacts of earthquake damage. Studies of economic impact, particularly reliable and comprehensive ones, are rare, especially for developing countries.

A recent UNDRO study of 19 countries shows that major disasters--including earthquakes--have cost an average of more than 2% of the GNP per year over the past 20 years. Six of these 19 countries lost more than 5% of their GNP annually during this period. Moreover, these numbers represent only direct losses: those sustained during the year the disaster occurred. Indirect or secondary losses, which typically affect countries for several years after the disaster's actual occurrence, have not been taken into account.

DHA-UNDRO was, formerly, simply known as UNDRO, or the United Nations Disaster Relief Office. As part of a major restructuring of the United Nations system, UNDRO has become part of the Department of Humanitarian Affairs. DHA has offices in New York and Geneva. The New York office deals mainly with the political dimensions of catastrophes, complex emergencies like civil strife, and long-lasting emergencies like drought. The Geneva office mainly implements natural-disaster and other disaster-management programs and projects. This operational unit is divided into three principal branches: disaster mitigation, disaster relief coordination, and information.

The disaster-mitigation branch of DHA-UNDRO is responsible for formulating, designing, and implementing disaster-mitigation programs. The unfolding of a natural hazard like an earthquake is a chain of events. If we are not able to eliminate some link in this chain, the disaster will take place. It is very difficult to influence the earth's shaking, but we can make buildings and infrastructure stronger and more resistant to earthquakes. Careful evaluations of the lessons learned from each disaster can feed back into future preparedness activities.

The biennium 1990-1991, which also corresponds to the first two years of the International Decade for Natural Disaster Reduction, has seen growing confidence in the utility and cost-effectiveness of disaster-mitigation measures. This confidence has increased demand considerably from developing countries for UNDRO's technical assistance. We have made a special effort to determine the potential effects of earthquakes in earthquake-prone areas. We have also elaborated an integrated sequence of earthquake-mitigation activities that maximizes the involvement of local people and organizations.

UNDRO uses the term "scenario" differently from its usage in the expressions "damage scenario" and "planning scenario" employed above. An earthquake damage scenario characterizes an earthquake's anticipated impact in terms of deaths and injuries, and damage to key buildings, utility lifelines, and transportation lifelines. In my experience, damage scenarios portray only earthquake impacts, while planning scenarios include recommendations for future planning actions and countermeasures but do not implement these recommendations.

UNDRO's scenario could be called an "action scenario": it identifies and applies logical sequences of disaster-mitigation steps to different types of potential natural hazards. Earthquake-action scenarios of this sort are currently being applied in three major Latin American cities: Cali and Manizales in Colombia and Guayaquil in Ecuador. Action scenarios begin with hazard evaluation and mapping and continue with risk assessment, preventive measures, preparedness planning, and public information. The damage scenario thus represents a key segment of UNDRO's action scenario. Due to shortages of personnel and financial resources, however, UNDRO has not been in a position to develop detailed damage scenarios as they are developed in California and Japan.

Earthquake-mitigation projects play a prominent role in DHA-UNDRO disaster-mitigation activities. Figure III.1 shows disaster-mitigation projects that have been implemented by UNDRO during the 1990-1991 biennium. Earthquakes represent 40% of the total, the highest percentage of any type of disaster.

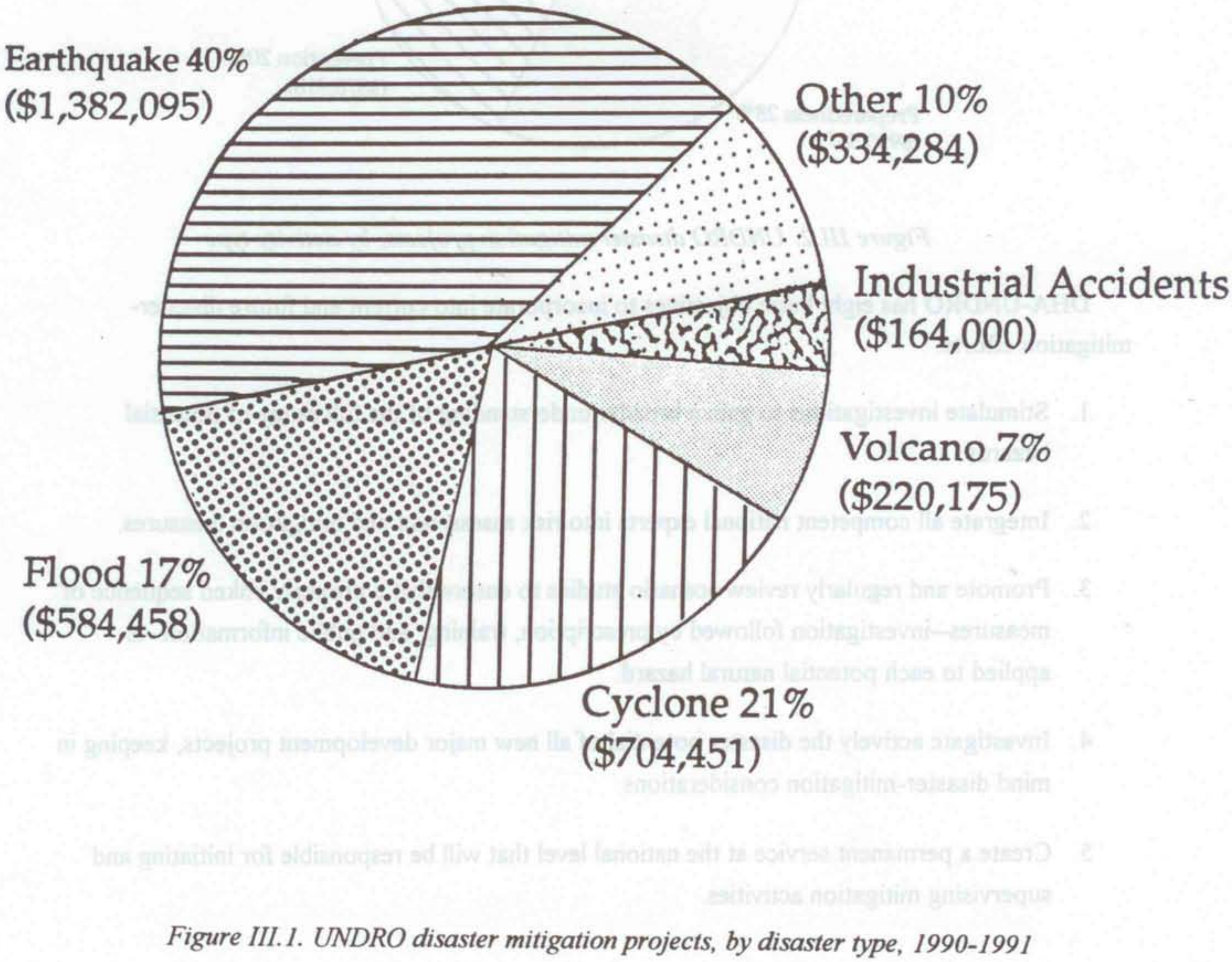

Figure III.1. UNDRO disaster mitigation projects, by disaster type, 1990-1991

Figure III.2 gives a breakdown of activities carried out as part of DHA-UNDRO's disaster-mitigation projects. The major focus was on information, training, and preparedness activities.

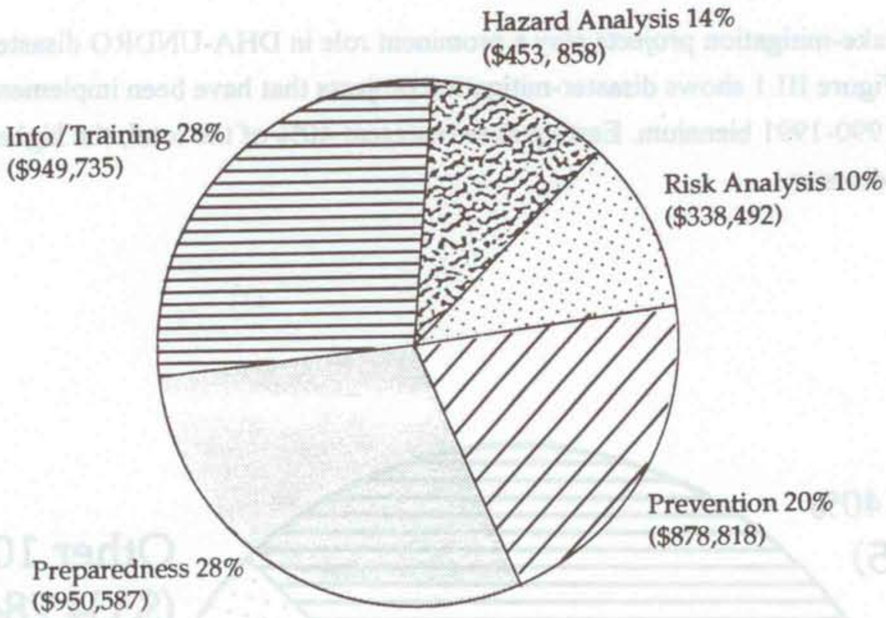

Figure III.2. UNDRO disaster mitigation projects, by activity type

DHA-UNDRO has eight basic objectives to incorporate into current and future disaster-mitigation efforts:

1. Stimulate investigations to gain a broader understanding of the full range of potential hazards.

2. Integrate all competent national experts into risk assessment and mitigation measures.

3. Promote and regularly review scenario studies to ensure that a properly linked sequence of measures--investigation followed by prescription, training, and public information--is applied to each potential natural hazard.

4. Investigate actively the disaster potential of all new major development projects, keeping in mind disaster-mitigation considerations.

5. Create a permanent service at the national level that will be responsible for initiating and supervising mitigation activities.

6. Integrate into this program all relevant national authorities, international agencies, nongovernmental organizations, bilateral organizations, and, if possible, the private sector.

7. Capitalize on new disasters in order to initiate or expand mitigation efforts.

8. Ensure an active exchange of experience and methodologies between countries with similar vulnerabilities and socioeconomic characteristics.

Mr. Zupka is relief coordinator with DHA-UNDRO. Since 1987, he has been responsible for designing, developing, and implementing UNDRO disaster-mitigation projects in several Latin American countries and is currently in charge of coordinating these efforts in Colombia, Ecuador, and Peru.

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS TO EARTHQUAKE DAMAGE ESTIMATION

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

For the past two years, Mexico has been developing a geographic information system (GIS) data base for the most populated area of the Mexico City federal district, which covers a 20-by-20-kilometer area. The GIS runs on a relatively small program on an IBM-compatible personal computer. It processes several different types of information and has already computed some earthquake damage scenarios.

This data base includes the distribution of population, different types of construction within the city, strength of ground motion, depth of the first soft layer of the liquid zone, and expected damage due to specific hypothetical earthquakes. All information about construction, population, and depth of soil layers is earthquake-independent.

Figure III.3 shows the cells into which the city was divided. There are approximately 800 cells, each typically one-quarter of a square kilometer in area. Cell boundaries tend to follow major streets and municipal political demarcations.

Figure III.4 shows the distribution and depth of the first soft clay layer. Light gray denotes the absence of a soft layer--what we call "firm ground," which is not actually that firm. The depth of the clay layer ranges from zero meters in the light gray area to 75 meters in portions of the old lake. In fact, there once was a second lake where the deep clay is now.

Mexico City has a 75-meter-deep soil layer with a shear velocity as low as 50 meters per second and water content of several hundredths of a percent.

Figure III.5 shows the distribution of total construction, regardless of type, measured in square meters. Buildings have been divided into 14 classes, for example, masonry of less than three stories, masonry of more than three stories, frame structures of four levels or less, frame structures between five and 10 levels, light nonengineered structures, and heavy nonengineered structures.

Total construction can also be measured in terms of density (Figure III.6), calculated by dividing the area covered with structures by the plan area for a cell. Densities reach 3.2, meaning an area 3.2 times the plan area of the cell. These high-density areas are located in the oldest part of the city, the downtown area.

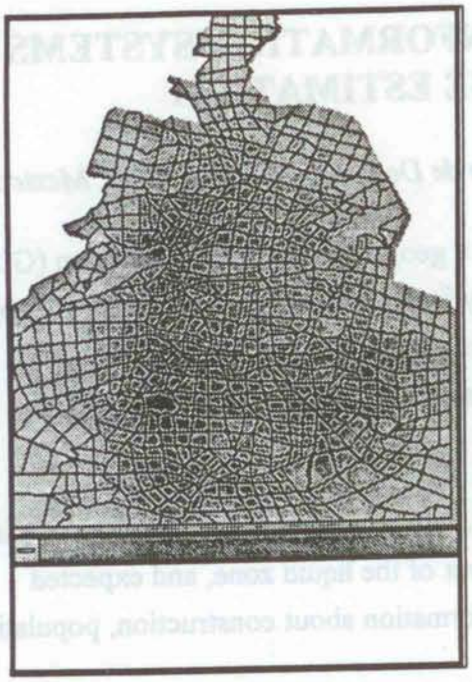

Figure III.3 Mexico City divided into cells

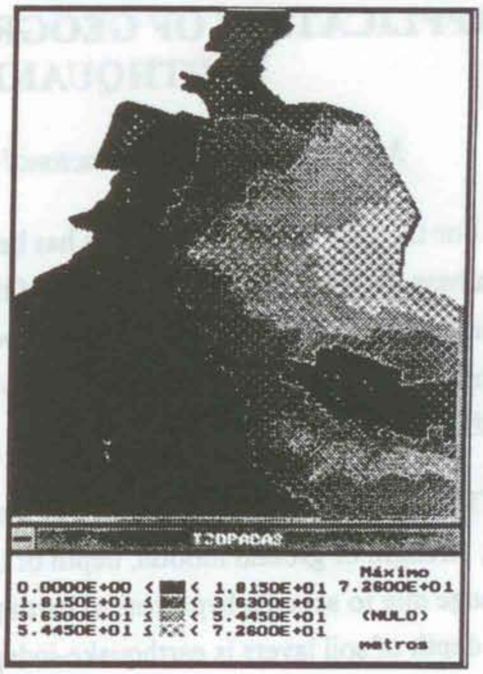

Figure III.4 Distribution and depth of first soft clay layer

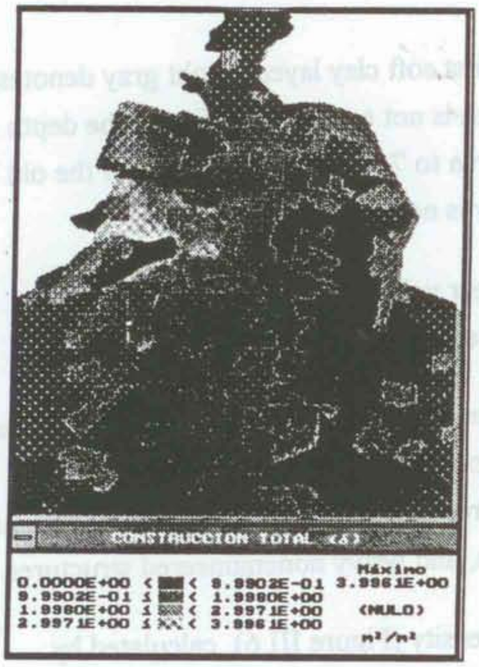

Figure III.5 Distribution of total construction (in square meters)

Figure III.6 Distribution of total construction (by density)

Figure III.7 shows the construction density for framed buildings with more than 10 levels. These are very flexible, tall buildings whose resistance strength is provided primarily by their frames. Gray indicates absence of that kind of building in an area.

Figure III.8 shows the distribution of braced frame structures with more than 10 stories.

We have postulated an earthquake similar to the 1985 earthquake: magnitude 8.1, epicentral distance from Mexico City approximately 300 kilometers.

Figure III.9 shows the distribution of peak ground acceleration in the east-west direction. We see clearly that the strongest motion at these frequencies concentrates in a strip running from north to south. The range of acceleration is between 3% g and 20% g. Ground acceleration peaks are indicated in dark and light gray.

Figure III.10 shows distribution of peak ground acceleration in the east-west direction for a ground period of 1.5 seconds, with 5% damping.

Figure III.11 shows the same distribution for 3.5 seconds and highlights sites where the predominant ground period is 3.5 seconds.

Figure III.12 shows the distribution for a 4.5-second period. Dark cells correspond to the deepest portions of the lake, where spectral ordinates go up to 30% g for the dark cells.

Figure III.13 shows the expected damage from the postulated earthquake. Dark areas indicate the highest levels of expected damage. Significant levels of damage are predicted in the southern part of the city and in several other areas. This map depicts total damage, measured in square meters and regardless of structural type. A predicted damage of 2.7×10^5 m^2, for instance, means a total damage cost equal to the reconstruction bill for an area that size.

For any given point on this map, the GIS can provide information on the expected damage by type of structure for a given earthquake (Figure III.14). The computer is equipped with a mouse marker, and a simple click on any given point will give the north-south and east-west response spectra for that point.

Figure III.15 shows expected damage to masonry structures of four stories or less. Figure III.16 shows expected damage to frame structures of more than 10 stories. Figure III.17 shows expected damage to frame structures between five and 10 stories.

Figure III.7 Construction density, framed buildings > 10 stories

Figure III.8 Distribution of braced frame structures > 10 stories

Figure III.9 Distribution of peak ground acceleration, E-W direction

Figure III.10 Distribution of peak ground acceleration (E-W direction, 1.5-second period)

Figure III.11 Distribution of peak ground acceleration (E-W direction, 3.5-second period)

Figure III.12 Distribution of peak ground acceleration (E-W direction, 4.5-second period)

Figure III.13 Total expected damage from postulated earthquake

Figure III.14 Expected damage in cell indicated by pointer

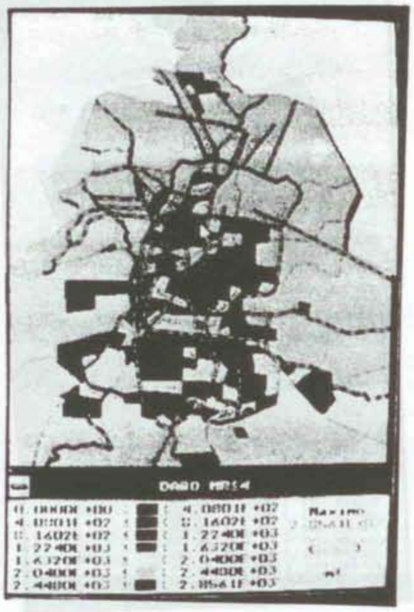

Figure III.15 Expected damage to masonry structures ≥ 4 stories

Figure III.16 Expected damage to masonry structures > 10 stories

Figure III.17 Expected damage to frame structures 5-10 stories

CENAPRED has given this system to the Mexico City authorities. We foresee its use in microzoning, building codes, and land-use and soil-use planning. It remains to be seen, however, how the Mexico City authorities choose to employ this new tool.

Dr. Ordaz directs the Geological Risks Division of the Mexican government's Centro Nacional de Prevención de Desastres (CENAPRED). He is also an associate professor of Structural Engineering at the Universidad Nacional Autónoma de Mexico (UNAM). His primary fields of interest include seismic risk analysis, engineering seismology, and building codes.

GUIDING EMERGENCY RESPONSE ACTIVITIES USING DAMAGE SCENARIOS: A PROMISING PROSPECT

Frederick Krimgold, Virginia Polytechnic Institute and State University, USA

Loss estimates and damage scenarios have been used in the United States for the past 20 years. A major function has been to gain attention through shock value: big numbers precipitate action and cause public bodies and political leaders to take earthquake issues seriously. Recently, however, journalists have begun to review past estimates and the methodologies used in arriving at them and have compared the estimates made by government agencies with actual experience. A July 1992 *New Republic* article by Jay Mathews entitled "The Big One: Why California in Safe", for example, takes the Federal Emergency Management Agency to task for using unrealistically high numbers in early damage scenarios for the San Francisco Bay Area and the Los Angeles area in order to bolster preparedness action. The article argues that unreliable numbers will sooner or later prove damaging to the cause of earthquake mitigation because people will lose confidence in official pronouncements and will not take seriously advice concerning necessary mitigation measures.

Earthquake scenarios in the United States have contributed to motivating mitigation, land-use planning, and building regulation. The same format and much of the content of these scenarios might be applied to immediate post-disaster response activities. My work for the past few years with the U.S. Agency for International Development's (USAID's) International Search and Rescue Team has afforded me insight into this significant possibility.

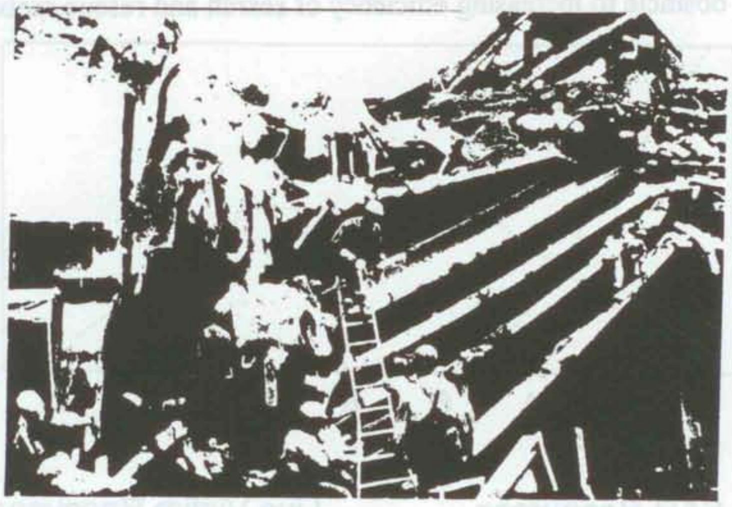

Figure III.18 Search and rescue activities in Mexico City

Figure III.18 shows search and rescue activities in Mexico after the 1985 earthquake. Approximately 10,000 people were trapped in collapsed buildings in Mexico City, and rescuers from a number of countries collaborated in efforts to locate victims. We have had several similar experiences since that time.

Any means of locating specific targets for search and rescue attention would be extremely helpful. Mexico City is, of course, an extremely large city. Although it may sound incredible, when we arrived in Mexico City we had a difficult time finding the earthquake. Locating priority search and rescue sites (the collapsed major buildings with high occupancy) was the initial phase of search and rescue in Mexico City. It took a long time, and only after this phase was complete could we begin making decisions about rational allocation of search and rescue resources for this large and complex urban environment.

In making a pre-event estimate of the probability of failure, a 1-in-3 probability that a building will fail is sufficient. However, when trying to allocate resources after an event, we must know which one of three adjacent, identical buildings has failed. This distinction between a generalized estimate and a specific assessment is important in search and rescue.

In search and rescue, the period of feasible rescue for earthquake victims is short, in our experience a maximum of five days, with likely live rescue within the first two days (Figure III.19). Unfortunately, the application of resources generally follows an opposing curve. The intersection area of these two curves is quite small. Our aim is to increase the size of this intersection by initiating more rapid and effective application of search and rescue resources. Insufficient information is the major obstacle to increasing efficiency of search and rescue mobilization.

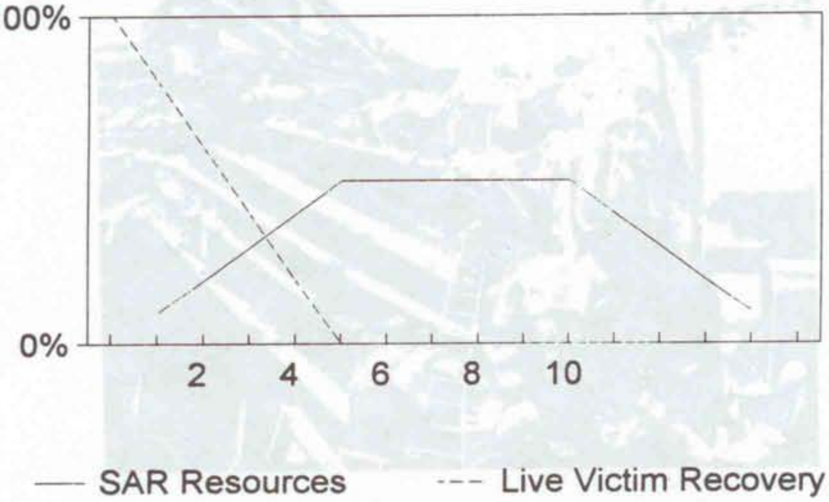

Figure III.19 Search and rescue mobilization efficiency

The Luzon, Philippines, Earthquake of July 1990 illustrates how rapid, effective information exchange can facilitate search and rescue activities. Within hours of the earthquake, the Philippine Institute of Volcanology and Seismology was able to fax to the United States Geological Survey (USGS) comprehensive information on the assumed location of the epicenter, including intensities experienced at a number of sites in central Luzon. We knew the essential characteristics of the event within 6 hours, before the search and rescue team was even dispatched from the United States.

Information on the projected isoseismal distribution showed us approximately where the heaviest damage should be and how far out life-threatening failure of buildings or other serious consequences could be expected. It thus indicated where we ought to look (Figure III.22). In addition, we received a specific list of damaged structures. Surprisingly, it did not correspond to the isoseismal projections.

By the time we had arrived at what was then Clark Air Force Base after a 23-hour flight across the Pacific, the focus of interest had shifted from the assumed epicentral area of Cabanatuan to Baguio. The isoseismal projection gave critical guidance in checking damage experienced in the area around Cabanatuan. The fact that there was virtually no damage in this area indicated that the character of the earthquake was more complex and that we needed to look in more detail around Baguio.

Figure III.20 gives a sense of the environs of Baguio, including the area's rough terrain.

Figure III.20 Terrain near Baguio, Philippines

Landslides along the roadways into Baguio made surface travel impossible. This kind of information is naturally essential to search and rescue teams. Landslides also isolated smaller settlements around Baguio. Although these did not all experience building damage, they were nonetheless isolated from any assistance for a long time.

The condition of the long runway at Baguio Airport was not inviting (Figure III.21). It gives an idea of potential impacts on transportation lifelines.

Figure III.21 Baguio Airport runway

Figure III.22 Agoo, Philippines

The locations of important buildings were indicated on a detailed topographical map of Baguio. Search and rescue teams need this level of detail in order to locate specific priority rescue sites as rapidly as possible and to maximize their effectiveness.

We flew over the town of Agoo near Baguio (Figure III.22). It is not immediately obvious that Agoo has sustained severe damage. The rubble in the street is an indication of nearby damage. But from the air, it is often quite difficult to distinguish between a low roof and a collapsed roof.

Figure III.23 Severe structural and fire damage

Another important factor in locating specific rescue sites is distinguishing between "hopeless" and "hopeful" sites. The building in Figure III.23 had severe structural damage during the earthquake and a devastating fire in the aftermath. This virtually ruled out the possibility of survivors. The building was deemed "hopeless" and therefore of low priority.

The Hyatt Hotel complex in Baguio was easily identified from the air as a failed structure (Figure III.24). When we found out that it contained 69 unaccounted-for people, it immediately became a major focus of rescue activity. A general plan of the condominium tower and specific plans for the basement and other areas of the building served as guides to rescuers (Figure III.25). Thanks to the plans, we were able to find the presumed location of the majority of the victims at the time of the earthquake.

Figure III.24 Hyatt Hotel, Baguio

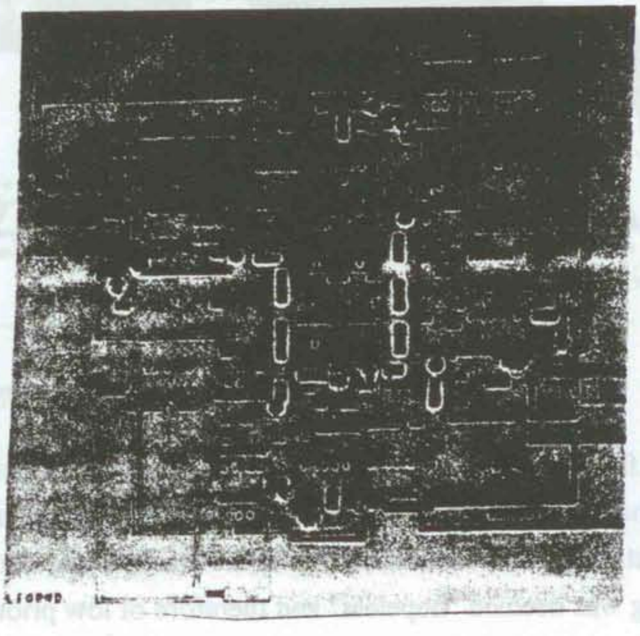

Figure III.25 Hyatt Hotel floor plan

The first two stories of another hotel in Baguio, the Nevada Hotel, collapsed (Figure III.26). As with the Hyatt, we were able to obtain fairly detailed building plans. In fact, we found a plan of the collapsed floor with the assumed location of the victims that had been left by an earlier search party. The man in Figure III.27 was successfully rescued and has recently come to the United States for prosthetic assistance.

The details of the Luzon Earthquake point out the need for consecutive focusing: from the global to the national to the regional level to the specific city, then, if possible, to specific target buildings in the city, the design of these buildings, and the probable locations of survivors within them. This consecutive focusing is feasible and has proven immensely helpful to search and rescue teams.

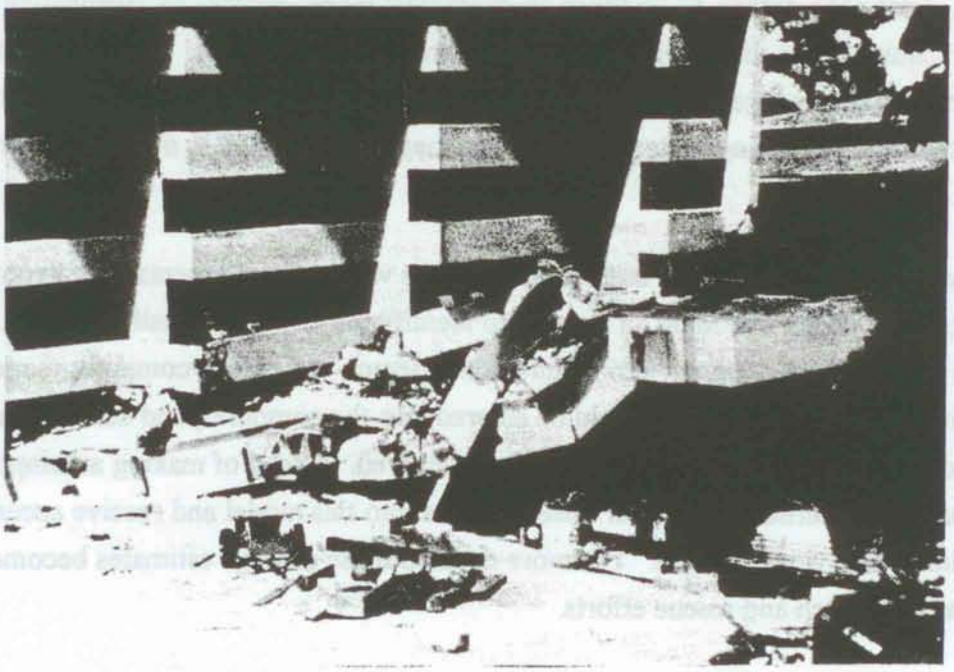

Figure III.26 Nevada Hotel, Baguio

Figure III.27 Successful rescue, Nevada Hotel

Obviously, earthquake damage scenarios will not contain detailed designs of all the buildings in a major city. I propose, rather, to establish an interactive model capable of assimilating new information acquired over the course of responding to a particular event. This must not be a model developed in an office and mailed to City Hall, but instead a computer modeling capacity whose turnaround time for generating updated damage estimates is measured in minutes rather than semesters.

If a scenario existed for the city under consideration with even rudimentary or hypothetical building distribution data, including an attempt to identify the city's potentially hazardous buildings, the scenario could then be plugged into an interactive search and rescue computer model. The actual parameters of the earthquake could be entered into the computer, and damage assessments could be updated as new observed information was entered. Instead of making assumptions about building behavior, scientists could enter observed data into this model and receive accurate and detailed building behavior estimates. The more detailed these damage estimates become, the more useful they are to search and rescue efforts.

Keishi Shiono of Tokyo Metropolitan University and I have attempted to develop a method for estimating response needs by analyzing remotely available data. The problem we have encountered is that potential error increases with the accumulated error of individual assumptions. The proposed interactive model limits the error margin by limiting the number of assumptions involved in each estimate.

Five days after the Luzon Earthquake, experts on the site agreed, based on their previous experience, that there was no significant possibility any further live victims could be found. Their view was immediately printed in the local newspaper. Some searchers ignored the experts' opinion and found three trapped people on the 11th day whom they were able to save. This potentially tragic error--seeking to halt this particular search and rescue effort after five days--was due partly to inadequate information about the nature of the destruction and partly to inadequate on-site handling of available information.

The Austrian Army has developed a phased search and rescue procedure. The initial phase is reconnaissance and inquiry, which includes observation, inquiry of survivors, and assessment of types of destruction (Figure III.28). An adequate earthquake damage modeling approach could be a great asset to this phase of the process.

The top priority in search and rescue is to identify lightly damaged buildings in which rescue is relatively easy. We tackle these first. We then move to buildings that have sustained serious damage, but have a high probability of holding survivors. Only once these first two phases are complete do rescue teams look through structures that are unlikely to hold survivors.

These patterns of probable building damage can be identified before earthquakes occur. Information about building category, such as the ATC-21 (Applied Technology Council) classification shown in Figure III.29, is highly useful immediately after a disaster. By identifying particularly hazardous categories of buildings, we can estimate patterns of collapse and lethality, which can in turn help to determine the likelihood of live rescue in these buildings after an earthquake.

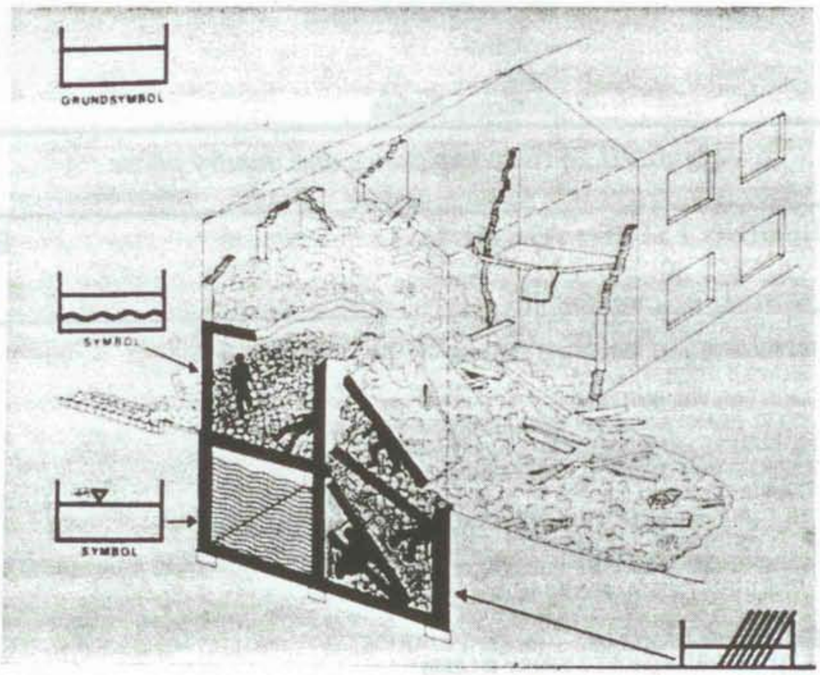

Figure III.30 Symbolic code of structural collapse patterns

Figure III.30 shows part of a German system of symbols relating to patterns of structural collapse. Such an evaluation code, standardized and incorporated into a central data base, could greatly facilitate the allocation of rescue resources in the immediate post-earthquake period.

First Phase

➔ reconnaissance and inquiry:

— own observation;
— inquiry of survivors (whereabouts missing persons, last stay of those persons)
— judgment of types of destruction

➔ immediate rescue of slight buried people

➔ elimination of special threats

EQUIPMENT

— medical equipment
— means of transportation
— lightings
— tools
— protective clothes

Figure III.28 Reconnaissance and inquiry phase

STRUCTURAL BUILDING TYPES • ATC-21-1 BF 1

IDENTIFIER	GENERAL DESCRIPTION
W	WOOD BUILDING OF ALL TYPES
S1	STEEL MOMENT RESISTING FRAMES
S2	BRACED STEEL FRAMES
S3	LIGHT METAL BUILDINGS
S4	STEEL FRAMES W/ CAST IN PLACE CONC WALLS
C1	CONCRETE MOMENT RESISTING FRAMES
C2	CONCRETE SHEAR WALL BUILDINGS
C3/S5	CONCRETE/STEEL FRAME W/ URM INFILL WALLS
TU	TILT-UP CONCRETE WALL BUILDINGS
PC2	PRECAST CONCRETE FRAME BUILDINGS
RM	REINFORCED MASONRY BUILDINGS
URM	UNREINFORCED MASONRY BLDGS

BUILDING TYPES MOST LIKELY TO BE DAMAGES

URM	1 TO 6 STORIES (MOST 3 STORY & LESS) 8000 IN LA 6000 IN SF 50000 IN CAL. INCLUDES STEEL & CONC FRAMES W/ URM INFILL 1986 SB 547 CH 250 REQUIRES IDENTIFICATION.
C1/C2/C3	PRE 1947 CONCRETE BUILDINGS
PC2/TU	PRECAST CONCRETE BUILDINGS (OLDER — POORLY CONNECTED BUILDINGS) • MULTI STORY RESIDENCE BUILDINGS • LOW RAISE COMMERCIAL & PARKING STRUCTURES • TILT-UP CONC WALL BLDGS, 1 TO 3 STORY • SIMILAR BLDGS 2/ CONC BLOCK WALLS • POST TENSIONED LIFT SLAB BUILDINGS
OTHERS	NON UNIFORM BUILDINGS • MULTI STORY W/ SOFT FIRST STORY • OPEN FRONT COMMERCIAL BUILDINGS • ODD SHAPED BUILDINGS T, L, ETC • CORNER BLDGS — TORSION

Figure III.29 ATC-21 classification of building category

In the United States, earthquake loss scenarios have focused on physical damage resulting from the recurrence of specific historical events. Such a scenario was developed for the St. Louis, Missouri, area. The last major earthquakes struck there in 1811 and 1812, before modern civilization arrived in the area (Figure III.31). This scenario made real the idea of earthquake risk to a population having no experience with earthquake damage. The study identified soil types and expected intensities for scenario earthquakes (Figure III.32) and focused on total loss and disaster response capability.

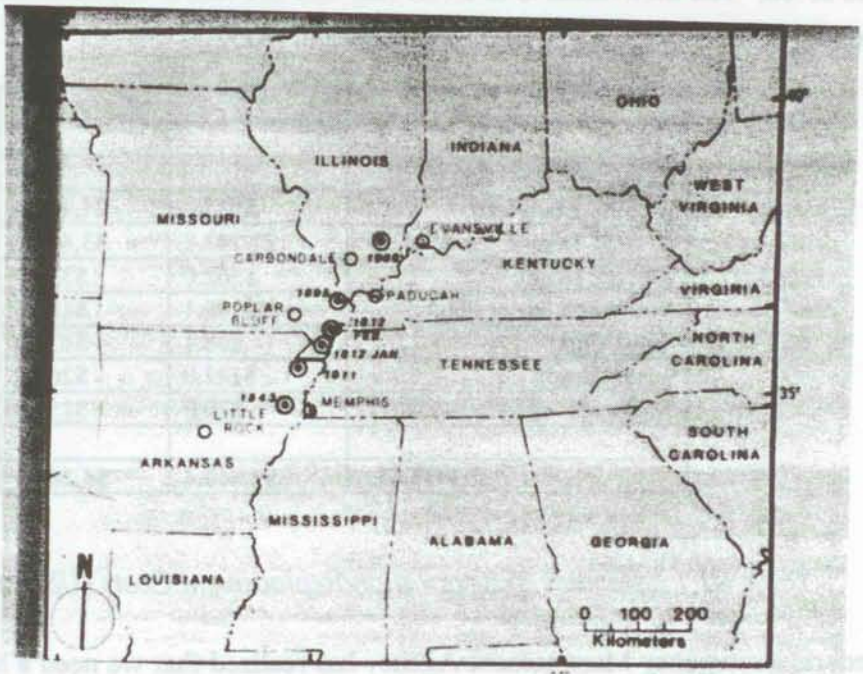

Figure III.31 Recent major earthquakes in St. Louis area

Figure III.32 Expected intensities, St. Louis scenario event

This old-style scenario typically provided information on casualties, nighttime or daytime occurrence, the availability of structures for provisional accommodation, and replacement cost estimates for a given level of disaster. For example, it estimated a $5 billion loss for a magnitude 8.6 event striking St. Louis, Missouri.

Table III.1 shows projected impact on lifelines, including utilities, gas, roads, railroads, water, sewers, and so on. The motivation is to strike fear into the hearts of public officials so that they will initiate mitigation activities to minimize human and material losses.

	Ms = 7.6	Ms = 8.6
Occupied Structures		
St. Louis City	$927.0	$1,799.0
St. Louis County	$1,243.2	$3,401.4
Electric Utility	$262.0	$333.0
Water and Sewer Plants	$148.1	$187.7
Gas Utility	$68.1	$123.0
Major Roads	$142.0	$268.0
Railroads	$70.0	$150.0
TOTAL	$2,860.4	$6,262.1

Table III.1 Estimates of Restoration/Replacement Costs (US$ millions)

The Federal Emergency Management Agency has realized that we need a new generation of scenarios and loss estimates for American cities. The agency is currently seeking to establish standards for scenarios and to develop a consensus methodology for generating loss estimates. The resulting new generation of scenarios could better meet the needs of post-disaster response, especially if they are based on a dynamic rather than a static model.

Under the new model, the primary objective of mitigation efforts is to improve hazardous structures in order to minimize collapse. A secondary objective is to facilitate the successful rescue and rehabilitation of people from collapsed buildings.

In conclusion, applying the data that become available after an earthquake to improving a country's search and rescue capacity offers a promising particular application of the principle that available data must always be used to answer useful questions. Post-event damage information could usefully be merged with pre-event hypothetical damage scenarios in the post-event environment.

Dr. Krimgold is associate dean for research and public service at the College of Architecture and Urban Studies at Virginia Polytechnic Institute and State University in Blacksburg. He has served as a consultant to the United Nations (UNDRO, HABITAT). His current research includes search and rescue in collapsed buildings and earthquake-injury epidemiology.

DISCUSSION

Yoshinori Iwasaki, Osaka Geo-Research Institute, Japan

In 1854, Osaka was hit by a magnitude 8.4 earthquake whose epicenter was 130 kilometers from the city. Damage distribution maps for the event show that damage was strongly concentrated in the Holocene sediments and was much lighter in the Pleistocene sediments. Typically, Holocene sediments add a Japan Meteorological Agency (JMA) intensity level of 2 to an earthquake, while Pleistocene sediments add a factor of 1.8. This difference in added intensity was, in fact, estimated to be 0.5 instead of 0.2 in this case.

Two conclusions about ground-motion intensity distribution can be drawn: (1) great earthquakes of magnitude 8 or stronger with epicenters more than 100 kilometers distant often show large shaking intensity differences depending on soil type, and (2) soil differences near the epicenters of earthquakes have comparatively little impact on shaking intensity.

Glenn Borchardt, California Division of Mines and Geology, USA

In California, we increase our bedrock intensity prediction by the same amounts: 2.0 for Holocene sediments and 1.8 for Pleistocene sediments. However, these factors apply only to shaking. Pleistocene sediments seldom liquefy. I suspect that the Osaka Holocene sediments bearing structures with greater-than-predicted damage experienced liquefaction or settlement in addition to shaking. This would account for the differences in damage between Holocene and Pleistocene sediments being greater than 0.2 intensity units. The Modified Mercalli Intensity (MMI) scale actually has three additional intensity units that are specifically designed to reflect levels of permanent ground failure.

David Dowrick, Institute of Geological & Nuclear Sciences, Ltd., New Zealand

With so many people from different disciplines involved in earthquake-preparedness efforts and other earthquake-related issues in various countries, how can we learn what work relevant to our own has already been done by someone publishing in a foreign language or journal?

Dusan Zupka, DHA-UNDRO, Switzerland

The DHA-UNDRO office in Geneva has a major reference library. Those interested in a specific aspect of earthquake preparedness and response can send in a request. Our office will then compile and send a list of publications available on the topic through its library or through others linked to its data base. Although the office may not have a copy of a particular publication, it usually has at least the publication's title in its data base. It also sends out printouts of related documents available through UNDRO, and users can order publications from these lists.

The office sends out copies of UNDRO's publications upon request. Until recently, UNDRO published mainly manuals that focused on the prevention and preparedness aspects of mitigating different types of disasters. For the last four or five years, the primary focus of UNDRO's information output has been *UNDRO News.*

Glenn Borchardt, California Division of Mines and Geology, USA

How much money, Dusan, is the United Nations prepared to spend on scenario preparation, possibly on a 50-50 aid basis, in certain highly vulnerable, developing countries? Is it true that UNDRO has U.S.$1.8 million in its budget for this? What fraction of this sum is being contributed to scenario preparation or to corresponding planning stages at present?

Dusan Zupka, DHA-UNDRO, Switzerland

It is difficult to give a precise figure of how much was spent. UNDRO's limited personnel and funding resources have not, however, permitted it to develop detailed damage scenarios like those produced in the United States. It has developed only simple damage scenarios, or mapping of risks associated with potential earthquakes.

Mark Klyachko, Kamchatka Center, Russia

The time is ripe for beginning much broader international cooperation in the area of damage-scenario preparation. Standardized and unified approaches to several aspects of scenario preparation are needed, including collecting and processing relevant data, producing seismic vulnerability maps, producing scenarios of seismic data, and developing geographic information systems. Elaborating strategies for better utilization of existing knowledge and experience could also prove useful.

Christopher Rojahn, Applied Technology Council, USA

Gathering inventory information is probably the most difficult part of damage estimation.

Could Dr. Ordaz specify how size, location, and structure type were assigned to the inventory of Mexico City?

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

We gathered information about construction in Mexico City by conducting a survey using an army of students. Instead of surveying the whole city, we took aerial photographs, sampled a number of typical cells, then extrapolated to generate information for the whole city.

Brian Tucker, GeoHazards International, USA

Dr. Ordaz has demonstrated the output of his computer system for one particular hypothetical earthquake. Could it generate an entirely new set of information for a different hypothetical earthquake with a different magnitude and location?

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

The personal computer version requires 4 hours to compute a new scenario. The GIS software, however, has now been transferred to several work-station platforms, and a work station could calculate the projected effects in 4 minutes. The parameters of the postulated earthquake would simply be altered, and maps corresponding to the new event could be ready in a matter of minutes.

We are now designing an early-estimation system. This system uses strong-motion instruments to determine the magnitude of actual earthquakes as they begin. The resulting data are entered immediately into a GIS that generates a corresponding damage scenario. We could probably produce such a scenario-to-order within 2 or 3 minutes after the earthquake started, provided we have electrical power. In the case of Mexico City, this would mean the scenario could conceivably be ready before the earthquake ends, as earthquakes tend to last a long time there.

Barclay Jones, Cornell University, USA

Does the Mexico City model calibrate with the 1985 earthquake?

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

Significant parts of the system were calibrated with the 1985 earthquake. Expected total damage, for example, was calibrated using the observed total damage in 1985.

Shirley Mattingly, City of Los Angeles, USA

The Mexico City model highlights precisely the direction in which we in Los Angeles want to go, that is, toward combining all relevant data bases into a GIS.

Once a scenario is generated, the next step is utilization. Dr. Ordaz indicated that he had turned this damage mapping system over to the Mexico City officials. Mexico City has various ongoing mitigation and preparedness programs in its secretariats. As it is critical that scenarios be a part of a continuum of ongoing programs, how will this wonderful tool fit into Mexico City's current mitigation and preparedness programs?

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

The Mexico City authorities apparently do not let their right hand know what their left hand is doing. I was unaware of the cooperative agreement for seismic hazard information exchange between Los Angeles and Mexico City! Such an agreement could be quite useful.

I am not familiar with the city government's various mitigation and preparedness efforts, so I cannot comment on how its ministries might receive and use this new tool. However, the system is not the property of the Mexico City government and is potentially available to anyone who finds it useful.

Jon Traw, International Conference of Building Officials, USA

Buildings differ throughout the world. In developing a world model, it is useful to establish generalized groupings of structures. Yet we must somehow take into account the significant differences between nominally similar structures occurring in different countries.

It is important to avoid getting too involved in details, as engineers at times have a tendency to do. Refining data to gain an extra 5% accuracy, when 90% accurate results can be acquired in a quarter of the time, for instance, must be recognized as an inefficient use of time and money, in particular in cases where funds are scarce.

In the area of structural design, few improvements are likely to be made that could have a significant impact on earthquake-hazard mitigation, except perhaps in the areas of soils and seismicity.

The best approach to earthquake-hazard mitigation is to focus on improving our retrofitting capacity. For the moment, information relating to retrofitting buildings is deplorably scarce. For developing cities, however, it is even more important to ensure that new construction is earthquake resistant.

How information on earthquake-mitigation strategies is utilized boils down to a matter of public policy. Public policy is one thing in Los Angeles and quite another thing in a developing country. When scarcity of housing becomes a pressing issue, as is the case in much of the developing world, local authorities and others become more willing to accept lower standards. We must not lose sight of this fact in considering international solutions to hazard-mitigation problems.

Kyriazis Pitilakis, Aristotle University, Greece

A damage scenario is a complicated story whose emphasis changes significantly depending on one's viewpoint. A politician and an engineer, for instance, are likely to come up with completely different conclusions as to what action should be taken on the basis of the same damage scenario.

The discussion should perhaps instead focus on the more manageable topic of seismic scenarios, which consider hazards on the surface of the soil but avoid extensive consideration of the engineering of structures. Codes governing structural engineering in different cities, and for different categories of buildings within a city, vary immensely. Also, because engineering aspects of structures are quite complicated, it would be imprudent to search for a generalized way of preparing scenarios for large cities that included specifications of engineering standards.

Anand Arya, University of Roorkee, India

Effective, economical approaches must be elaborated for making damage scenarios in developing countries.

India has two very highly seismic areas, one in the western Himalayas and one in the eastern Himalayas, where earthquakes of magnitude 8 in 1905 and 8.4 in 1934, respectively, have occurred. Detailed reports of these earthquakes are available, including intensities, damage, and other information. I have made two scenarios using a data base of this information.

Fortunately, the Indian government conducts a housing census every 10 years. I superimposed the 1981 census for these areas, which listed numbers and types of buildings both by district and by village, on the actual damage figures for those two earthquakes, using the MMI scale. Damage scenarios were thereby developed with relatively little effort for these two areas.

The scenarios that emerged are fearful. In one area, depending on the time of day and season the earthquake occurs, more than 300,000 people could be killed. In the 1905 earthquake, by comparison, only 20,000 people lost their lives. In the other area, approximately 350,000 could be killed, depending on time of day and seasonal factors. These shaking tolls are not figures for megacities but for rural areas. If a big city were located in one of these two areas, the estimated damage would be still more severe.

These scenarios have been presented to the Indian authorities. But drawing the attention of government officials to such dangers is a critical problem in developing countries. Perhaps this problem should also draw our attention.

In my experience, most rural buildings need only minor engineering intervention or small additions to make them collapse-proof, although perhaps not damage-proof. Damage will inevitably occur, but collapse and loss of life can be minimized with a relatively minor effort.

If the soil in a particular area is relatively homogeneous, then a technique like the one I used might allow scenario developers to obtain a quick, inexpensive, and reasonably accurate earthquake damage scenario for the area.

Robin Spence, Cambridge University, UK

As Fred Krimgold said, it is important to ensure that discreditable earthquake damage scenarios are not produced so as to protect the credibility of scenarios and avoid setting back the cause of earthquake-hazard mitigation. It is also crucial that scenario makers be honest about the levels of uncertainty associated with earthquake-loss scenarios and the difficulty of pinning down many of the parameters on which they are based. Results must be presented responsibly, especially those relating to casualty figures. A given scenario should not say, for instance, that 864 people will be killed in a certain event. Instead, it should say that between 0 and 3,000 people will be killed, with an expected toll of approximately 800.

W. D. Liam Finn, University of British Columbia, Canada

Several speakers have discussed presentation of scenario study results, and Ms. Mattingly eloquently stressed the importance of inducing communities to make proper use of this information. As an engineer, however, I am disappointed that the relationships of type and amount of damage to earthquake characteristics, ground conditions, and building type have not received more attention. These relationships, or vulnerability functions, are the key to effective damage scenarios.

Although the effects of the Mexico City Earthquake have been presented here in some detail, these findings are not of broad application because Mexico City is a special case due to the highly plastic nature of its foundation soils. These soils remain elastic over a significant strain range during strong shaking, which results in increased duration of strong shaking and a peaked-shape response spectrum. Buildings with periods close to the periods of peak response therefore tend to have especially heavy damage. On most sites, however, soil response tends to be more broad-banded and a broader distribution of building heights sustains serious damage.

Studies of deep-site response in Vancouver have shown that strong long-period response can be obtained even on sites that are not underlain by significant deposits of clay. These studies showed that a multiplier of 2 must be applied to the base shear of buildings in order to take into account the effects of deep sites.

It has become apparent from studies conducted in Canada and the United States in preparation for building code revisions for the year 2000 that loose descriptions of site conditions are not adequate to characterize properly the damage potential of particular geological formations. Roger Borchardt and his colleagues at the United States Geological Survey have done extensive work on the responses of various geological formations to low-level motions generated by nuclear explosions and strong-motion data from the Loma Prieta Earthquake. They have provided a continuous specification of average spectral amplification at a single site over the period range 0.2 to 2 seconds. This average amplification provides a relative index of site damage potential. The amplification is expressed as a function of the average shear wave velocity, V_S, in the top 30 meters of the site's soil. A preliminary estimate of the amplification is given by $700/V_S$ for strong motion and $600/V_S$ for weak motion.

From today's presentations, it is clear that the GIS technology exists for generating damage scenarios as fast as needed. It is also clear that eloquent and effective spokespeople are available to convince responsible governments, when they face major infrastructure damage, disruption of business, or horrendous human losses from a major earthquake, to take effective action to minimize adverse effects. While the implementation of effective mitigation arrangements may take a long time, continuing actions of the right kind will eventually produce substantial progress. The weak link in this long chain, however, from entering of basic data to scenario development to mitigation implementation, is the vulnerability function. This function responds to the fundamental question, "What will happen to infrastructure if an earthquake actually occurs?" Progress in the development of vulnerability functions has not kept pace with recent advances in scenario presentation and disaster-management planning.

A measure that could help to mitigate this shortcoming is ensuring that structural engineers experienced in practical seismic design are well-represented on teams of scenario developers. Experienced geotechnical earthquake engineers should be represented, too, particularly in efforts to assess the impact of local site conditions.

SUBMITTED COMMENTS

Anand Arya, University of Roorkee, India

In developing damage scenarios, local disaster management capacities should also be determined. Such capacities include skilled personnel, technical skills, local government capabilities, and secure structures.

Michio Hashizume, United Nations Educational, Scientific, and Cultural Organization (UNESCO), France

Satellite images, such as the SPOT images, could be usefully incorporated into GIS work. In particular, information gathered by intense ground investigation for microzoning in Mexico City could be compared with SPOT images to facilitate general microzoning work.

Sudhir Jain, Indian Institute of Technology, Kanpur, India

We have not clearly delineated the role that international disaster management agencies play in disaster-hazard mitigation activities or how they propose to utilize completed scenarios.

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

Much more time should be devoted to discussing the communication barriers that all too often exist among engineers, the authorities, and the public. Also, some consideration should be given to the problem of "optimum investment" in reducing risk. That is, given a limited budget, available funds should be allocated to achieve an optimal reduction in loss of life. Questions such as, "How much of this money should be used to reduce earthquake risk? Environmental risk?" could usefully be explored.

Michael Reichle, California Division of Mines and Geology, USA

All scenarios mentioned in Part III were treated as if they would produce the same set of results. The different uses of planning and damage scenarios were not clearly distinguished. It would be useful to examine the uses and benefits of each type of scenario and the resources needed to produce them.

PART IV: EARTHQUAKE DAMAGE SCENARIOS FOR INTERNATIONAL INSURANCE COMPANIES

Åke Munkhammar, Chairman

Mr. Munkhammar is senior vice president with the Skandia Group. He heads the company's earthquake insurance program and oversees its underwriting worldwide.

THE INSURANCE INDUSTRY'S CONCERN WITH EARTHQUAKES

Åke Munkhammar, Skandia Group, Sweden

While we do not know very much about the various types of natural hazards confronting human civilization, such as ground motion, tsunami, volcanic eruption, and land stability following an earthquake, we actually know less about the locatión and character of insured values. Although this may sound like a simple thing to understand and keep track of, in reality it is quite complicated and seldom done by the insurance companies. Oddly enough, we are better off on a society level where national censuses often can provide good information on the whole stock of buildings. But the insurance industry is only interested in those buildings that are insured. If we manage to get information on three key aspects of insurance--hazard, vulnerability, and insured value--we can generate what we call a "probable maximum loss" (PML) estimate, which is essentially a type of damage scenario.

Earthquake insurance is more than protecting against physical damage to property. That is a big and important part of what earthquake insurance does, but there is also the question of fires caused by earthquakes. In some markets, like the United States, this protection is included in regular fire protection policies. In most earthquake-prone countries, however, insurance against earthquake-related fire is provided as an addition to the fire policy, for an additional, separate premium. Likewise, insurance against damage caused by tsunamis is usually purchased as an addition to the fire policy.

Another aspect of insured loss is the economic loss caused by the downtime of support systems and lifelines such as sewage lines, water lines, and power supplies. A standstill period for manufacturing plants, for example, means a costly downtime for the insurance industry. The "just-in-time" concept in manufacturing makes small slowdowns in the delivery of raw materials, or stoppages anywhere along a production line, cause very big economic losses. Disruption of "just-in-time" loops can multiply the economic damage caused by an earthquake.

There is also third-party liability, whereby the employer has liability for customers or clients injured on the work site during or immediately after an earthquake. Third-party liability is important in the United States. Personnel accidents can place great demands on both health insurance and life insurance companies. Automobile policies are affected, as a large proportion of building rubble typically falls on automobiles. All goods that move in and out of harbors or are onshore within harbors are normally insured under marine insurance transport policies. Bonding insurance covers loans, for example, on the construction of buildings. If a building under construction is destroyed, the insurer is responsible to repay the loan or advance payments made. So, in addition to regular property damage, there are other soft lines of business.

Åke Munkhammar is Senior vice-president with the Skandia Group of Stockholm, Sweden, responsible for underwriting control worldwide. He is also a member of EERI.

EARTHQUAKE HAZARD ESTIMATION BY THE INSURANCE INDUSTRY

Herbert Tiedemann, Swiss Reinsurance Company, Switzerland

Consultants and university researchers often ask, "Why does the insurance industry not give more money for us to do more research?" Today I will discuss what we in insurance need: researchers should consider whether they are in a position to supply the needed data. If so, insurance companies would probably be quite interested in assisting them with their research.

A simple formula, that I developed 30 years ago, when property insurance and risk assessment were still in Paleolithic states, is:

$$X_{0/00} = \frac{LE * f * u * P * 100}{SI * R}$$

This formula shows what we require in order to assess the exposure, or insured risk, for any particular event. X is the rate we should charge in order for our ship to travel on an even keel. LE (loss expected or mean-damage ratio) needs to be determined as a sum or percentage. The overhead is f, the uncertainty or safety is u and the period of exposure is P. SI is the sum insured (full new replacement value) and R is the loss-return period causing damage equal to LE.

A reinsurance company professionally insures insurance companies against large losses. Insurance companies, though, are generally as clever as insurance brokers: both like to pass on risk to avoid the true gamble involved in insurance. Brokers appraise insurable risks to the insurance companies in the most beautiful colors and ask high brokerage fees for them. Meanwhile, the insurance companies worry that the risks might, in fact, not be quite as good or safe as the broker made them out to be. To avoid a potential catastrophe, they transfer the majority share of the risk to the reinsurer, letting the reinsurer pay for the mistake if something happens. The reinsurer is thus interested in minimizing the potential for catastrophic damage. The reinsurer must be safer than the insurer, and the insurer must in turn be safer than the engineers. This explains to some extent why reinsurers tend to be conservative.

Insurers are interested in the uncertainty associated with their risk assessment. Most engineers present their data on beautiful graphs without indicating the level of uncertainty associated with their projections. However, insurance people must have a clear sense of levels of uncertainty.

The insurance industry is also interested in the return periods, or annual probability, of high-exposure events. Exposure is normally appraised on an annual basis, so we generally do not have to worry about it. Multiannual exposures such as earthquakes are an exception. For these, we must ascertain the total sum insured, which is, approximately, the sum of the new replacement value for each year separately.

If researchers can supply this information, they will be in business with the insurance companies. Otherwise, they must work toward generating these types of information if they wish to do business with us.

A simplified tabulated version of my global equation can be used to generate LE estimates for buildings (Table IV.1). There are, of course, other formulas for other elements at risk. In this case, we analyzed about 250,000 buildings in detail to determine actual damage resulting from different intensities of shaking. A sizable error margin remains within each intensity level. We then generated mean-damage ratios for buildings. This quality of information is good but not excellent. If researchers can provide this sort of information, they have reasonably good chances of getting financial backing from insurance companies.

	VI	VII	VIII	IX	(X)
ADOBE, RUBBLE MASONRY	28	55	84	100	100
BRICK, UNREINFORCED	11	28	55	85	100
RC - 2-3% g	3	11	28	50	85
RC - 3-4% g	1	6	17	36	60
RC - 6% g		3	11	26	50
RC - 12% g		1	6.5	17	38
RC - 2-% g			3	12	30

Table IV.1 MDR in percent depending on MMI and building quality, assuming medium-hard alluvium and moderate irregularity

By plotting this information in the right way, it becomes a detailed basis for estimating loss (Figure IV.1). The mean-damage ratio is seen as a percentage of the new replacement value. Intensity of shaking and building quality are taken into consideration. These estimated-loss calculations are roughly valid for medium-hard alluvium and regular buildings.

Holocene deposits in the Fondo del Lago, Mexico City, produced no damage to adobe buildings during the 1979 earthquake. However, the beautiful Universidad Ibero-America, although designed according to the best engineering standards, collapsed: fortunately, it was a few hours before students arrived. The builders of the university seem only to have looked at the upper layer of the Holocene sediments, but the soft deposits at the Fondo del Lago go down to bedrock

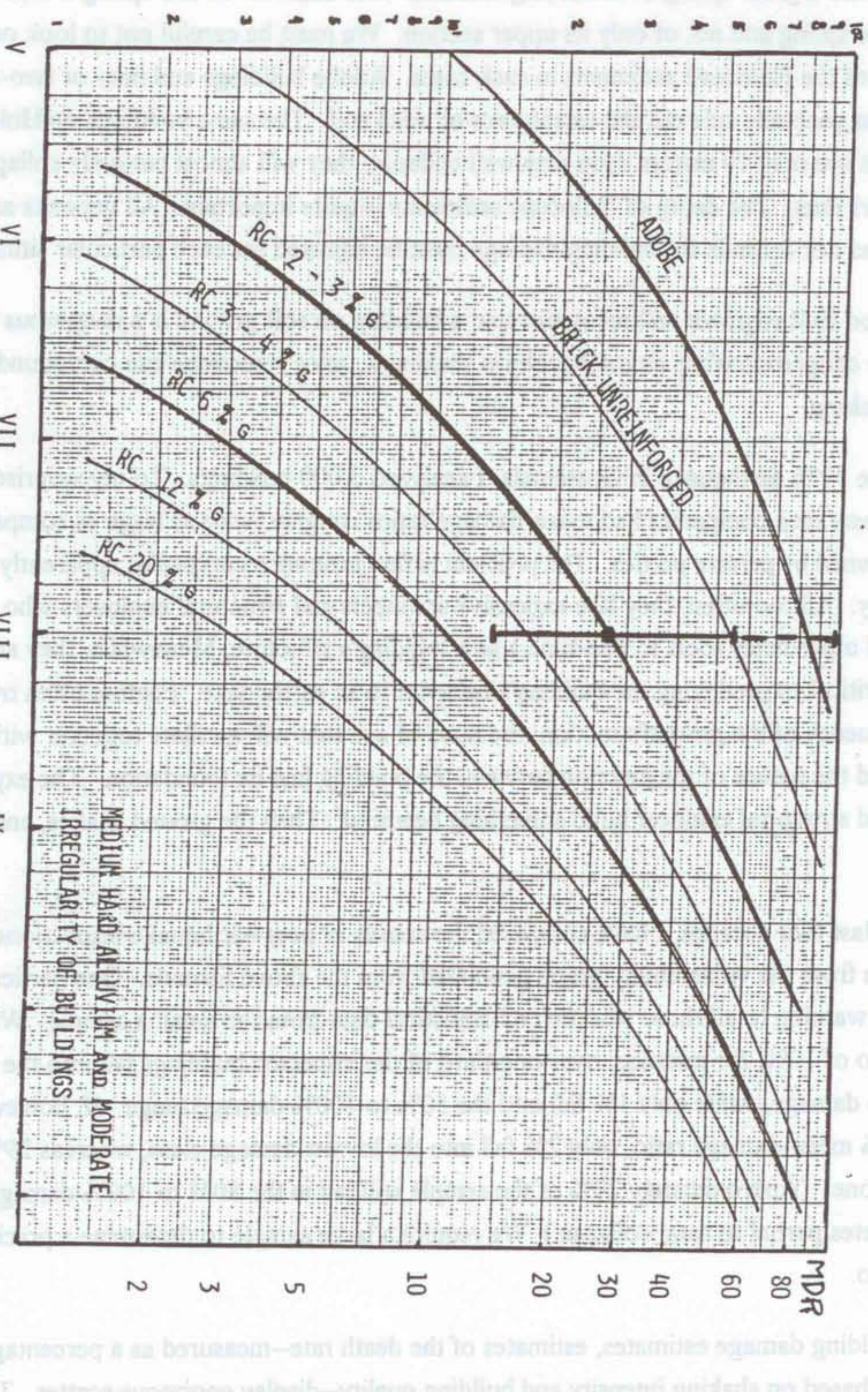

Figure IV.1 Graph of mean damage ratio as a function of shaking intensity and building type and behave like a great spring of increasing stiffness. The behavior of this spring is a property of the complete spring and not of only its upper section. We must be careful not to look only at the upper layer of the Holocene sediments in such cases. Adobe buildings and one- or two-story buildings can generally ride out the earthquake on such soil. The same buildings on Holocene deposits that are only 10 meters deep may well collapse; they will almost certainly collapse if it is only 5 meters deep. The depth of Holocene sediments is quite important. All deposits are different, however, and our formula for building damage must be adjusted for each particular situation.

Any good civil engineer will recognize that a building on soft ground is a dangerous building. It is especially dangerous when an earthquake is shaking it, since resonance can compound the ground's shaking.

After the 1976 earthquake in Guatemala, I analyzed 3,000 buildings. To my surprise, buildings owned by insurance companies had mean-damage ratios roughly twice as large as comparative buildings owned by private parties. The problem is that insurance companies apparently have too much money. All too often, they hire expensive architects and structural engineers who use modal analysis and other fancy tools to fine-tune a new building's structure. Meanwhile, they are ignorant of factors critical to predicting the building's behavior in an earthquake. Factors often overlooked are the frequency of the ground's motion, the mass of soil that will oscillate together with the building, and the nature of the junction between the building and its foundation. The expensive architect and structural engineer build something beautiful. Then the ground shakes, and it collapses.

For the last two decades, I have compared the results of post-earthquake inspections with values taken from the vulnerability graph generated from the above formula. One particular result should be a warning to all those who extract statistical data from too small a sample. With a mean-damage ratio of 10%, for instance, over one-third of the inspected buildings fall into the range of 0% to 1.5% damage, while only 1% fall into the 50% to 100% damage range. If, however, we select a 37% mean-damage ratio, only 2% fall into the lowest damage class, whereas 29% fall into the highest one. (Approximately 20% of the sample will fall in the 80% to 100% damage range, which indicates partial to total collapse.) We require a large sample to determine a precise mean-damage ratio.

Like building damage estimates, estimates of the death rate--measured as a percentage of the population, based on shaking intensity and building quality--display enormous scatter. This is because many parameters, including the season, time of day, and other factors, are essential to determining loss-of-life estimates.

It is important not to jump to conclusions when developing damage scenarios. California's attenuation calculations have been used to estimate damage for earthquake-prone areas worldwide. A paper written by the United States Geological Survey 20 or 25 years ago extrapolated from damage records of the 1906 San Francisco Earthquake to arrive at a magnitude of 9.5 for the Lisbon Earthquake of 1755. Attenuation in Portugal, however, is different from that in Northern California, and the extrapolation is based on a faulty premise.

Insurance companies also need to know the average size of the area affected by an earthquake. Obviously, the larger the area, the higher the probability that more than one city is involved and the greater the probable loss. Average-size estimates are a complicated matter.

Moreover, insurers require indications of seismicity, such as seismic gaps. Swiss Reinsurance Company is interested in refining its data on seismic gaps, but this would require additional research that the company is too small to afford to undertake by itself.

If such information is compiled and supplied to insurance companies, then perhaps even less developed insurance companies, which are quite numerous even in the industrialized nations, will be able to use similar formulas to assess earthquake damage and calculate suitable rates.

Dr. Tiedemann is an engineering consultant with Swiss Reinsurance Company, the second-largest international reinsurance company in the world. He worked for many years on engineering projects in Asia and has worked with the United Nations and various governments as a senior consultant and leader of international teams of experts.

TRENDS IN WORLDWIDE EARTHQUAKE RISK TO INSURANCE COMPANIES

Anselm Smolka, Munich Reinsurance Company, Germany

I will attempt to expound on the Paleolithic stage of risk assessment in the insurance business.

The insurance industry faces two basic problems. The first is premium calculation. The second is catastrophic loss protection or, simply, preparation to withstand losses associated with a major earthquake.

Efforts to assess catastrophic earthquake losses go back to the late 1970s, when, largely as a result of the 1976 Guatemala Earthquake, Munich Reinsurance Company developed a zoning system to address earthquake insurance problems.

In order to obtain information on the values at risk, we introduced so-called accumulation-assessment zones, which show the regional distribution of insured values. We also introduced loss-accumulation zones, which define the areas affected by a particular large earthquake.

For a specific insurance market in a specific country, it is essential to get uniform information on the regional distribution of values. To this end, an organization called Catastrophic Risk Evaluating and Standardizing Target Accumulations (CRESTA) was founded in the late 1970s. CRESTA is a loose association of reinsurance companies and some primary companies with worldwide business. It has recently added some insurance brokers. CRESTA was founded to develop uniform criteria for reporting insured sums in all countries that have significant earthquake risk.

Figure IV.2 shows an example of earthquake accumulation-assessment zones for Mexico. The country is divided into 19 zones. The Valley of Mexico was divided into four specific zones because of the peculiar soil conditions there (Figure IV.3). These zones were actually determined at a time when personal computers were in their infancy; therefore, the figures show a basic approach lacking in regional detail. One of Mexico City's four zones, a zone of soft subsoil previously called Zone C, was subdivided after the 1985 earthquake. The area that was heavily affected in 1985, 1979, and 1957 was designated Zone G, and the remainder of the lake-bed zone became Zone H.

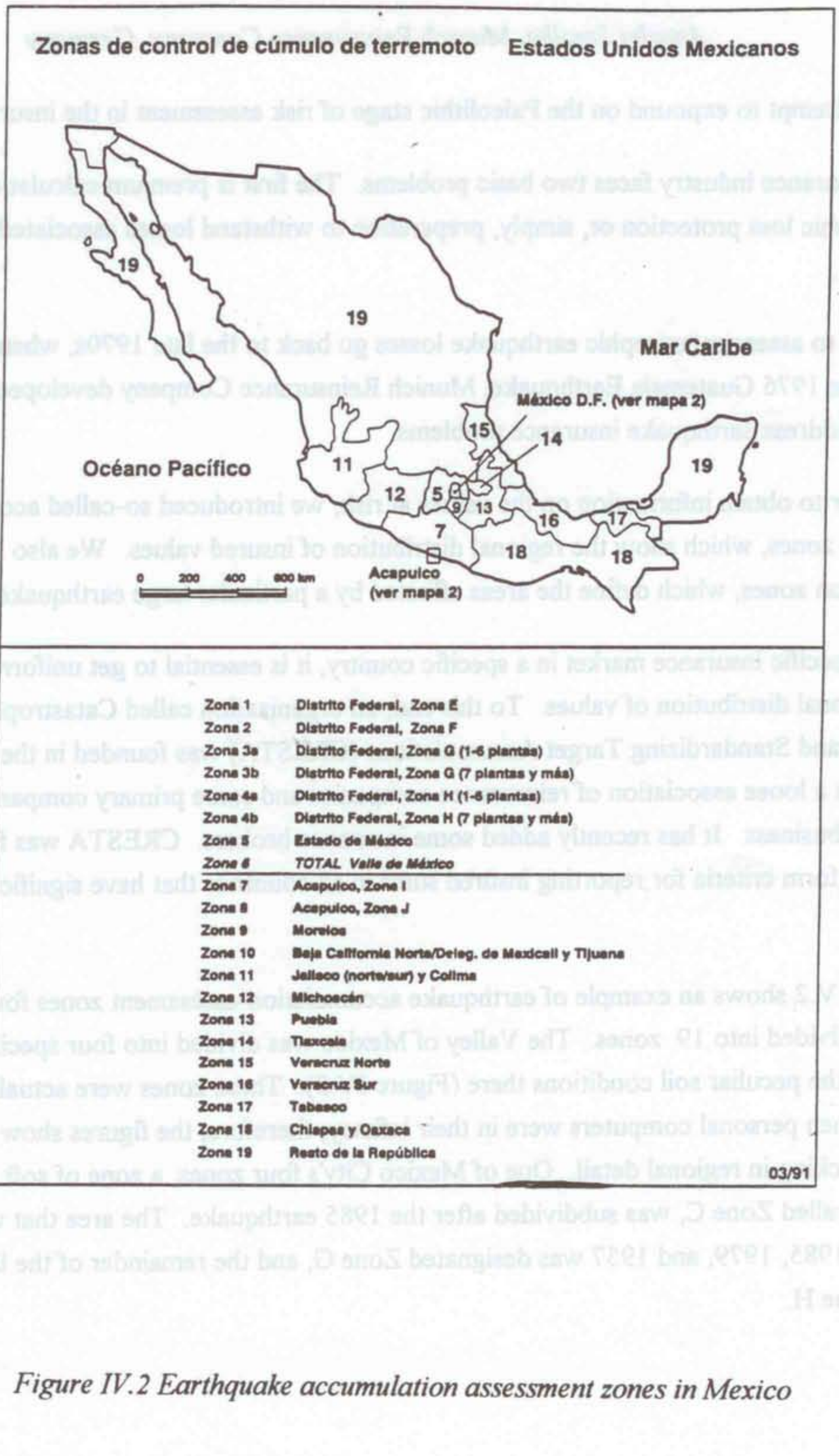

Figure IV.2 Earthquake accumulation assessment zones in Mexico

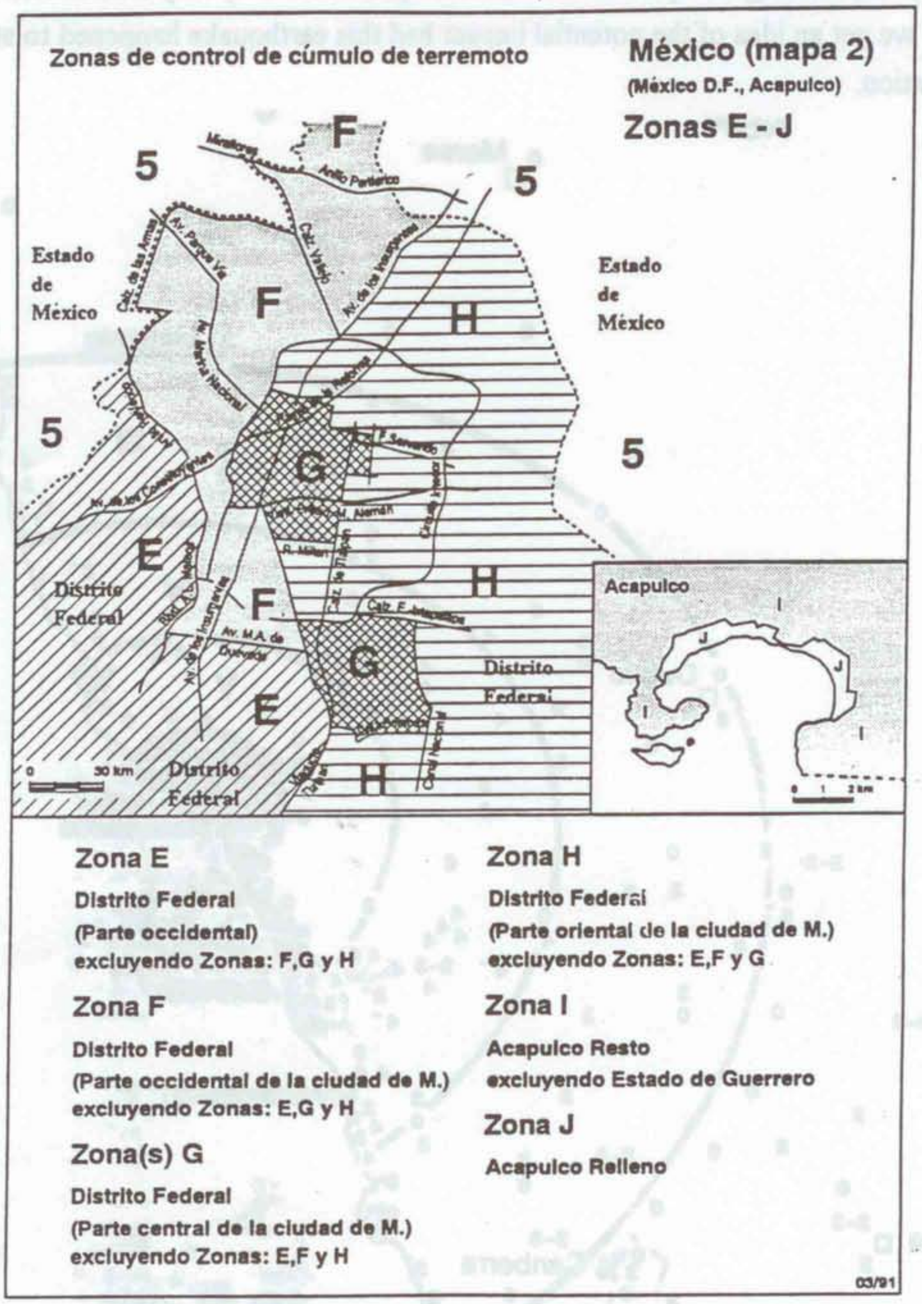

Figure IV.3 Earthquake accumulation assessment zones in the Valley of Mexico

The recent Newcastle Earthquake in Australia provides an example of loss-accumulation zones (Figure IV.4). By shifting the epicenter of this earthquake to the Sydney area or another urban area in Australia, we get an idea of the potential impact had this earthquake happened to strike a slightly different location.

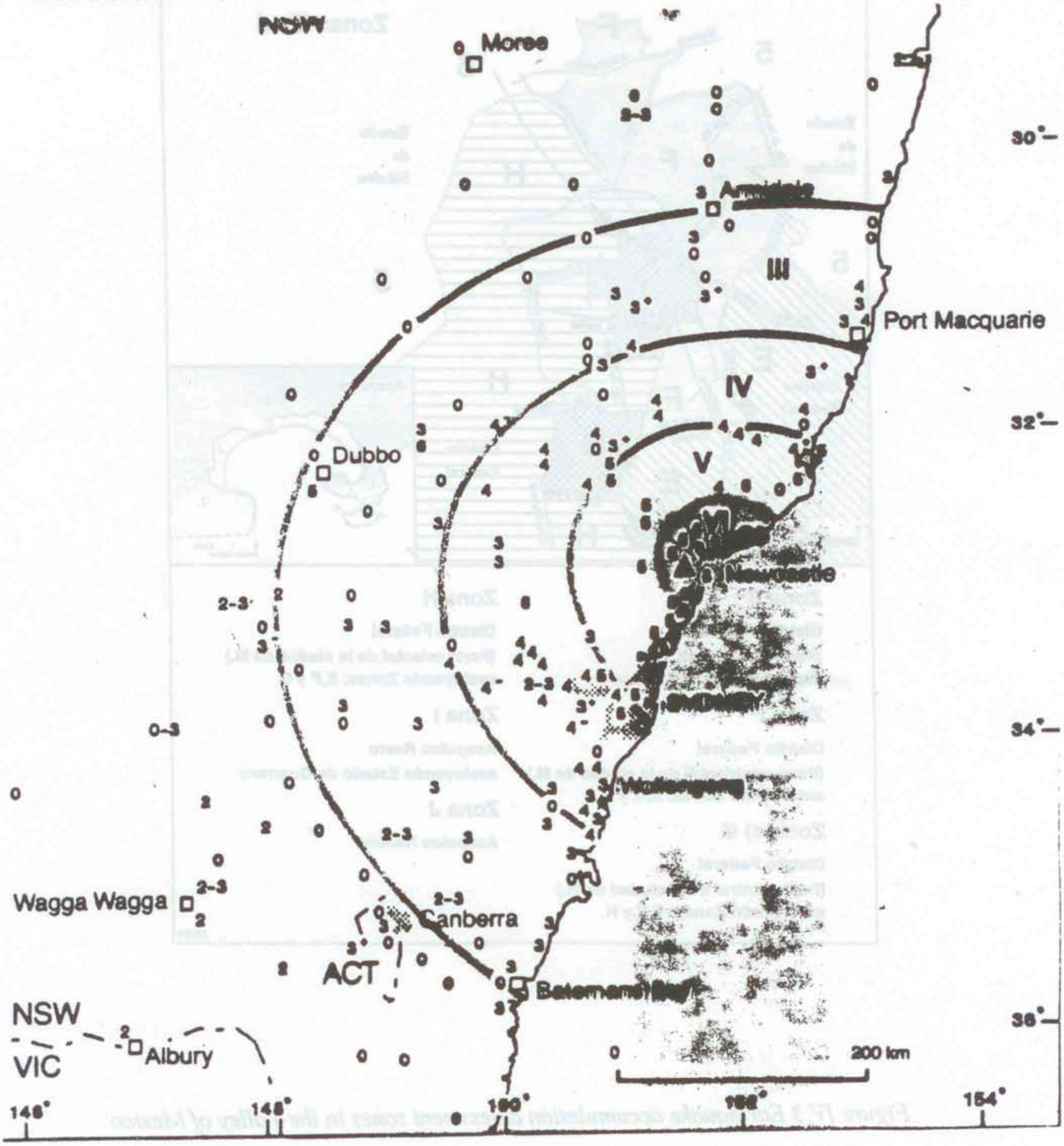

Figure IV.4 Newcastle Earthquake, Australia

Several events during the 1980s made clear the need for more details about regional distributions of insured values. The single most significant of these events was the Mexico City Earthquake of 1985. Table IV.2 shows the geographical loss distribution for that event based on insured damage. Ninety percent of the total insured losses were concentrated in a single zone, Zone C, of Mexico City. Ninety percent of that figure was concentrated in what since 1985 has been called Zone G; 2.5% of the losses were in the rest of the Valley of Mexico, and 7.5% were in the rest of the country, primarily on the Pacific coast.

Area	Distribution of claims (%)	Net claims rate (%)
Mexico City Zone "C"	90	4.5
Rest of Valley	2.5	0.1
Rest of Mexico	7.5	0.07

Table IV.2 Geographical loss profile, Mexico earthquake, 1985

Figure IV.5 shows the total losses caused by earthquakes in the last three decades. The thick black line gives the average dollar losses for each decade and shows a clear trend of increasing costs over time. Losses are listed in indexed figures tabulated in 1991 values. Solid bars indicate insured losses. These were minimal in the 1960s and only become a factor in the 1970s. The figure for total insured loss for the year 1976, which saw five large earthquakes worldwide, shows that only an extremely small fraction of the total loss was insured. The decade of the 1980s showed an increasing trend toward insured earthquake losses.

Several trends in recent decades have contributed to the increase in dollar losses: increasing values; increasing concentration of people in conurbations; increasing significance of consequential and infrastructure losses in the developing countries; and increasing insurance density, or numbers of people insured against earthquakes.

Generally, the focus of attention shifts with the increasing degree of a country's development from loss of life to monetary loss. Of course, what interests insurance companies primarily is monetary loss. On the other hand, the focus also shifts from large-scale assessment to assessment of smaller-scale areas because the highest loss potential is located in heavily developed and industrialized urban regions.

I have observed several trends of likely future developments in the insurance sector. The increasing threat of catastrophic earthquake damage will unavoidably cause some capacity problems following major events. There were horrible losses to the insurance sector due to natural catastrophes in the 1980s, and we can already observe that not as much capacity is available now as

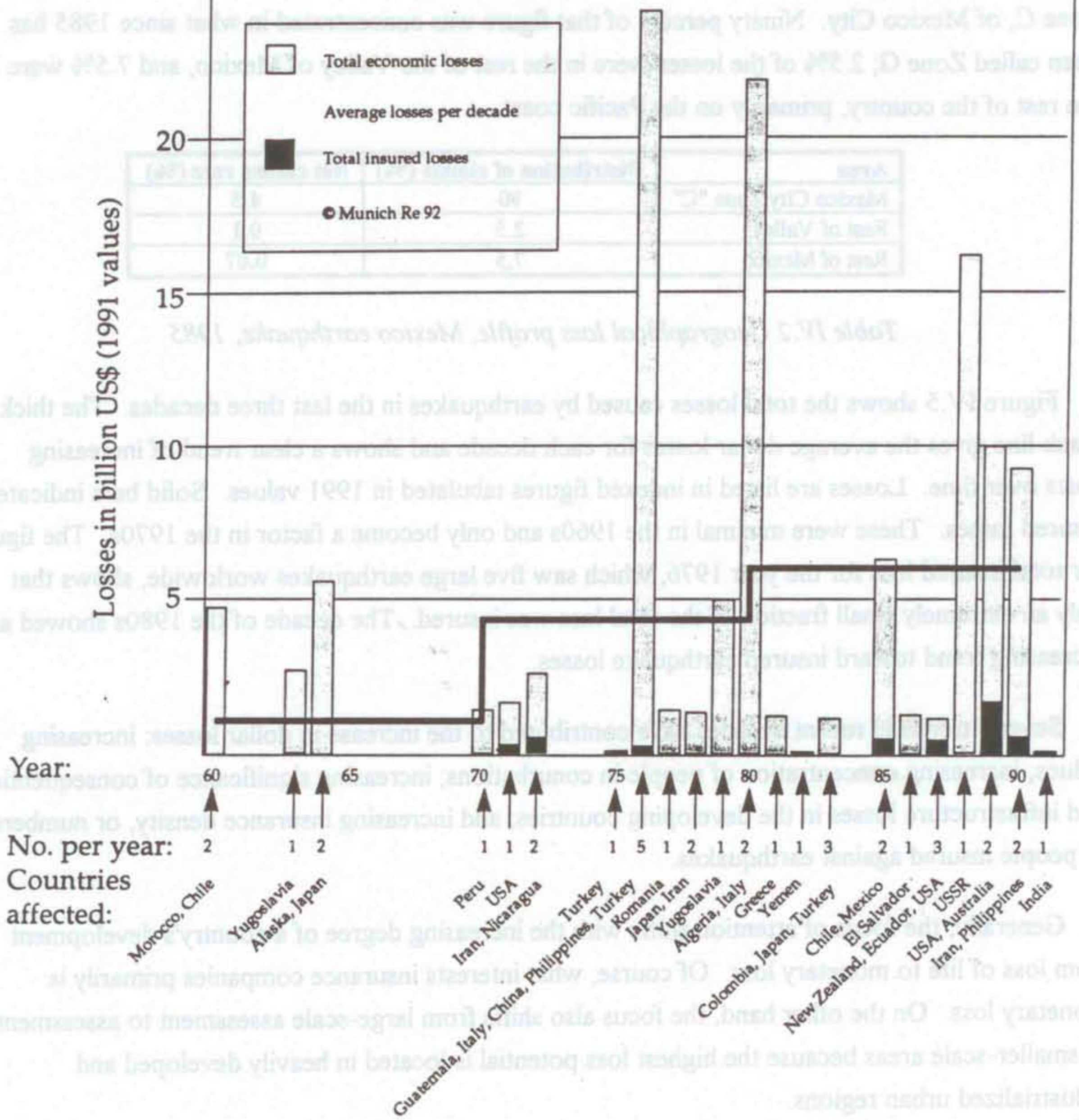

Figure IV.5 Economic and insured losses due to great earthquakes, 1990-1991 in earlier years. Loss potential now tends to be concentrated in pockets, as was seen in the Mexico City, Loma Prieta (Northern California), and Philippines earthquakes.

Probable maximum loss (PML) estimations must be improved in order to generate better-quality data. Microzonation would be a useful tool for improving PML estimates and thereby diminishing the degree of uncertainty in loss estimates. These are among the changes that would be necessary to optimize existing insurance capacity for the future.

There is obviously a need for risk data that are, on one hand, accessible and comprehensible to the manager or decision maker of a company and, on the other hand, sufficiently detailed to give a realistic picture of the situation. Earthquake scenarios are certainly an efficient tool for presenting risk data in a clear and easily comprehensible form. Several important qualifications to this statement must, however, be observed.

Scenarios should not present general solutions, but should instead specify problems and raise salient questions. After the Mexico City earthquake, I had a chance to analyze earthquake-related insurance losses company by company. The average percentage of loss suffered by different companies varied by a factor of 10. There is nothing approaching a general PML for a given insurance market, since PML for a particular earthquake may vary widely from company to company, depending entirely on the composition of that company's portfolio. But if the manager of an insurance company is asked what results he or she would like to see from an earthquake damage scenario, in 95% of the cases the manager will ask to see a PML figure for the area in question. The manager may not know exactly what is meant by that and will most likely be unaware that generalized PML figures are not very useful.

Earthquake damage scenarios must be sold to, and accepted as a useful tool by, the user. Selling to the user is just a starting point, however. A scenario should ideally serve as the basis for decisions to reduce future losses. Therefore, the implicit message that scenarios carry about needed mitigation measures must also be sold to the user. Insurance companies in New Zealand have used a straightforward strategy. Based on scenario loss estimates, insurance companies there try to avoid renewing policies or writing more business in heavily exposed areas. That is, companies shift their portfolios away from these areas. This, however, is only a solution to the problem in the narrow sense of helping to ensure an individual insurance company's continuing viability. A comprehensive approach should reduce the losses themselves by using earthquake scenarios as a basis for defining risk-mitigation measures.

It is important to include probability in earthquake scenarios by specifying the probability of a specific event occurring in any given year. It is also important to keep in mind that the probability of a given earthquake occurring is quite different from the probability of a given level of earthquake damage being registered. A magnitude 8 earthquake affecting Los Angeles or any large city may cause different losses due to several circumstances. One such circumstance is the relative fire hazard. There may be big fires, for instance, that were able to spread rapidly due to the wind conditions at the time of the earthquake. Or, fires might remain a minor factor if the earthquake occurs on a still day or during a rainstorm.

Citing probability figures helps to put damage estimates into a larger context. Depending on their needs, different users will take different mitigation measures based on the hypothetical information furnished by a particular scenario. Catastrophic earthquake loss may have top priority in one country, while in another it has only secondary priority, simply because the different nations have different public policy priorities. Response measures will vary from country to country, from company to company within the insurance sector, and from country to country within the same insurance company.

The original input data for a scenario, such as subsoil zoning and vulnerability functions, must be kept available to the scenario user. That will enable the user to find his or her own specific solutions. The degree of technical expertise within insurance companies and insurance markets varies greatly. While companies like Swiss Reinsurance Company or Munich Reinsurance Company may be able to consider every possible detail regarding a set of input data, many other companies will not have the capacity to do so. Keeping the original input data available to the user leaves room for either a more thorough study of these data or a better understanding of what underlies a given figure derived from those data, such as a loss estimate.

A final point: efficient use of input data requires a level of technical expertise that users sometimes do not possess. To remedy this problem, scenario makers should try to familiarize users with relevant technical information and background. Alternatively, they could require that users demonstrate a certain level of technical expertise.

Dr. Smolka works for Munich Reinsurance Company, the largest reinsurance company in the world, as a member of the company's Geoscience Research Group. He has worked in the areas of geology, seismology, remote sensing, and natural-hazards insurance.

DISCUSSION

Haresh Shah, Stanford University, USA

Earthquake risk is assumed by insurance and reinsurance companies as well as companies dealing with mortgage-backed securities, and retirement accounts. No one party is solely responsible for our relatively poor earthquake-response capacity. Insurance companies, and financial institutions in general, have not until recently begun talking to the technologists who possess the earthquake-mitigating tools. In addition, the engineers, or toolmakers, have for their part generally been rather bad at articulating what they know. Both sides are therefore to blame.

We need better channels of communication between knowledge users and knowledge generators. Continued poor communication between these two groups may condemn large segments of the insurance community to continued reliance on the sort of archaic methods used 20 years ago. At that time, insurers would essentially wet their finger, put it in the air, see which way the wind was blowing, and then take their risk.

On a more hopeful note, some technologies in use today do take into account many of the important issues that Dr. Tiedemann eloquently raised. Certain technologies incorporate state-of-the-art uncertainty gauges and are able to handle fuzzy data.

Recently, I was in Lloyds of London and learned something about how Lloyds takes risks. Seeing how the major reinsurance companies underwrite risks was highly educational and aroused in me a sense of humility. These reinsurers, it seems, typically do not even have a clear sense of what the insurance companies are selling them. They do not know where the portfolio is or where the insured structures are located, but only that they are taking a certain percentage of risk.

Both the technologies and the aggregate data necessary to inform companies like Lloyds about the risks they are taking are available, but they are not being used. The data could be manipulated, perhaps through pattern recognition, to come up with systems by which the impact of a given disaster on a specific reinsurance company could be determined.

Earthquakes need not pose an ominous threat to the insurance industry, if only we can begin talking to each other more often and more clearly.

by Åke Munkhammar, Skandia Group, Sweden

On this point, Walter Hays of the United States Geological Survey (USGS) has started a working group for the transfer of technology between scientists and end-users, including the insurance world.

David Pugh, International Finance Corporation, USA

Dr. Smolka cited important causes of the recent rapid increases in insured exposures to earthquakes. Several other reasons for this trend have not yet been mentioned.

Financial institutions are beginning to wake up. Historically, when banks have lent money, they have asked borrowers to provide a fire insurance policy. Most people did just that and nothing more. Banks are now realizing, however, that fire is not the only catastrophe to which borrowers are exposed. They have begun telling prospective borrowers located in earthquake-prone areas that they must have earthquake insurance coverage.

A second and even more significant cause is that many countries are witnessing decreasing levels of government control over their insurance industries. This has led to severe price wars. People can now afford to buy insurance in such countries as Mexico and Chile. I would not want to discuss with either Dr. Tiedemann or Dr. Smolka what constitutes a fair price for earthquake insurance, as that is a difficult question to which I am not sure anyone knows the answer. It is probably more, however, than people are currently paying. Until recently, controlled markets in many countries were charging quite high prices for earthquake insurance. To cite one example, Mexican insurance rates have probably dropped by 80% in the last three years, and many more Mexicans are now buying earthquake insurance than ever before.

Due to these factors and those mentioned by Dr. Smolka, the exposures of the insurance companies to earthquake risks are increasing exponentially. Meanwhile, most insurance companies worldwide continue to underutilize available technical information. "Rolls Royce" protection is available from Swiss Reinsurance Company, Munich Reinsurance Company, and certain other companies, but "Trabant" protection is also easy to find. Clients must be careful where they buy their insurance and reinsurance because many companies could go bankrupt in the event of an earthquake. Munich Reinsurance Company and Swiss Reinsurance Company are to be commended for working to ensure that they will survive large future earthquakes. The fact that many insurance companies are not making this effort is cause for concern.

Anselm Smolka, Munich Reinsurance Company, Germany

To respond to Dr. Shah: while technology is available, technology is not everything. What are needed now are input data, and the current relative lack of input data is a big problem. Even in California, for instance, surface geology is still being used to establish subsoil zoning. An inadequate method is still used in what may be the most developed earthquake insurance market in the world.

Ernst Leffelaar, Cologne Reinsurance Company, Germany

Probability is a key concept. From the insurance industry's viewpoint, no loss scenario should be produced without figures stating the probability that the scenario event will occur. We must be careful to ask the right questions regarding probability, however. We could ask, for instance, what the probability is that an earthquake will occur on a certain fault. This will give one answer. Or we could ask what the probability is that Los Angeles will be affected by a Modified Mercalli Intensity VII earthquake. This is an entirely different question that will have an entirely different answer. We could ask still another question about the probability that an event will occur causing losses of a certain dimension. This will give still another response.

Probability estimates are important for public services, too. If the authorities calculate the size of the fire brigade necessary to respond to a once-in-a-thousand-year event striking Los Angeles, the level will be quite high. If, instead, they make calculations for an event likely to repeat every 25 years, a much smaller fire brigade would be sufficient. Having a clear sense of the probability of a given event can help public policy planners make informed judgments about appropriate earthquake-response preparations.

Herbert Tiedemann, Swiss Reinsurance Company, Switzerland

Unfortunately, most universities are not yet oriented toward, funded for, or interested in investigating actual earthquake losses to develop informed vulnerability functions. Consequently, we in the insurance industry often have to do this legwork ourselves. Collecting field data and developing vulnerability functions are not as academic or prestigious a job as running an elaborate computer program, but models not firmly grounded in sound data and practical experience are not useful. The insurance industry must worry about the soundness of its data because it has to put its money where its mouth is.

Dr. Smolka is right to say that far more data are needed. It is unacceptable, however, that the reinsurers and a few international insurance companies, Skandia Group, for example, are saddled with the task of collecting and analyzing data from which the rest of humanity is profiting. This is not their job, as commercial enterprises, and they have too little money and personnel to take on this giant responsibility. It would be a great service to the cause of earthquake-hazard mitigation if the data these companies have collected--much of which will soon appear in a handbook--could be critically analyzed by universities.

Insurers and reinsurers understand the language of commerce, not of science. People with a scientific background working in the insurance industry must recognize this fact and word their proposals accordingly.

Glenn Borchardt, California Division of Mines and Geology, USA

Our experience in California has shown that making probability statements is critical. The first California scenarios were developed for the northern and southern sections of the San Andreas Fault in 1982. A third was developed for the Hayward Fault in 1987. It was not until 1988, however, that the USGS published probability estimates for these faults. The northern section of the San Andreas Fault had a 5% probability, while the Hayward Fault had a 25% probability. In retrospect, it is clear that our priorities were skewed and that we should have developed the Hayward Fault scenario first.

Unfortunately, there is significant uncertainty in these figures. A good deal of work must still be done in paleoseismology--the study of prehistoric earthquakes--before establishing reliable probabilities will be possible.

SUBMITTED COMMENTS

Thomas Anderson, Fluor Daniel, Inc., USA

Efforts to include statements or definitions of uncertainty in government codes are misguided. Public code drafters, building officials, plan-check agencies, and design engineers must all employ specified, unvarying numerical values, formulas, and limits if they realistically expect their designs to be carried through to the construction phase. Uncertainty could be expressed in a parallel but separate document, as we currently do for the design basis for a project. The design basis explains how and why risk choices were made in establishing the actual fixed criteria.

David Dowrick, Institute of Geological & Nuclear Sciences, Ltd., New Zealand

For the past five years I have been studying New Zealand's 1987 Edgecumbe Earthquake, a moderate-size event for which we were able to collect a highly complete data set on damage to commercial and industrial property. Damage to buildings, building contents, and various types of equipment, stock, and manufactured goods were considered. The study dealt specifically with costs incurred by insurance organizations as a result of earthquake damage. These statistical data on property damage and insured losses can be useful to urban planners and others interested in estimating likely levels of damage or potential danger to people.

The study considered all statistically relevant factors. It considered damage in terms of building age, for instance, because the quality of a building's structure depends to a large extent on the codes that were in effect at the time it was built. It looked at buildings with different uses, including residential buildings, hotels, shops, offices, industrial buildings, and community halls, and derived statistics on the average damage ratio and probability distributions for each class. It also looked at different building materials and found that steel was the worst building material instead of the best (as is sometimes thought), since steel buildings typically sustain high levels of nonstructural damage due to their extreme flexibility. Data about property damage and insured losses, then, can facilitate efforts to predict likely levels of earthquake damage to specific structures. This information, in turn, can be used to support the efforts of people working in three key areas: minimizing casualties, minimizing damage costs, and encouraging earthquake-responsive engineering practices.

Mustafa Erdik, Bogaziçi University/Kandilli Observatory & Earthquake Research Institute, Turkey

Some insurance companies work with archaic premium rules and yet have reinsurance coverage with Swiss Reinsurance Company or Munich Reinsurance Company. Are there efforts to involve insurance companies in developing solid assessments of earthquake risk to assets?

Wilfred Iwan, California Institute of Technology, USA

Contrary to what Dr. Tiedemann has implied, the vast majority of studies on the effects of earthquakes has come from the non-insurance community, frequently from universities. He has inappropriately cast university researchers as uninterested in or overly busy for fieldwork. University researchers have actually pioneered field investigations of earthquake damage and its causes.

Ernst Leffelaar, Cologne Reinsurance Company, Germany

Return periods must be taken into account in loss scenarios. As a general rule, all catastrophes have a common behavioral pattern: the more severe the event, the less often it occurs. This pattern applies to earthquakes, windstorms, and floods.

Despite the best intentions on the part of responsible authorities, it will never be possible to protect a population against a natural occurrence of maximum possible severity. A compromise must be sought, and protective measures must be found that are economically viable yet still effective. Expressed in mathematical terms, those responsible must decide on the degree of probability up to which they wish to protect the population. Nothing can relieve them of this difficult decision and enormous responsibility.

A loss scenario is intended to provide concerned authorities with an overview of the damage to be expected as a result of a natural disaster. For this purpose, we require detailed studies of both the natural phenomenon's origin and development and the objects (human behavior, buildings, infrastructure) upon which it acts.

As a rule, municipal authorities, scientists, civil engineers, and urban planners are scarcely able to communicate with one another on this subject, due to the very different fields in which they are trained. Often they are not even able to formulate relevant questions for a loss scenario to strive to answer. For example, if municipal authorities ask a seismologist how often there is an earthquake in San Francisco, the seismologist will likely present them with a tectonic map, which, on the basis of numerous faults and past earthquakes, is supposed to demonstrate that San Francisco is greatly at risk. The seismologist will indicate all earthquakes occurring in San Francisco and specify their Richter magnitude. From a scientific point of view, this type of information is undoubtedly interesting, but for the local authorities it has basically no value.

For the purposes of disaster-mitigation planning, however, municipal authorities should ask questions such as, "How often and with what degree of severity do earthquakes occur in the city limits of San Francisco?" In this context, the exact magnitudes and locations of earthquake epicenters are of no significance at all. What is important, instead, is the intensity of the earthquakes at the earth's surface and the expected frequency of such occurrences in the area under consideration. Having obtained these data from a geoscientist, the next step is to ask a civil engineer for information on the expected structural damage in the event of an earthquake with the specified characteristics. Questions about the effects of earthquakes of various magnitudes on lifelines such as electricity supply, gas supply, and water supply must also be addressed by specialists from the appropriate disciplines.

A loss scenario for an earthquake, for instance in San Francisco, should be based on several epicenters with earthquakes of various magnitudes for each epicenter. If scenario makers selected, for example, 10 different potential epicenters each with four different magnitudes ranging from 5 to 8, the model would have to simulate a total of 10 x 4 = 40 hypothetical earthquakes. Additionally, a geophysicist would have to indicate the return period, or probability of occurrence, for each earthquake. In each case, the effect of these different earthquakes on San Francisco is crucially dependent upon the earthquake's magnitude, the depth of its hypocenter, and its distance from the city. These factors must be incorporated into the scenario using the appropriate attenuation functions.

By considering a mathematical combination of all 40 model earthquakes and their frequency, or return period, it is possible to ascertain the city's earthquake hazard. In addition to its immediate usefulness to the municipal authorities and others, this information provides a starting point for further studies, such as expected damage ratios for buildings. One should strive to obtain the curve shown in Figure IV.6.

On the basis of these findings, the municipal authorities must decide, for example, how many hospital beds are to be made ready in order to cope with a once-in-a-century event. If they base their decision on such an event, then they must recognize that they are not prepared for a once-in-a-millennium event and must draw up supplementary rescue measures for the resulting surplus of injured persons.

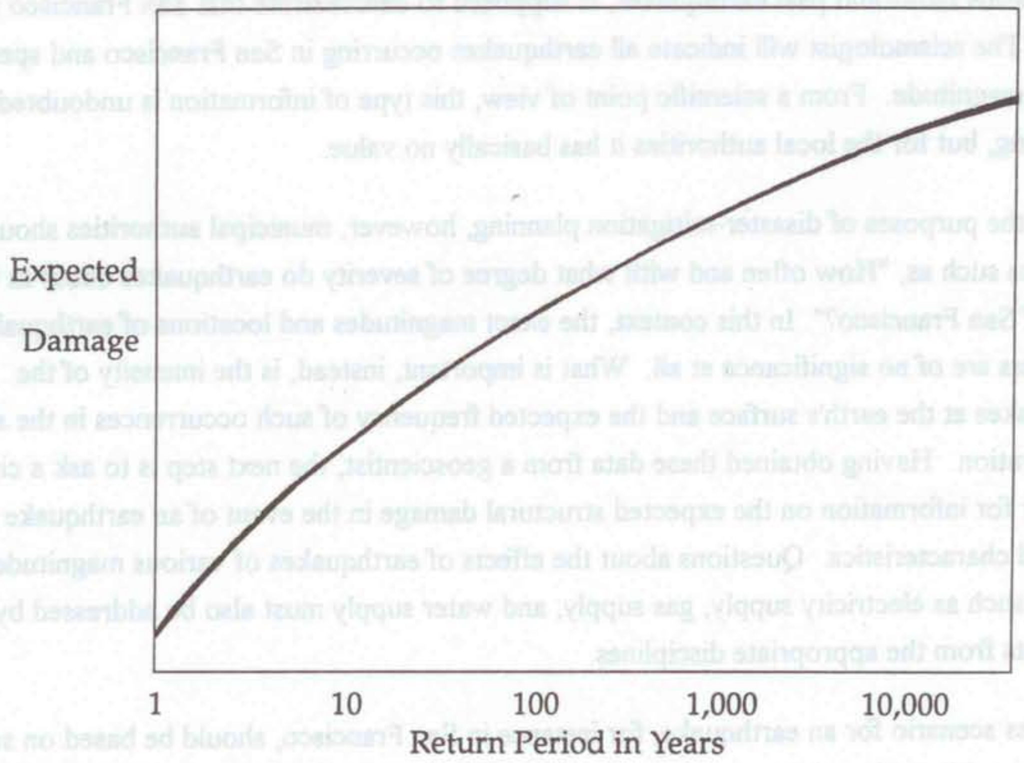

Figure IV.6 Frequency affected by earthquakes of differing severities (any earthquake - prone city)

Similarly, insurance companies need to know how much reinsurance they should buy in order to cover losses associated with various potential earthquakes. In reaching this decision, it is important to know how often, or with what level of probability, an event of a given size occurs. If an insurer equips him- or herself with enough reinsurance to cover the once-in-a-century event (probability = 0.01), the insurance company's shareholders must realize that in the event of, for instance, a once-in-three-centuries event, they will have to make a capital injection to keep the company afloat.

Mario Ordaz, Centro Nacional de Prevención de Desastres (CENAPRED), Mexico

I am curious about the possibility of using insurance policies as tools for land-use planning. Are there any particular examples of this being done?

PART V: EARTHQUAKE DAMAGE SCENARIO METHODS

The following four papers present alternative perspectives on earthquake damage scenario methods. Other reports about scenario methodologies not appearing in this volume include "A Study of the Economic Impact of a Severe Earthquake in the Lower Mainland of British Columbia," by Munich Reinsurance Company (1992); "Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States," by the Applied Technology Council (1991); and "Special Publication for Seismic Microzoning Technique: A Case Study for Kawasaki City, Japan," by OYO Corporation (1988).

PREPARATION AND USE OF EARTHQUAKE PLANNING SCENARIOS

Glenn Borchardt, California Division of Mines and Geology, USA

1. INTRODUCTION

Californians can expect the next few decades to produce several major earthquakes in large urban areas along the San Andreas fault system (WGCEP, 1990). Destructive as these events may be, there are numerous ways to reduce their effects. State residents have learned to build with wood and steel instead of stone or bricks. They bolt their houses to foundations and their bookshelves to walls. Public agencies are also preparing for the inevitable. Advanced planning by state and local agencies will be critical in reducing the death, injury, and destruction.

The infrastructure consists of "lifelines," critical public facilities such as highways, bridges, railroads, airports, hospitals, marine installations, electrical transmission systems, and pipelines for water, natural gas, and other petroleum products. If we could predict which lifelines will survive, we could prepare emergency plans to cope with those that will not. Search and rescue efforts implemented during the critical first hours will be smoother if we have some idea of what to expect.

Each earthquake teaches us a lesson, pointing out with stark realism the vulnerabilities of the infrastructure.

Thus, much of the damage to lifelines caused by the magnitude 7.1 Loma Prieta earthquake of October 1989 was expected (Figures V.1-V.3) and much was not (Figures V.4 and V.5). The knowledge gained from each earthquake helps us to prepare for the next. How should we organize such hard-won information? How should we put it into action?

One practical and effective method is to develop earthquake planning scenarios, hypothetical yet realistic assessments of lifeline performance for particular earthquakes. Scientific-based and engineering-based earthquake planning scenarios are important tools for planners because (1) they approximate the effects of earthquakes on lifelines; (2) they provide important insight for use in earthquake-preparedness planning by emergency-response agencies and for law enforcement, fire fighting, medical, and search and rescue services; and (3) they are used in response exercises that simulate emergency decision making.

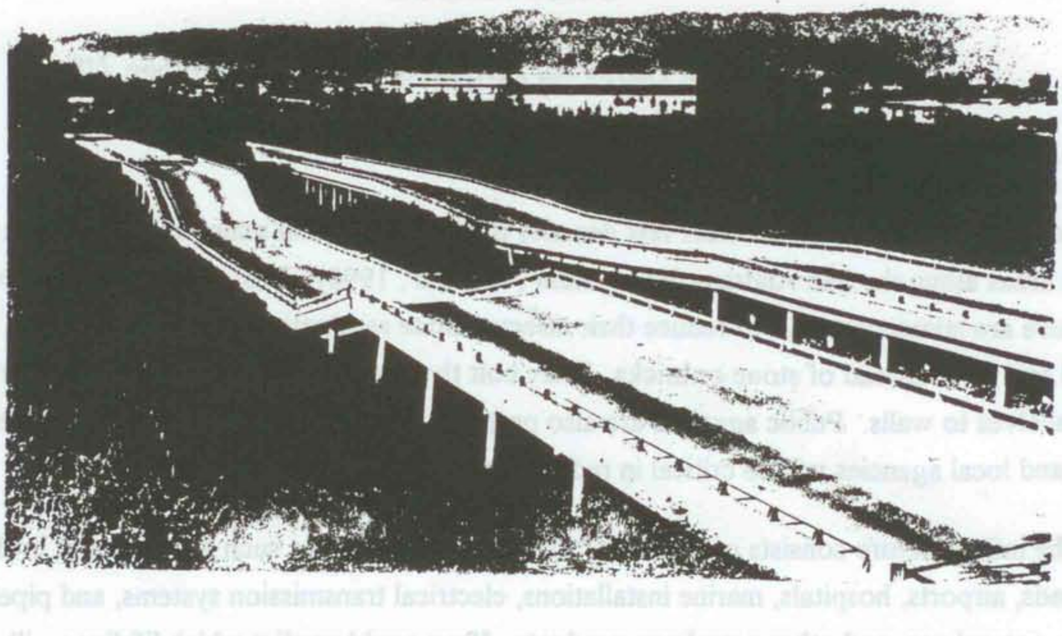

Figure V.1 Collapsed portion of State Highway 101, Pajaro Valley

Figure V.2 Liquefaction damage, Port of Oakland

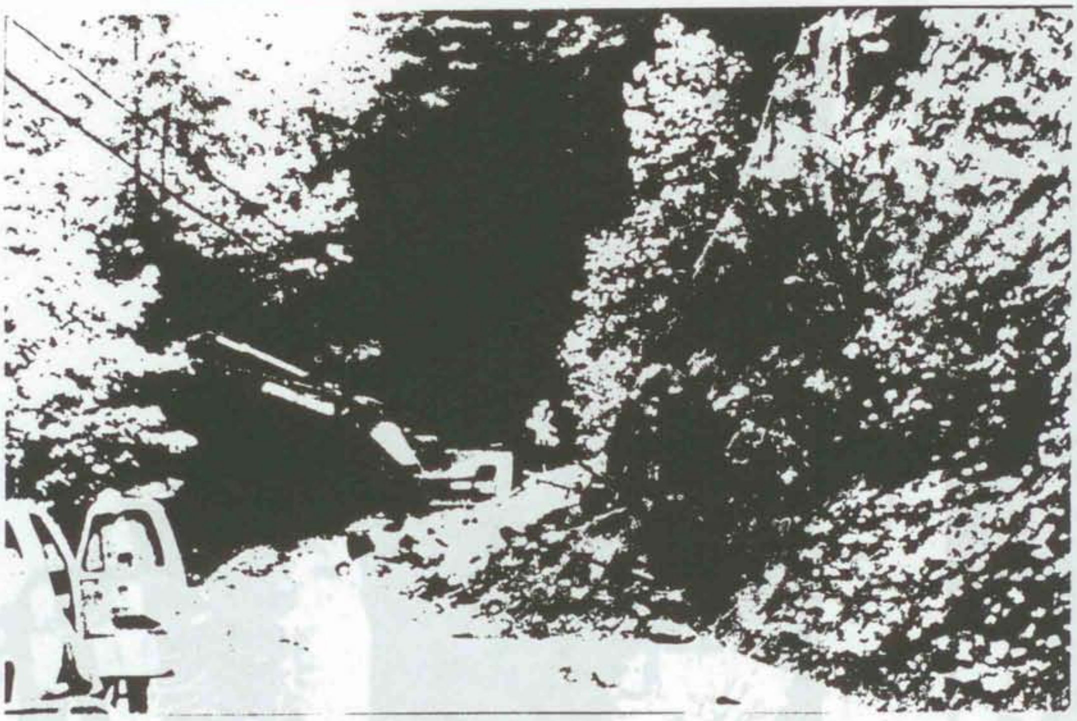

Figure V.3 Landslide blocking Highway 17, Santa Cruz Mountains

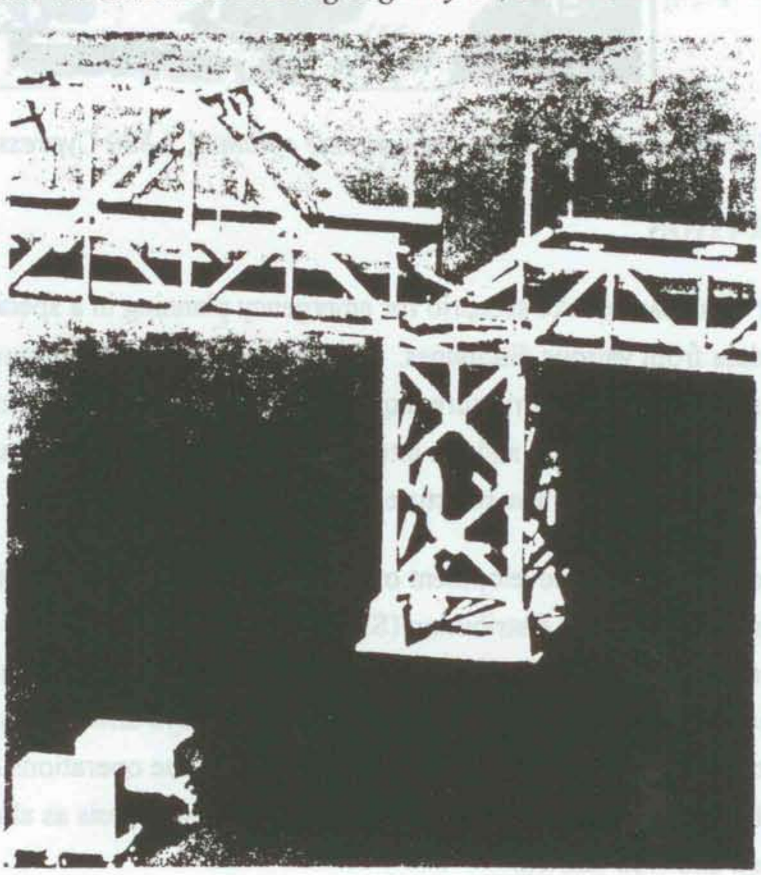

Figure V.4 Collapsed upper section of the San Francisco-Oakland Bay Bridge

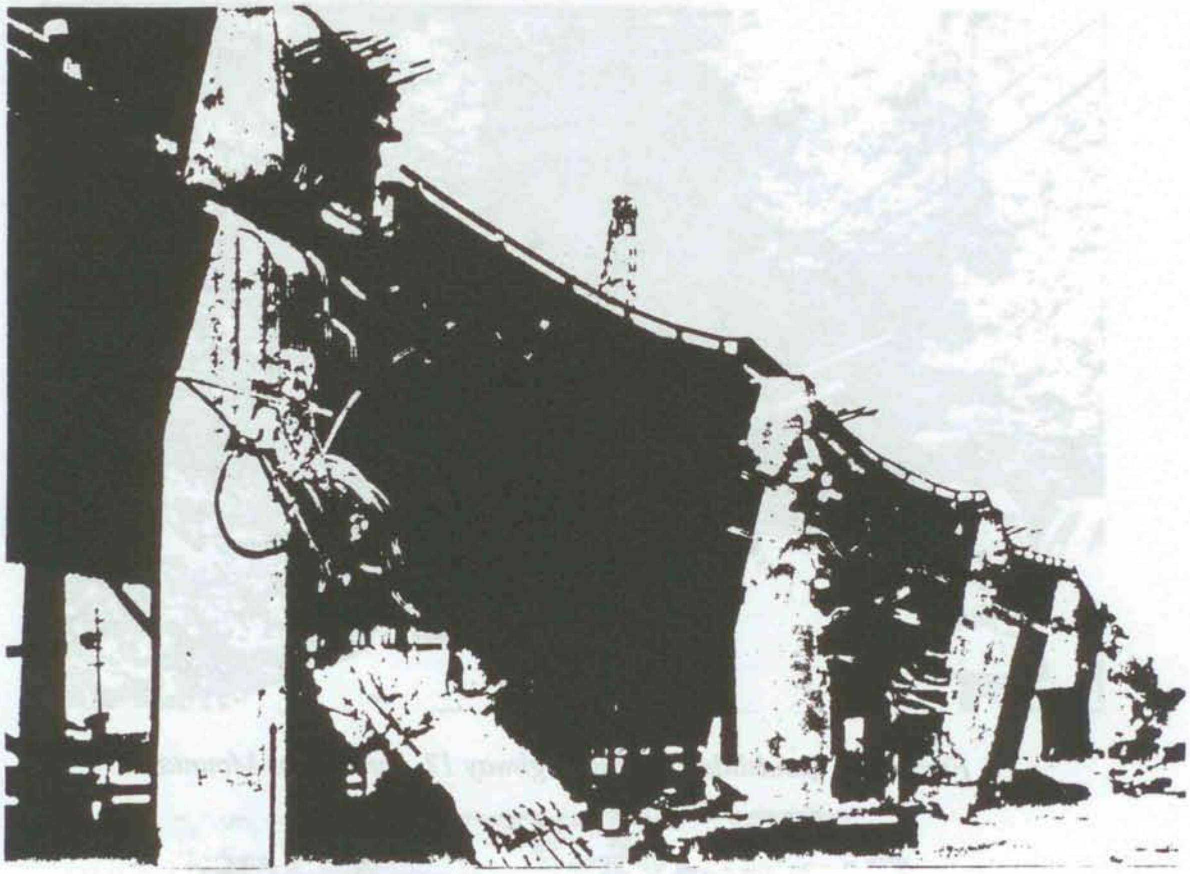

Figure V.5 Collapsed steel rebar and concrete columns, I-880 Cypress structure, Oakland

2. PREPARATION

Development of an earthquake scenario for emergency planning in a specific area incorporates vast amounts of data from various disciplines. The ability of a lifeline structure to withstand the effects of earthquake shaking, fault rupture, liquefaction, landsliding, and associated ground failure largely depends on the site geology and the intensity of earthquake shaking, as well as the design and engineering characteristics of the structure.

There are two phases in the development of an earthquake planning scenario. Phase I is the preparation of a seismic intensity distribution (SID) map showing the relative degree of shaking and the areas of ground breakage. Phase II is the preparation of lifeline maps annotated to show the hypothetical status of the infrastructure during the first three days after the earthquake. Only three days are addressed because the effectiveness of search and rescue operations diminishes after a day or two. Inevitably, postdisaster reality supplants predisaster hypothesis as alternative lifelines become established and well-known.

2.1 Scenarios

Five scenarios have been published by the Division of Mines and Geology (DMG) for expected major earthquakes in densely urbanized regions of California (Figure V.6) (Davis and others, 1982a, 1982b; Steinbrugge and others, 1987; Toppozada and others, 1988; Reichle and others, 1990). Each DMG scenario includes maps showing the expected distribution of earthquake damage to lifeline facilities based on seismology, geology, and engineering considerations. The two phases of the development and preparation of a scenario are described below.

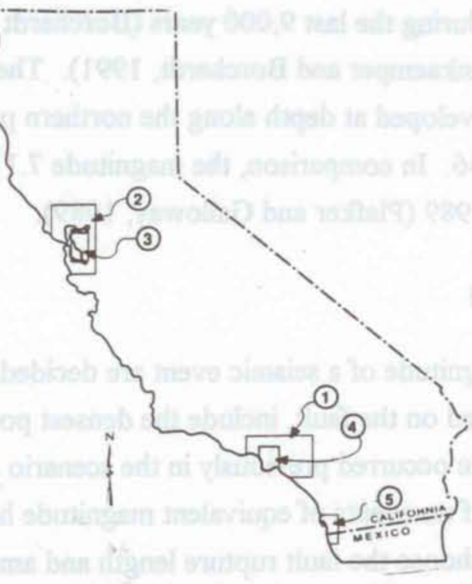

Figure V.6 Areas of DMG earthquake planning scenarios (as of 1992)

3. PHASE I: PREPARATION OF THE SID MAP

3.1 Earthquake Scenario Selection

The first phase of scenario development includes choosing an earthquake-prone urban area based on its earthquake history (Toppozada and others, 1986; WGCEP, 1990). Although there is extensive historic documentation of earthquakes in California during the past 200 years, additional data are required to select a likely event. Paleoseismology, a recently developed branch of seismology, includes various methods of investigating the movement along major fault zones over geologic time. Fault slip rates, the amount of displacement from specific earthquake events, and the recurrence interval of earthquakes have been determined for some fault segments in California.

In his classic study, Sieh was able to date offset peat and sediment layers, obtaining a detailed record of the last dozen events on the southern San Andreas Fault (Sieh, 1984). Magnitude 8 events, like the 1857 Fort Tejón Earthquake, seem to occur at intervals of 145 $\pm$ 8 years. Other faults, particularly those in the eastern part of the state, have event recurrence intervals that are 10 times longer. For example, investigations of offset soils and volcanic ash along the Honey Lake Fault in northeastern California showed that only four magnitude 7 events occurred there during the last 7,800 years (Wills and Borchardt, 1990).

Even where fine stratigraphic detail is unavailable, information about the slip rate and relative movement along faults over geologic time can sometimes be determined. For example, cooperative studies by DMG and U.S. Geological Survey scientists show that the Hayward Fault had a slip rate of between 5.5 and 9 mm/yr during the last 9,000 years (Borchardt and others, 1987; Borchardt, 1988a; Borchardt, 1988b; Lienkaemper and Borchardt, 1991). These investigations infer that up to 4.6 feet of strain may have developed at depth along the northern part of the fault since the last major earthquake there in 1836. In comparison, the magnitude 7.1 Loma Prieta Earthquake resulted in 6.5 feet of slip in 1989 (Plafker and Galloway, 1989).

3.2 Developing SID Maps

Once the location and magnitude of a seismic event are decided, a SID map is prepared. Planning areas, usually centered on the fault, include the densest population and the most significant lifelines. If a major earthquake occurred previously in the scenario area, its characteristics are incorporated into the study. If no events of equivalent magnitude have occurred in the area, data from other areas are used to choose the fault rupture length and amount of surface displacement. For example, a magnitude 7.0 event typically causes up to 3 feet of ground displacement along a fault segment over a distance of at least 20 miles.

Unfortunately, the estimation of regional patterns of seismic intensity is not yet as accurate as scientists and engineers would like it to be. Each type of structure responds in a unique way to seismic motion. At present, it is not practical to develop the necessary intensity scale for each type. Nevertheless, researchers have found that the Modified Mercalli Intensity (MMI) scale is an effective tool for generalizing earthquake intensity at any location (Table V.1).

Scenario SID maps display intensity, fault rupture, and ground failure information. Some features are developed especially for the scenario, while others depend on earlier studies.

Developing a SID map begins with a computer-generated, isoseismal contour map centered on the scenario fault rupture (Evernden and Thomson, 1985). Each contour on an isoseismal map shows the area that would undergo the same amount of earthquake-shaking intensity. Assuming perfectly uniform bedrock geology, shaking will decrease with distance. Successive contours from the proposed fault rupture zone indicate areas that hypothetically undergo progressively less shaking.

MODIFIED MERCALLI INTENSITY SCALE

The severity of an earthquake is described by the Modified Mercalli Intensity scale introduced in 1931 by American seismologists Harry Wood and Frank Neumann. They established 12 categories of intensity. The following is a condensed version:

I	Not felt except by a very few under favorable circumstances
II	Felt only by a few persons at rest, especially on the upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but not necessarily recognized as an earthquake. Standing cars may rock slightly. Vibration similar to that of a passing truck.
IV	If during the day, felt indoors by many; outdoors by few. If at night, few awakened. Dishes, windows, and doors rattle, walls creak. A sensation such as a heavy truck striking the building. Standing cars rock noticeably.
V	Felt by nearly everyone, many awakened. Some dishes and windows broken, some plaster cracked, unstable objects overturned. Disturbance of trees, poles, and other tall objects. Pendulum clocks may stop.
VI	Felt by all, many people run outdoors. Fallen plaster, minor chimney damage. Movement of moderately heavy furniture.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings. Panel walls thrown out of frame structures. Chimneys, factory stacks, monuments, walls, and columns fall. Heavy furniture overturned and damaged. Changes in well water. Sand and mud ejected in small amounts. Persons driving cars are disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great damage in substantial buildings, which suffer partial collapse. Buildings shifted off foundations, ground noticeably cracked, underground pipes broken.
X	Some well-built wooden structures destroyed, most masonry structures destroyed, foundations ruined, ground badly cracked. Rails bent. Considerable landslides from steep slopes and river banks. Water splashed over banks. Shifted sand and mud.
XI	Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipes out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Total damage. Waves seen on ground surfaces. Lines of sight and level are distorted. Objects thrown into the air.

Wood, H.O., and Neumann, Frank, 1931, Modified Mercalli Intensity scale of 1931: Bulletin of the Seismological Society of America, v.20, p.277-283.

Table V.1 Descriptions of Modified Mercalli Intensity (MMI) scale intensity categories

Rock types and their respective correction factors illustrate how the underlying geology affects earthquake shaking. These correction factors are added to seismic intensities calculated for well-consolidated unweathered bedrock.

Rock Type	Correction Factor for Seismic Intensity
Instrusive igneous and metamorphic rocks	0.0
Volcanic rocks	0.3
Miocene nonmarine sediments	1.3
Miocene marine sediments	1.5
Pliocene and Pleistocene sediments	1.8
Holocene sediments	2.0

Table V.2 Seismic intensity correction factor, by rock type

3.3 Geologic Map

An accurate geologic map is essential to scenario preparation. The geology of an area is never uniform. For most structures, earthquake damage is usually greater on soft sediments than on hard bedrock. In developing an intensity map, it is estimated that structures on young unconsolidated sediments, for example, will incur damage described by intensities 2 units higher than those on intrusive igneous rocks (Table V.2). Therefore, within 5 miles of the fault rupture of a magnitude 7 earthquake, the MMI is estimated to be VII in well-consolidated bedrock and IX in soft sediments.

The isoseismal contour map is typically developed by DMG at a scale of 1:100,000. A composite geologic map at this scale is used to modify the isoseismal contour map in order to account for differences in the geology. The completed SID map (see page 211) also shows areas likely to suffer permanent ground breakage such as fault rupture, liquefaction, and landslides. These areas will produce MMIs up to XII that cannot be predicted by the computer program generating the isoseismal contour map.

Fault Rupture. The scenario postulates a specific rupture along mapped fault traces shown on the 1:24,000-scale maps that are produced as part of DMG's Alquist-Priolo Special Studies Zones fault mapping project (Hart, 1988).

Liquefaction. Three conditions are present in areas where liquefaction is shown on scenario maps: (1) a high water table, (2) layers of loose sand, and (3) earthquake shaking of sufficient intensity and duration. Flat-lying areas having shaking intensities greater than VI generally satisfy the third criterion. Alluvium with groundwater within 10 feet of the surface is highly susceptible to liquefaction, while alluvium with groundwater deeper than 30 feet below the surface is not.

Landslides. Because few existing maps delineate areas subject to seismically induced landsliding (SIL), maps showing areas of general susceptibility to climatically, as well as seismically, induced landslides are used in scenario preparation. Where landslide maps are not available, topographic maps are used to delineate areas of weak rock having slopes greater than 30%. Future scenarios will subdivide SIL into at least two categories: falls and slides. Falls dominate on slopes greater than 70%, whereas slides dominate on slopes between 30% and 70%. The distinction is important because falls damage lifelines from above and slides damage them from below.

4. PHASE II: ASSESSMENT OF THE EFFECTS OF THE DISASTER ON LIFELINES

The second phase of scenario development involves the preparation of separate maps showing the likely effects of the event on each significant type of lifeline. This phase involves (1) comparing the SID map with maps showing lifelines, (2) assessing the damage expected at the vulnerable points of specific lifelines, and (3) projecting the performance and operational use of each lifeline system during the first three days following an earthquake.

For example, in DMG's Southern California Newport-Inglewood earthquake planning scenario, some electrical facilities are expected to be inoperative for at least three days following a major earthquake. These facilities are in areas of high liquefaction potential within the MMI IX region of the SID map. Certain types of modern electrical substations are highly vulnerable to shaking even when liquefaction does not occur.

4.1 Lifeline Damage Assessments

Scenario damage assessments rely on observations of damage to similar lifelines exposed to comparable shaking or ground breakage during previous earthquakes. Lifeline repair times are also estimated from previous experience.

Structural engineers develop the damage estimates in collaboration with DMG earth scientists. The managers of lifelines included in the scenario are asked to review the estimates using their expertise and knowledge of specific lifelines. The combined background and experience of professionals from various disciplines significantly augment our understanding of earthquake damage expected for facilities.

5. SCENARIO USES

Earthquake planning scenarios are designed to give a realistic image of an anticipated earthquake. They teach us an important lesson: some lifeline facilities will be damaged and others will not. By pinpointing the areas where extensive damage is likely, scenarios highlight locations where lifeline facilities need special attention from emergency planners, public officials, and engineers.

Scenarios identify locations where lifelines are vulnerable so that emergency operations can cope with probable lifeline failure. Emergency plans develop contingencies based on important facts brought to light in the scenarios.

The scenarios show that major earthquakes in densely populated areas produce abundant synergistic effects. Lifeline managers must be aware of weaknesses within their own systems and know how damage to other lifelines will impact their systems. Pre-earthquake planning can be especially effective where two or more lifelines interact (such as a city water main, a state highway, and a private power line), causing normal jurisdictional lines to become obscure.

Scenarios have stimulated site-specific geotechnical reviews of existing lifeline facilities. For example, Berryman Reservoir, built in the Hayward fault zone, was reexamined by geotechnical engineers after its failure was hypothesized in the Hayward scenario. Having passed the geotechnical review, Berryman Reservoir's hypothetical failure no longer can be used for purposes of disaster-response planning.

Another example of action taken partly as a result of the pre-earthquake planning prompted by the scenarios is the deliberate lowering of the water table in the city of San Bernardino. It has been lowered to 10 feet below the surface, and long-range plans involve lowering it permanently to 30 feet below the surface--the depth beyond which liquefaction is considered unlikely.

These hypothetical scenarios provide examples of typical problems. It is up to lifeline managers to open communication links and establish political arrangements that will facilitate a swift and smooth response. Well-rehearsed managers and personnel can save many lives during the critical first hours after an earthquake.

6. CONCLUSIONS

The data presented in earthquake planning scenarios assist planners and emergency-response agencies in reducing California earthquake losses. Scenarios contain SID maps that show how various geologic units respond to earthquake shaking and ground breakage. Maps showing critical lifeline systems are superimposed on a SID map to highlight facilities likely to undergo the most damage in the hypothesized earthquake. Identifying lifelines that will be unusable following a major earthquake helps planners and emergency-response agencies to lessen the impact.

Scenarios stimulate geotechnical reviews and encourage the upgrading of certain critical structures. In addition to providing a focus for emergency planners, earthquake planning scenarios are becoming an important tool for informing the public of anticipated damaging earthquakes.

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PLANNING SCENARIO FOR A MAJOR EARTHQUAKE, SAN DIEGO-TIJUANA METROPOLITAN AREA

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Editors' note: The following is a summary of the report, "Special Publication 100," published by the California Division of Mines and Geology in 1990.

1. INTRODUCTION

Historically, the San Diego area has been relatively free from the effects of damaging earthquakes. Earthquakes occurring offshore and beneath the mountains and deserts to the east have inflicted only minor damage on San Diego. Studies by Toppozada and others (1981) and Toppozada and Parke (1982) list 13 earthquakes that inflicted at least Modified Mercalli Intensity (MMI) VI on San Diego since 1800. It cannot be assumed, however, that this historic quiescence will continue indefinitely. The Rose Canyon fault zone (which includes the Silver Strand Fault), the La Nación Fault, the Coronado Bank Fault, the Vallecitos Fault (San Miguel fault zone), and myriad smaller faults pass through, or close to, the San Diego metropolitan area. Of these, the Rose Canyon is probably the most hazardous, followed by the highly active Coronado Bank and the San Miguel fault zones.

The seismic hazard in the San Diego area is difficult to quantify. Extensive cultural development and a lack of well-dated Quaternary deposits have limited both the quantity and quality of the data relating to the more recent geologic history of the area's faults. Critical parameters, such as geologic rate and sense of movement along local faults, recurrence times of damaging earthquakes, and recency of faulting, are not well known. The recent evidence of earthquake activity on the Rose Canyon Fault within the last several thousand years (Lindvall and others, 1990) suggests that it would be prudent to assume that damaging earthquakes could occur in the San Diego area at any time.

To assist local and state emergency response planners in their preparation for a damaging earthquake, the Division of Mines and Geology has published an earthquake planning scenario for the San Diego area (Reichle and others, 1990). This information is intended for those responsible for emergency response and to facilitate both local and international efforts to prepare for such an occurrence. The scenario does not predict detailed patterns of damage that will follow the occurrence of the postulated earthquake. An assessment of the degree and types of damage to existing lifelines and other structures is placed in a regional context for general response planning purposes. The damage assessments contained in the scenario are intended for emergency planning purposes only and are not to be construed as site-specific engineering evaluations.

The data discussed in the scenario reflect conditions in San Diego in the mid-1980s. Analyses were conducted with the cooperation of the various lifeline operators. This article summarizes the scenario.

2. THE SCENARIO EARTHQUAKE

The scenario describes the regional pattern of shaking intensity, ground failure, and impacts on lifelines of a magnitude 6.8 earthquake on the Silver Strand Fault, which lies immediately offshore of the San Diego waterfront (Figure V.7). Perhaps more hazardous faults exist and could have been used for a regional planning scenario, but this scenario was developed for a particular use: international response planning, assuming an earthquake inflicts significant damage on both the San Diego and Tijuana metropolitan areas. Damage assessments of the postulated earthquake, however, are generally confined to United States facilities and lifelines.

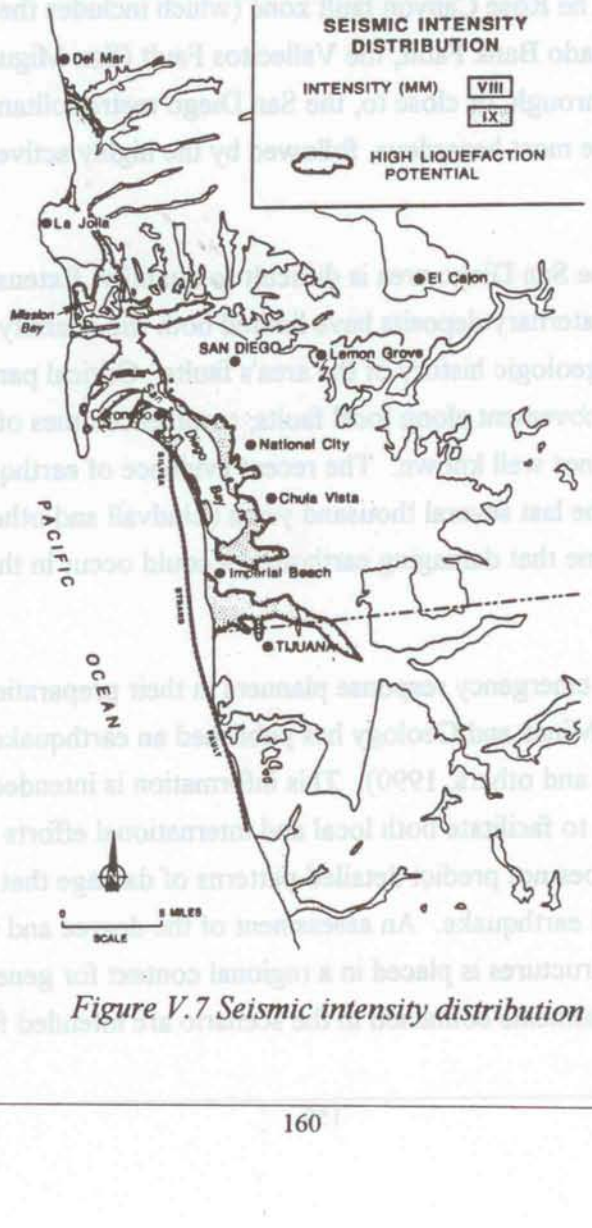

Figure V.7 Seismic intensity distribution

For the scenario earthquake, surface-fault rupture extends from the downtown San Diego area approximately 24 miles along the coast to the south, terminating approximately 16 miles south of the international border. Potentially damaging shaking continues for 10 to 15 seconds within 12 miles of the fault. Frequent aftershocks continue for several weeks, including events of magnitude 5.0 or larger.

Areas subject to shaking of MMI IX include those areas of recent (Holocene) alluvium and artificial fill between the Tia Juana River Valley (California portion) and downtown San Diego/Coronado.

Areas subject to shaking of MMI VIII extend from below Rosarito to Del Mar along the coast and as far as 23 miles inland for the poorest ground conditions. Intuition and the damage distributions from historical California earthquakes suggest that areas of firmer ground (such as Point Loma and Hillcrest) will shake differently than will areas of recent alluvium or fill (such as Mission Bay). Less damage should occur on firmer ground than on looser ground even though both lie within the area of intensity VIII.

Areas with high susceptibility to liquefaction are also shown in Figure V.7. Secondary ground failures resulting from liquefaction are expected to be common, particularly in areas of hydraulic fill in Mission Bay, Loma Portal, and along the margins of San Diego Bay. Also, areas of recent alluvium, particularly along river channels, such as the western reaches of Mission Valley and the Tia Juana and Otay river valleys, will experience moderate to severe liquefaction effects.

Seismically induced landslides pose an additional threat in those geologic conditions where both ancient and modern slides have been mapped. Areas where landslides could pose particular problems include the north side of Mission Valley, Murphy Canyon, Mount Soledad, Torrey Pines Mesa, the canyons of Otay Mesa, and portions of La Mesa.

3. IMPACT ON TRANSPORTATION LIFELINES

3.1 Major Freeway Routes

The major corridors of highway traffic in the San Diego area are illustrated in Figure V.8. They include

- Three major north-south routes: Interstates 5, 805, and 15
- Two major east-west routes: Interstate 8 and Highway 94

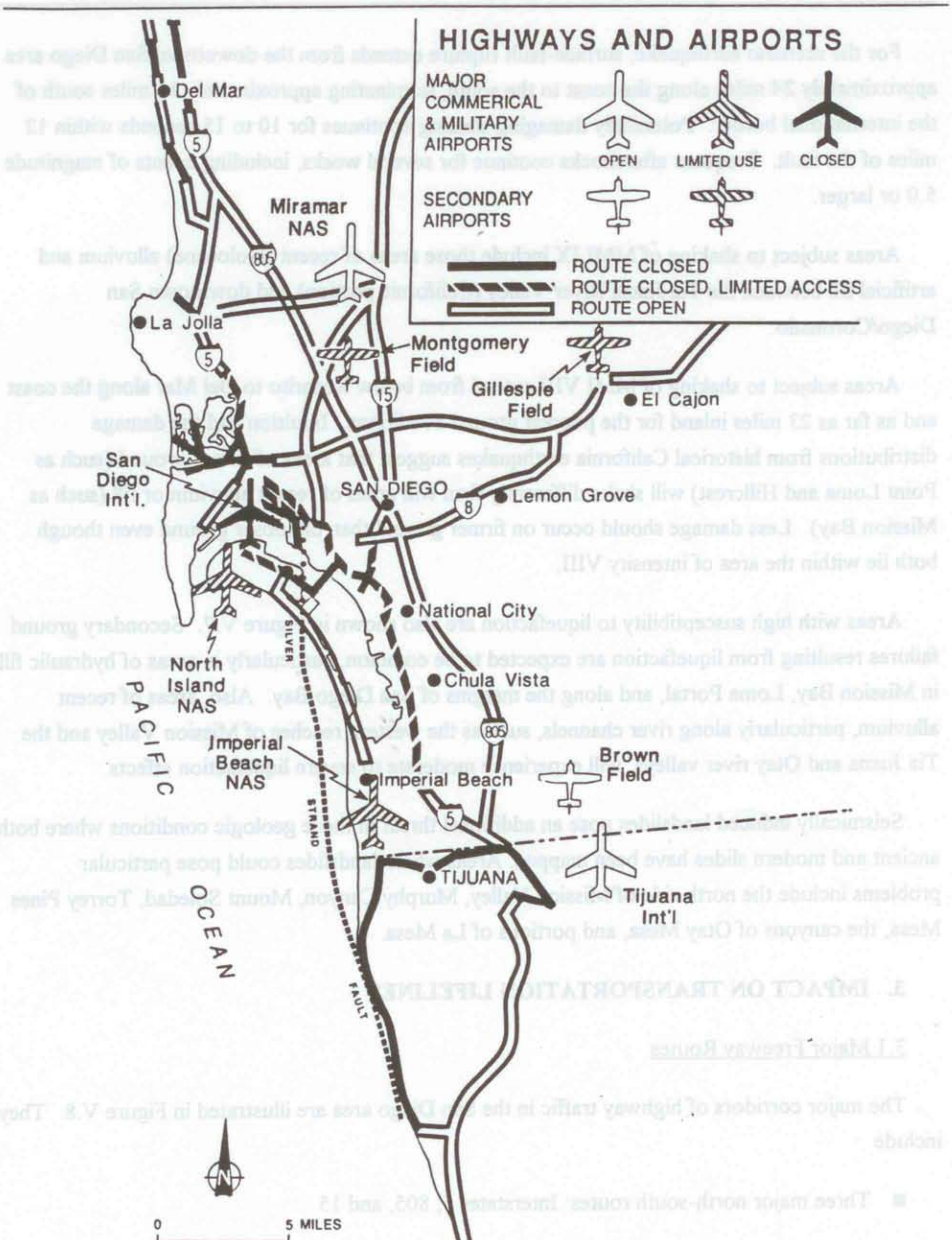

Figure V.8 Highways and airports

Interstate highways 5 and 15 lead into the area from the north. Interstate 5 leads to the Mexican border on the south and passes by both Mission Bay and San Diego Bay. Interstate 8 is the primary access to points east. Interstate 805 provides an alternative north-south corridor to the area east of Interstate 5. There are several alternative surface streets that can be used to bypass sections of the freeways, but primary access to the section of the city west of Interstate 5 in the Mission and San Diego Bay areas is limited to a few critical corridors. There are some city-maintained bridges along these critical corridors.

Damage to the freeway system in the San Diego area will result primarily from ground failure due to liquefaction in areas of artificial fill and recent alluvial deposits, and also from failure of built-up embankments for roadbeds and on/off ramps. Interstate 5 will be closed from Balboa Avenue on the north to Palm Avenue on the south. Both Interstate 5 and old Route 101 will also be closed where they cross each of the coastal lagoons south of Oceanside. Interstate Highways 805, 15, and 8, and Highways 163, 94, and 117 will be open except where they join Interstate 5. Long delays will occur along Interstate 8 and Highway 163, resulting from damage to their interchange. The Coronado Bridge will be closed. Access to Coronado on Highway 75 along the Silver Strand will be severely restricted. Although somewhat obstructed, major routes into and out of the greater San Diego area will be available. However, emergency vehicle transportation into and out of the most heavily damaged areas along the coast from Pacific Beach to Imperial Beach will be hampered by closures of all main arteries where they cross areas of unstable ground.

3.2 San Diego Border Crossing

The border station at San Ysidro, California, is the busiest port of entry in the world. It operates in conjunction with the recently constructed border station at Otay, located 5 miles to the east. The building and related facilities are maintained by the General Services Administration.

The San Ysidro Border Station houses U.S. Customs, U.S. Immigration, the Department of Agriculture, the U.S. Navy Shore Patrol, the U.S. Drug Enforcement Agency, and the International Boundary and Water Commission. It is the principal port of entry from Mexico for pedestrian and automobile traffic. The station presently operates at 70% capacity for automobiles (normally 16 of 24 primary inspection lanes are used). Truck traffic is primarily handled at the Otay border crossing.

Buildings at the border station will be severely damaged. Unreinforced masonry walls of the Old Port of Entry Building will have major structural damage or collapse, and the building will be evacuated. For planning purposes, the pedestrian bridge that spans the traffic lanes will be damaged and out of service for six months. Loss of electric power from the San Diego Gas & Electric Company (SDG&E) will occur. Emergency power generators on the site will not function. Limited power supply will not be restored for 72 hours.

The San Ysidro Border Station will be closed for at least three days for all but emergency use, because of severe damage to buildings, restricted access problems due to damaged freeway bridges, lack of power and utility services, and loss of backup emergency electric power. Damage assessment and cleanup will take 10 days to complete at the site, after which the border station will function at 50% capacity for six months and 80% for eight months before full operation is restored.

3.3 Airports

The major commercial airports in the planning area (Figure V.8) include

- San Diego International (Lindbergh Field)
- Tijuana International (General Rodriguez)

Secondary domestic airports include

- Brown Field
- Gillespie Field
- McClelland-Palomar
- Montgomery Field
- Oceanside Municipal
- Ramona

Military airports include

- Naval Air Station, Miramar
- Naval Air Station, North Island
- Naval Air Station, Imperial Beach

San Diego International Airport is located 2 miles from the center of the downtown business district. On its north, east, and west sides it is surrounded by densely populated military, commercial, and residential development. Its south side faces San Diego Bay. It is owned and operated by the San Diego Unified Port District. This airport handles approximately 11 million passengers per year, averaging 30,000 passengers per day. Usually 50 commercial passenger planes are parked overnight at the airport.

Brown Field Municipal Airport, owned by the City of San Diego, is planning for intensive emergency use in the event that the field is out of commission for an extended period. Brown Field is located 18 miles by freeway south and east of the central San Diego business district. It is approximately 1 to 1.5 miles directly north of the Mexican border and 2 miles directly north of Tijuana International Airport.

For planning purposes, San Diego International Airport will be closed for all but emergency operations for two weeks due to liquefaction affecting runways, access, electric power supply, and the East Terminal building. Accessibility by way of Harbor Drive and the overpass entrance to the airport will be impaired for 72 hours because of ground failure. Alternative access routes will have to be developed.

Electric power to the airport will be unavailable for 10 days because of damage due to ground failure along the feeder line routes. Impaired electric power will affect the pumping of aircraft fuel from underground storage tanks. For planning purposes, two of the five storage tanks will be out of service, so it will be necessary to bring in fuel by tank truck to fuel airplanes directly.

Four airports in the planning area provide the 5,000 feet of runway necessary for the landing of C-130 and C-141 aircraft. Two of the four, namely San Diego International Airport and Naval Air Station, North Island, are in zones of heavy damage and potential liquefaction. The other two (Brown Field and Naval Air Station, Miramar) are located in areas not subject to liquefaction and where predicted shaking will produce minimal damage. In general, only these two can handle emergency-response operations. Performance of the lifeline systems for airport operations will be critical. The success of air operations will depend more upon the availability of electric power and fuel and the survival of critical buildings than upon the condition of the runways.

3.4 Railroads

Only the Atchison, Topeka and Santa Fe Railroad (ATSF) serves San Diego. The San Diego and Imperial Valley Railroad (SDIV) formerly extended from downtown San Diego through Tijuana to El Centro. The line has been out of service from the border town of Tecate eastward for many years due to the loss of a major bridge structure, but it is still open from San Diego to Tecate, a distance of about 25 miles.

Rail lines to San Diego cross areas of high to very high liquefaction susceptibility. Service along the ATSF line from Los Angeles can be expected to be disrupted south of Oceanside. Tracks are subject to landslide damage or dislocation due to liquefaction where they cross the coastal sloughs and along Mission Bay. For planning purposes, service will not be restored for three weeks after the earthquake. Supplies can be off-loaded at Oceanside or Escondido and trucked south, although travel will be disrupted on major freeways due to damaged bridges blocking through traffic.

The SDIV and the San Diego Trolley cross areas of high and very high liquefaction susceptibility along San Diego Bay and in the Tia Juana River Valley. Roadbed damage will prevent use of the lines from downtown San Diego to the international border for about three weeks.

In addition to the liquefaction-induced failures, landslides along coastal bluffs or in the steeply cut roadbed between Oceanside and Mission Bay might inhibit rail traffic for 72 hours or, at worst, take out the tracks. For planning purposes, the line will be out of use for seven days due to damage by landslides.

The effects of the scenario earthquakes on terminal facilities in downtown San Diego will be serious. Those terminals serving marine facilities on the east side of San Diego Bay are located in areas that will experience severe ground shaking.

3.5 Marine Facilities (Ports)

The port area under the jurisdiction of the San Diego Unified Port District includes portions of the cities of San Diego, Chula Vista, Coronado, National City, and Imperial Beach. Approximately 2.3 miles of nonmilitary berths are available at the port facilities. They are located at three principal sites: B Street and Broadway piers, Tenth Avenue Marine Terminal, and National City Marine Terminal. Virtually the entire port of San Diego is built on artificial fill. Extensive liquefaction-induced lateral spreading is possible all along the bay front. This will affect structures built behind quay walls and also approaches (road and rail) to the dock area.

The B Street Pier was constructed in the early 1920s in several phases. The Transit Shed No. 2 on the B Street Pier has been renovated to serve as a cruise ship terminal. Liquefaction will damage the B Street Pier. Pile-supported docks and piers, with the exception of the B Street Pier, should fare well, but access problems may preclude their use during the initial post-earthquake period. For response-planning purposes, it is reasonable to assume that the port facilities will not be fully usable (a fairly conservative assumption) for three days. The loss of port facilities will have only minimal impact on public welfare.

4. IMPACT ON UTILITY LIFELINES

4.1 Communications

This section deals with Emergency Broadcasting System (EBS) stations and intergovernmental communication centers that are vital to emergency services. Both the City and County of San Diego operate communication facilities for use as emergency operation centers. The San Diego County Communications Center is located at the Overland Avenue County Operations Center in a part of the city called Kearny Mesa. The facility is housed in a modified warehouse of tilt-up concrete wall and steel-frame, metal deck roof construction. The center is operated by the San Diego County Sheriff's Department. The County Office of Disaster Preparedness has its primary communications center in this facility. The City Operations Building in downtown San Diego contains the fire, police dispatch, and emergency operations center in the basement.

The County communications system for departments other than the Sheriff's (roads, utilities, etc.) operates out of the County Operations Center in Kearny Mesa. Although the facility is located in an area of MMI VII, consoles rest on a raised floor and on desks with no anchorage against lateral forces. The Office of Disaster Preparedness's communications system operates as part of "Station X," which includes the VHF two-way system to the EBS stations KKLQ and KCBQ. This broadcast equipment for the EBS is similarly desk-mounted with no anchorage against lateral forces.

It may be assumed that the microwave system will be out of use due to the effects of ground shaking on the alignment of the antennae. For purposes of the scenario, the microwave system will be no more than 20% effective for three days following the earthquake.

The City of San Diego Administration and Operations buildings are in downtown San Diego. They house fire and police dispatch and the city emergency operations center. These are located in an area of high ground shaking (MMI VIII). While damage to the buildings may not be severe enough to cause collapse, severe nonstructural damage may be sufficient to cause functional impairment.

4.2 Electric Power

SDG&E distributes almost all of the electrical power throughout San Diego County. The actual service territory, which includes southwestern Orange County, covers 4,100 square miles (double the size of the state of Delaware) and includes over 940,000 customers. Major transmission lines, power stations, and principal substations are shown in Figure V.9. Two operating power plants (Encina and South Bay) are included in the planning area.

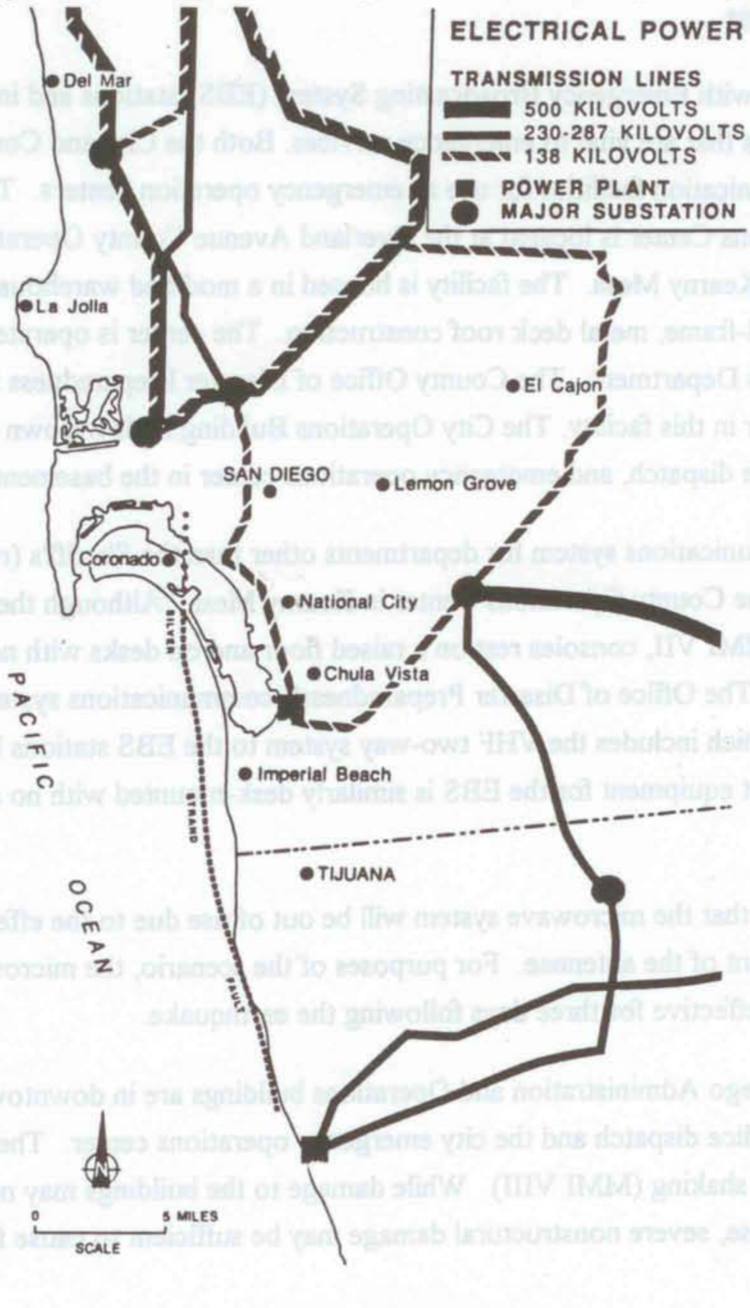

Figure V.9 Electric power

Transmission substations are essential to the routing of locally generated power and power available from outside the region affected by the earthquake. These major substations, which contain banks of switches, circuit breakers, and massive transformers, are particularly vulnerable to damage by earthquake shaking. In addition to the major transmission substations through which high voltage (greater than 230 kilovolts) is routed, many small local substations provide the vital links in the electrical power distribution network.

Transmission towers and lines are principally subject to damage through secondary effects, such as landslides and other ground failures. Conductor lines (usually distribution lines) swinging together could cause many "burn-downs."

The scenario earthquake will have a definite impact on local power-generating capabilities. In particular, damage or disruption to water supply to the power stations will have a critical effect on the power-generation capabilities. For planning purposes, the South Bay Power Plant should be considered inoperative for three days and significantly reduced in capacity for one to one-and-a-half weeks following the scenario earthquake.

4.3 Water Supply

San Diego County is a semiarid region and depends almost entirely on water imported from other areas. An adequate supply of water is critical during emergencies, not only for drinking purposes and fire fighting, but also for the operation of other utilities, such as waste water treatment.

The San Diego County Water Authority, which encompasses a 1,412.5-square-mile area, serves a population of approximately 2,106,000. It receives its supply of water from the Metropolitan Water District of Southern California (MWD) within San Diego County, approximately 6 miles south of the Riverside-San Diego county line. MWD is the sole source of the normal and supplemental water for San Diego County, accounting for 90% of the total water supply to the county (Figure V.10). The amount of water storage in San Diego County varies significantly among the different districts. The supply will last from three days to several years.

For planning purposes, it is projected that one of the five San Diego County Water Authority aqueducts in the north will fail with an estimated service outage of one to one-and-a-half months. One member agency with only a three-day supply of water will quickly become dependent on outside sources of potable water.

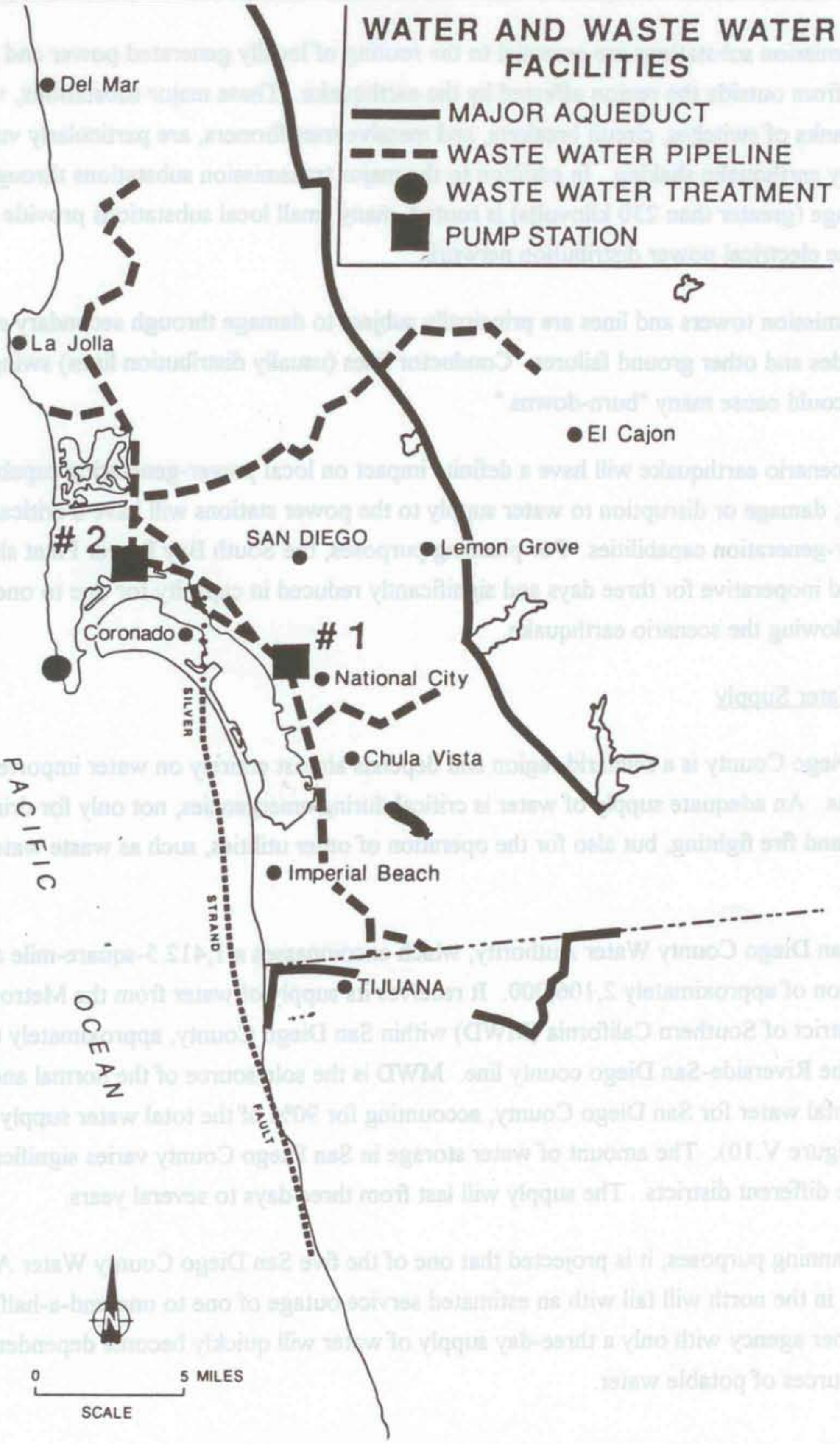

Figure V.10 Water and waste water facilities

Facility operations dependent on water, such as the Point Loma Waste water Treatment Plant (one-day supply of water storage) and the SDG&E South Bay Power Plant (two-to-five-day supply of water storage capacity) will be functionally impaired due to the lack of water.

For the scenario earthquake, the areas of the water-distribution system most vulnerable to damage are those bordering Mission Bay and San Diego Bay, coastal areas, western Mission Valley, and the Otay and Tia Juana river valleys. Mains (both primary and secondary) passing through these areas of recent alluvium and artificial fill will have several breaks per mile of pipe. Landslides in the Mount Soledad area, coastal regions of La Jolla, the north wall of Mission Valley, and the edges of Otay Mesa may also damage facilities and distribution mains. As a result, several of the above-mentioned areas will be without water for up to four weeks following the scenario event. For planning purposes, we also assume that parts of La Jolla, Pacific Beach, Ocean Beach, and Mission Beach will be without water for up to four weeks following the scenario earthquake.

Because of failures in local water-distribution systems, segments of the population will be asked to use emergency supplies, boil their water, or take other measures against contamination for one to four days.

4.4 Waste water

The metropolitan sewer system serves virtually all of the populated metropolitan area of San Diego and adjacent communities south of Del Mar, extending to the Mexican border and east as far as Spring Valley and Alpine. The principal components of the system are illustrated in Figure V.10. The system collects, transports, pumps, treats, and disposes of liquid waste from the cities of Chula Vista, Coronado, El Cajón, Imperial Beach, La Mesa, National City, and San Diego, and from the Lemon Grove, Montgomery, Orlando, and Spring Valley sanitation districts. The city also has an "emergency" connection to Tijuana. The total flow of waste liquid, all of which is treated at the plant on Point Loma, is currently about 180 million gallons per day.

For planning purposes, the flow capacity of the collection system carrying waste water to the sewer system will be reduced by 50%, and 50% of the service area will be nonfunctional. The main sewer line along San Diego Bay will be out of service for six weeks. Rupture of the tunnel below the streets of downtown San Diego will take it out of service for four months, during which time raw sewage will discharge into San Diego Bay. Pumping Station No. 2, the most vital spot in the entire system, will be functionally impaired for 45 days.

As a result of the anticipated damage to the San Diego metropolitan sewer system described above, the waste water connector line from Tijuana will be interrupted for 60 days before normal service is restored.

4.5 Natural Gas

Three transmission pipelines convey natural gas to the San Diego area from the north (Figure V.11). Two are located inland, running along the mesas. These will not be seriously affected by the scenario earthquake. The third runs along the coast and crosses several areas of high to very high liquefaction susceptibility. This pipeline will be damaged by lateral spreading at Soledad (Sorrento) Valley and by landslides along Torrey Pines grade, and will be out of service for more than 72 hours.

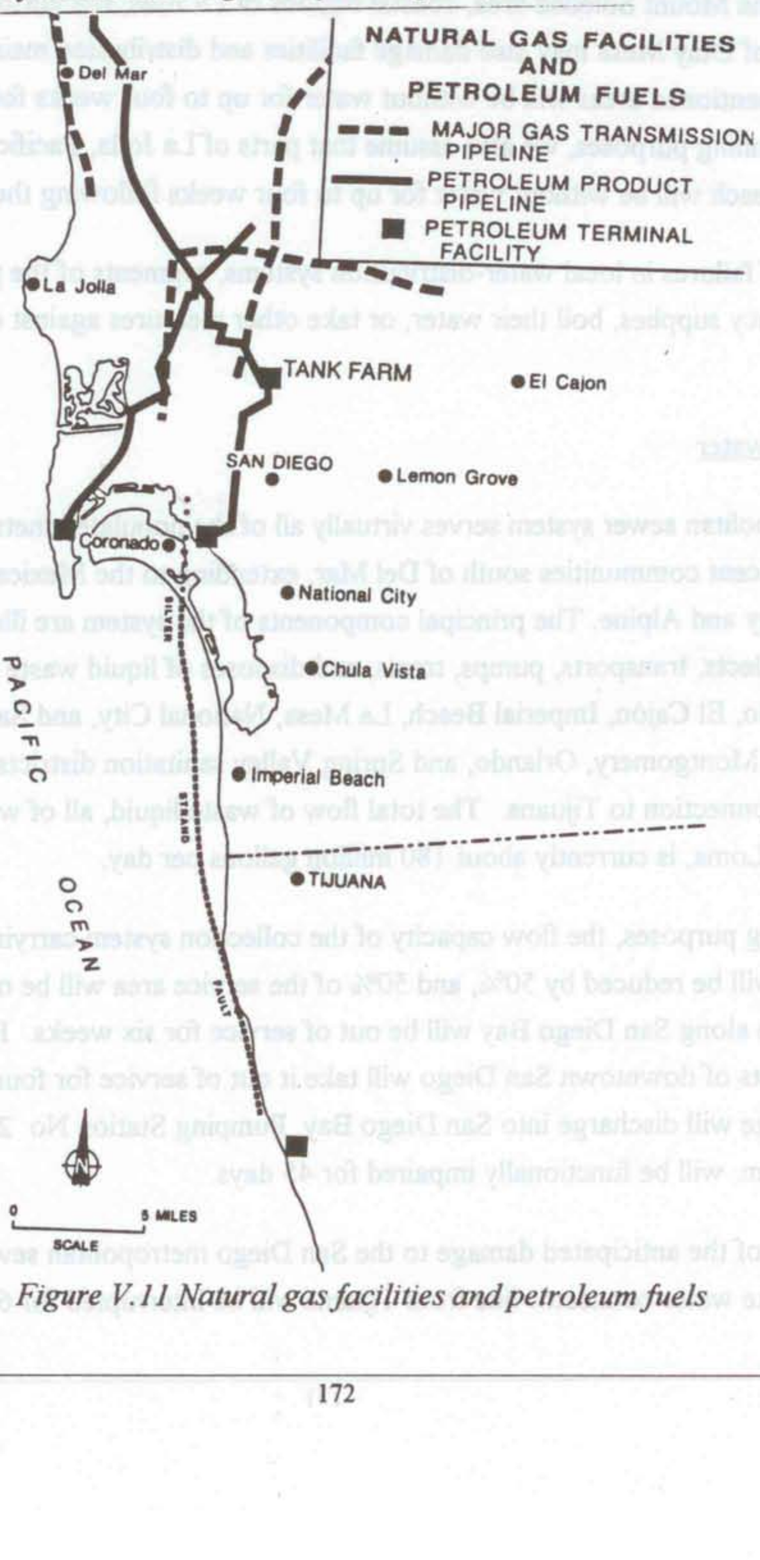

Figure V.11 Natural gas facilities and petroleum fuels

The primary impact of the scenario earthquake will be on the gas-distribution system where it crosses areas of high intensity and ground failure. In Pacific Beach, Point Loma, and downtown, repairs will be completed within 72 hours, but complete service restoration will take up to two weeks. Coronado could be without service for two to four months, until a new pipe is installed across the bay.

4.6 Petroleum Products

The petroleum products pipeline, like most of the utilities transmission facilities from the north, is routed primarily along the inland mesas (Figure V.11) and should be operational following the event. The tank farm is located on liquefiable alluvium near the north wall of Mission Valley. Because of its distance from the earthquake source, damage to the tank farm should not be severe. Fires may result where lines break at their junctions with the tanks. The tanks themselves may be damaged by sloshing liquids.

The navy fuel pipeline to Point Loma will be damaged where it crosses the Mission Bay-Loma Portal area of high to very high liquefaction susceptibility. The Tenth Avenue Marine Terminal fuel pier will sustain heavy damage from lateral spreading of the liquefied fill along the margins of San Diego Bay. Access to the fuel terminal and to the damaged portions of the navy pipeline will be difficult and limited, delaying repairs for several days.

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PREPARATION OF EARTHQUAKE SCENARIOS FROM SEISMIC MICROZONING STUDIES

Fumio Kaneko and Toshihiro Yamada, OYO Corporation, Japan

1. INTRODUCTION

Earthquake-disaster prevention has long been one of earthquake-prone Japan's most serious national concerns. The Large-Scale Earthquake Countermeasures Act was passed in 1978 in anticipation of an earthquake in the Tokai region. Since then, concern about earthquakes has increased nationwide, and earthquake-preparedness planning has helped to define concrete activities and programs. Many prefecture and city governments have now implemented seismic microzoning projects as the first stage in their earthquake-disaster mitigation and emergency-response programs.

In the 1970s, during the early years of earthquake-hazard assessment, most microzoning studies generated approximate quantitative estimations of the seismic damage to specific areas by focusing on seismic intensity distribution, building damage, and casualties (including deaths and injuries). The range of objectives has gradually widened, and a seismic study today typically includes damage to lifeline facilities such as roads, power and water supplies, and communication lines. The results from these more complete studies allow more realistic and effective planning programs.

Recent microzoning studies have been used primarily to outline concrete countermeasures and emergency-response policies. Immediate applications have included the preparation of earthquake scenarios and educational videos, and coordination of preparedness planning.

The seismic microzoning project conducted in 1980-1981 for the Saitama prefecture effectively spurred development and implementation of earthquake-hazard-mitigation measures in the prefecture. A more precise analysis conducted between 1989 and 1991 took into account changes in the prefecture's social environment. This second analysis was inspired by the threat that a moderate earthquake in the South Kanto area would inflict serious damage on surrounding regions. The first year of this three-year project was devoted to collecting geographical, infrastructure, and population data and preparing a SID map. In the second year we analyzed the various types of damage. From the analyses, we made an earthquake damage scenario, which summarized the results of the seismic microzoning project, and an educational video. These were used by the prefecture government for disaster-countermeasures planning. In the third and final year, we developed a computer program to allow the seismic microzoning process to be run on personal computers.

What follows is a sample earthquake damage scenario for one of four hypothetical earthquakes that we analyzed in the Saitama prefecture study. It is typical of recent Japanese microzoning studies.

2. BACKGROUND INFORMATION

2.1 Regional Seismicity

Over 1,000 years' worth of historical seismic catalogues, seismotectonic information, and active fault mapping are readily available for areas throughout Japan. Our study focused on the Saitama prefecture, located just north of the Tokyo metropolitan area. Based on an analysis of data for the Saitama prefecture, we selected four hypothetical earthquakes for microzoning studies (Table V.3, Figure V.12).

No.	Name	Description	Fault Length (km)	Presumed Magnitude
1	Minami-Kanto Earthquake	Recurrence of 1923 Kanto Earthquake	85	7.9
2	Nishi-Saitama Earthquake	Recurrence of 1931 Nishi-Saitama Earthquake	20	6.9
3	Ansei-Edo Earthquake	Recurrence of 1855 Ansei-Edo Earthquake	30	6.9
4	Ayasegawa Fault Earthquake	Though not recorded so far, it could cause severe damage	35	7.4

Table V.3 Hypothesized earthquakes, Saitama prefecture

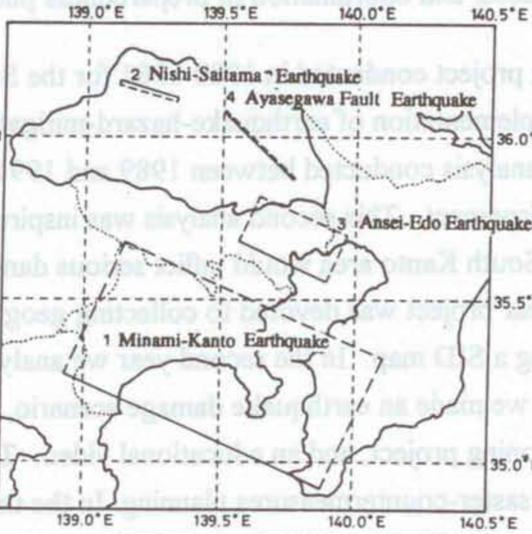

Figure V.12 Epicenters of the hypothetical earthquakes

2.2 Saitama Prefecture

The Saitama prefecture covers an area of approximately 3,800 square kilometers and encompasses 92 cities, towns, and villages. A January 1990 prefecture census recorded approximately 2 million households and 6.3 million residents. The cities of Kawaguchi, Omiya, and Urawa each had approximately 400,000 inhabitants at that time, and the cities of Kawagoe, Tokorozawa, and Koshigaya together had approximately 300,000 inhabitants.

Social activities vary significantly depending upon the time of day, season, weather, and other factors. Consequently, the level of damage caused by an earthquake also varies depending on when it occurs. The study assumed those conditions most likely to contribute to the spread of fires (Table V.4).

Season	Winter
Day	Weekday
Time	6 p.m.
Wind speed	8 m/s
Weather	Clear

Table V.4 Preconditions for the Saitama prefecture

The first map on page 223 shows the geomorphologic characteristics of the Saitama prefecture.

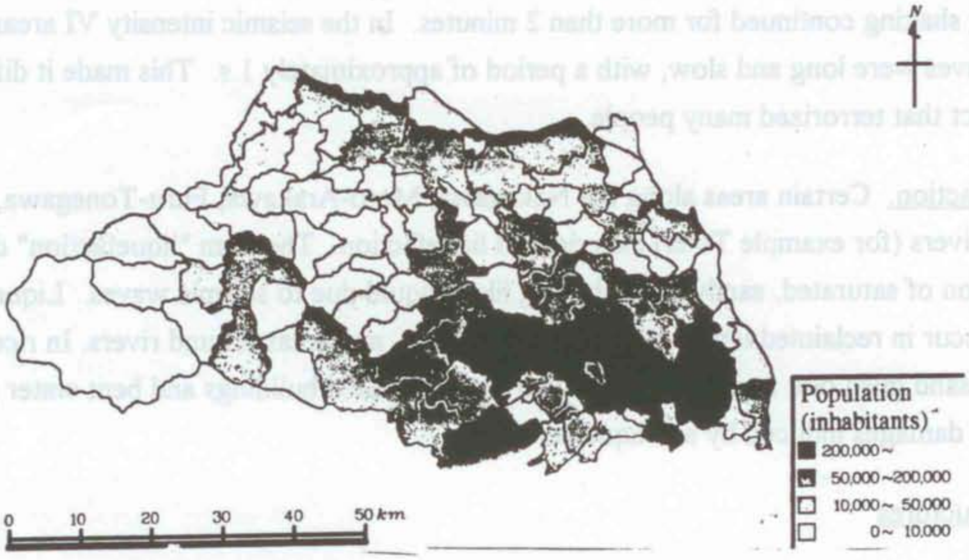

Figure V.13 Distribution of population in Saitama prefecture

Figure V.13 shows the distribution of the prefecture population. The western part of the prefecture is mountainous and sparsely populated, while the eastern part includes densely populated lowlands. The central, hilly region is currently experiencing rapid population growth.

All the data used in this study are from January 1991, or as close to that date as possible. The analysis was performed on a 15,000-square grid laid across the map of the prefecture. Each square represents a 500-by-500-meter sector of the prefecture.

3. SCENARIO FOR THE HYPOTHETICAL MINAMI-KANTO EARTHQUAKE

3.1 Features of the Earthquake

Following a rumbling of the ground, the southern part of the Saitama prefecture was struck with violent shaking ranging from V to VI on the Japan Meteorological Association (JMA) scale. The epicenter was located in the area surrounding Sagami Bay, and the magnitude of the earthquake was 7.9. The hypothetical earthquake analyzed, called the Minami-Kanto Earthquake, was essentially a recurrence of the Kanto Earthquake of 1923.

JMA Seismic Intensity. Seismic waves violently rocked the eastern half of the prefecture and the lowland areas along the Tonegawa River in the northern part, with seismic intensities between V to VI. Soft grounds along the Arakawa and Nakagawa rivers in the southern part of the prefecture were struck by seismic intensity VI shaking. Many hilly areas in the western part of the prefecture recorded a shaking intensity of IV. Stronger seismic motions were recorded in certain sections of the western area, such as mountain ridges.

Strong shaking continued for more than 2 minutes. In the seismic intensity VI areas, the seismic waves were long and slow, with a period of approximately 1 s. This made it difficult to stand, a fact that terrorized many people.

Liquefaction. Certain areas along the Nakagawa, Moto-Arakawa, Furu-Tonegawa, and Arakawa rivers (for example Toda) experienced liquefaction. The term "liquefaction" describes the phenomenon of saturated, sandy soil behaving like a liquid due to seismic waves. Liquefaction tends to occur in reclaimed lands, marshes, paddy fields, and areas around rivers. In rice paddies, water and sand gush out, leaving volcanic-like craters. Tilted buildings and bent water pipelines are among the damages induced by soil liquefaction.

3.2 Structures

Structural damage due to seismic motions and liquefaction was concentrated in the southern part of the prefecture.

Wooden Structures. In the city of Koshigaya, 7,000 wooden structures had either severe damage, which rendered them uninhabitable, or moderate damage, which left them essentially usable. In each of several cities, including Misato, Kasukabe, Kawaguchi, and Yashio, more than 5,000 buildings had severe or moderate damage. Throughout the prefecture, 42,000, or 2%, of the 2 million wooden buildings were damaged.

In Yashio and Misato, where liquefaction was particularly severe, damage rates exceeded 10%.

Other Structures. One thousand reinforced concrete buildings and just under 2,000 steel-framed buildings were damaged.

Steel-framed buildings, comprising mainly one- or two-story factories and warehouses, suffered serious damage when diagonal braces failed. Many steel-framed buildings constructed directly on the ground, or without piles, experienced severe settling due to soil liquefaction.

Falling Objects. In addition to damage to the buildings themselves, glass broke in many buildings in Kawaguchi, Kasukabe, Urawa, and Omiya. Signs and other objects that were attached to buildings fell during the earthquake, injuring many people.

3.3 Fires

Several minutes after the earthquake struck, fires broke out throughout the prefecture. In many cases, citizens were able to attack fire sources and extinguish fires immediately. In other cases, however, the impact of the earthquake interfered with fire-prevention activities.

Outbreak. Because many homes were using cooking fires at the time of the earthquake, fires broke out in many areas. Not including the fires extinguished by local residents, there were 22 fires in Kawaguchi, 12 in Urawa, and 83 throughout the prefecture. Roads were clogged with abandoned cars and fleeing people. Fire-control activities were carried out relatively quickly in most areas, excluding several heavily concentrated areas. The situation was complicated in some areas, however, by conflicting reports and water supply interruptions and failures. Throughout the prefecture, a total of 17 fires were extinguished by fire control activities within the first hour after the earthquake. The other fires spread rapidly.

Spreading of Fire. Those fires that were not quickly extinguished were spread by intermittent 8 m/sec winds. Evacuations proceeded relatively calmly in the period immediately following the earthquake, but after about 2 hours the increasing intensity of the fires caused complications.

In areas where buildings were less concentrated, the spread of fires was retarded by open spaces, roads, and rivers. In cities with heavy concentrations of buildings, such as Kawaguchi and Urawa, however, the intensity of fires continued to increase for hours after the event. Throughout the prefecture, 50,000 buildings were completely destroyed by fire, including 21,000 in Kawaguchi and 15,000 in Urawa.

3.4 Casualties

Fires and collapsed buildings killed and injured many. Many people lost their homes or were forced to evacuate.

Dislocated People. Approximately 200,000 people were forced to flee from four cities that experienced intense fires: Kawaguchi, Urawa, Warabi, and Yono. Many homes were destroyed and their residents permanently displaced.

Deaths. Where the fires were most intense, many people died: 480 people in Kawaguchi, 240 in Urawa, and 210 in Toda. In Shiki, 80 people died in fires in nonwooden buildings alone, a surprisingly large number considering the scale of the fires recorded in that city.

A total of 1,600 deaths in 18 cities and 3 towns throughout the prefecture was recorded.

Injuries. Injuries greatly exceeded deaths, with a total of 15,000 injured in 24 cities and six towns throughout the prefecture (Figure V.14). There were 3,000 injuries in Kawaguchi and a little less than 2,000 in Urawa and Toda combined. Nineteen cities and four towns had 100 or more injuries.

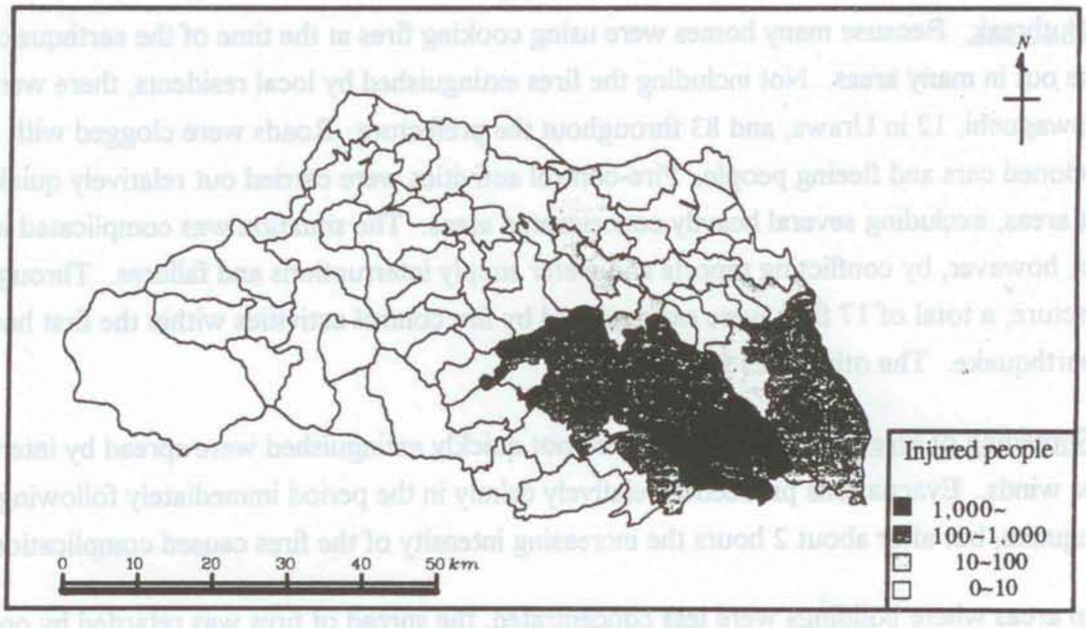

Figure V.14 People injured

Homeless. Fifty thousand homes, 2.5% of all homes in the prefecture, were destroyed, displacing 160,000 people (Figure V.15).

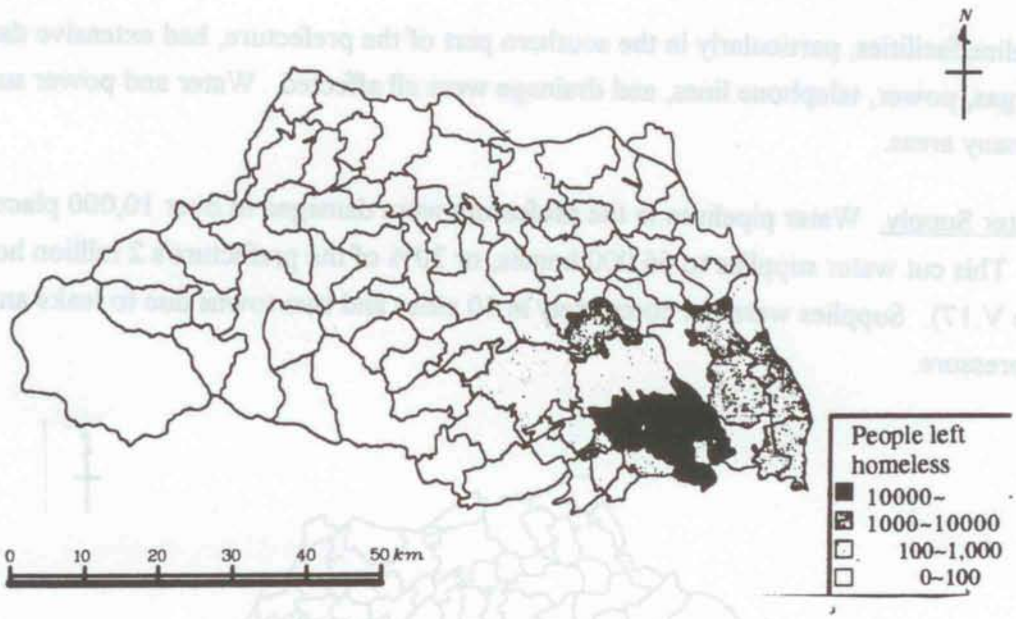

Figure V.15 People left homeless

3.5 Transportation Facilities

The earthquake caused road and railway damage that contributed to confusion during the aftermath.

Roads. Roads caved in or cracked in 3,000 places, mainly in the eastern part of the prefecture. This prevented traffic flow in certain areas.

Bridges. Damage to bridges also disrupted traffic flow. Many cars were temporarily abandoned, adding to the confusion of the evacuation process.

Roads in mountainous areas had shoulder collapses and road cave-ins. These incidents were isolated, however, and their impact on the mountainous areas was minor.

Pedestrian Bridges. Liquefaction caused slight damage to pedestrian bridges, but no obstruction of traffic was reported.

Railways. With the exception of the Chichibu and Seibu-Chichibu lines in the western mountainous region, all railways were rendered inoperable (see page 223). Because 2 million people throughout the prefecture commute to work or school by train, damage to rail lines affected many people, causing confusion, inconvenience, and psychological stress.

3.6 Lifelines

Lifeline facilities, particularly in the southern part of the prefecture, had extensive damage. Water, gas, power, telephone lines, and drainage were all affected. Water and power supplies were cut in many areas.

Water Supply. Water pipelines in the prefecture were damaged in over 10,000 places (Figure V.16). This cut water supplies to 66,000 homes, or 30% of the prefecture's 2 million homes (Figure V.17). Supplies were cut completely in 10 cities and two towns due to leaks and losses of water pressure.

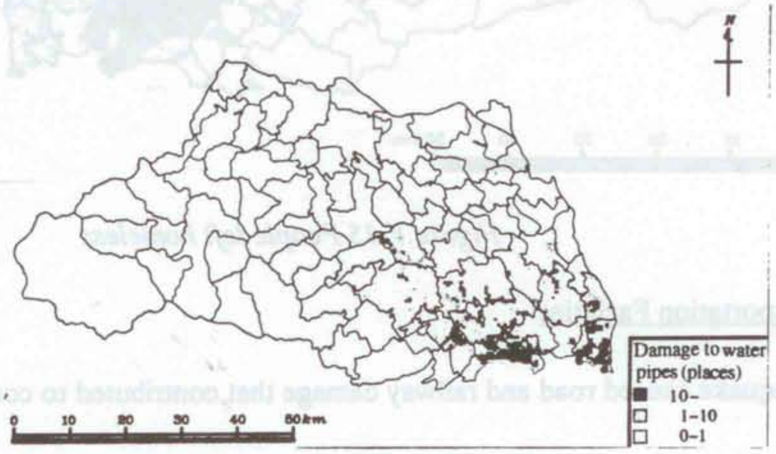

Figure V.16 Damage to water supply system

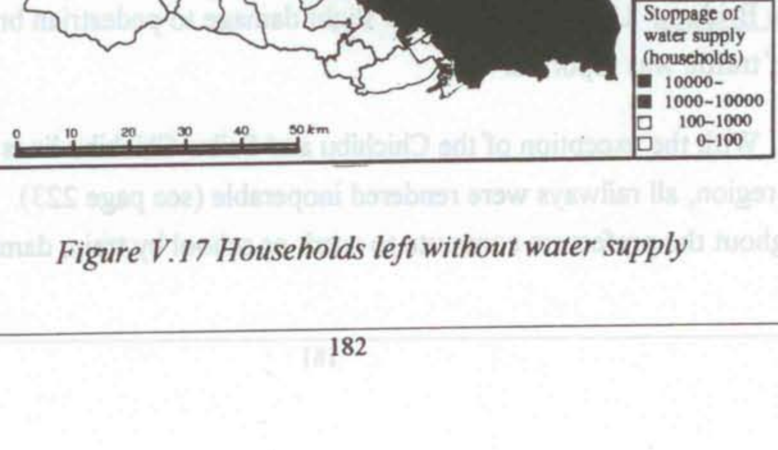

Figure V.17 Households left without water supply

Extensive reliance on earthquake-vulnerable, asbestos cement water ducts was blamed for the unusually high damage to water supply lines. The earthquake occurred shortly before the prefecture was able to implement its program to replace these ducts with earthquake-resistant ducts.

Sewerage. Drainage pipes broke in more than 1,000 places. In many cases, the damage was not apparent and was only discovered some time after the event. This further delayed full restoration of the sewer system.

Gas. Because emergency measures were taken to cut off gas supplies when the earthquake occurred, gas was completely unavailable for a time following the event.

Power Supply. Damaged electric poles and severed power lines caused power outages throughout the prefecture. The fires that followed the earthquake caused further destruction to power lines. Complete power failures occurred in the six cities and three towns where intensive liquefaction was recorded (Figures V.18 and V.19).

Figure V.18 Damage to power supply system

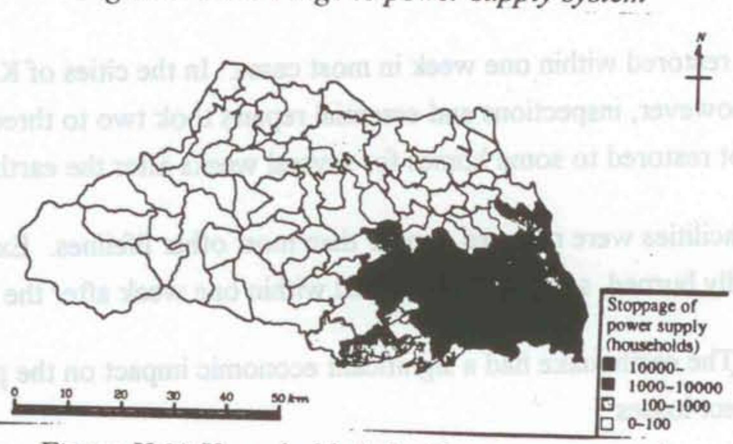

Figure V.19 Households left without power supply

Telephone. Although some service lines to private residences were temporarily cut, alternate routing prevented complete breaks in communications lines, even in areas where cables were damaged. Heavy telephone use following the earthquake temporarily exceeded the capacity of the system, especially in the southern part of the prefecture. Telephone-line irregularities continued for one to two days in the western part of the prefecture and for several days elsewhere in the prefecture.

On-line Computer Systems. On-line computer systems were temporarily halted in several banks. Thanks to backup files, only minor amounts of data were lost. Delays and other obstructions to banking activities continued for approximately one week.

3.7 Social Impact

The effects of the Minami-Kanto Earthquake were felt not only in the Saitama prefecture but throughout the South Kanto region. Damage to neighboring prefectures was most severe in the areas nearest the earthquake's epicenter, including the Kanagawa prefecture and the greater Tokyo area. The earthquake's broad impact prompted a nationwide rescue effort.

Daily Life of Citizens. Lifeline damage had a major impact on the daily lives of prefecture residents.

Water supply was restored to most of the heavily damaged areas in one week to one month. In some areas, however, insufficient numbers of repair personnel delayed full restoration of service for up to three months.

Though drainage supply lines had only minor damage, the drainage system was not fully restored for some time.

Gas service was restored within one week in most cases. In the cities of Kawaguchi, Kasukabe, Yashio, and Toda, however, inspections and essential repairs took two to three weeks. As a result, gas supplies were not restored to some homes for several weeks after the earthquake.

Electric-power facilities were restored sooner than most other lifelines. Except in those areas where lines were badly burned, service was restored within one week after the earthquake.

Damage Costs. The earthquake had a significant economic impact on the prefecture, causing both direct and indirect losses.

The cost of reconstructing buildings amounted to ¥370 billion in Kawaguchi and ¥250 billion in

Urawa. These were the areas where the fires were the worst. Rebuilding costs for the prefecture totaled ¥1,300 billion, which corresponds to 60% of the annual construction costs within the prefecture (Figure V.20).

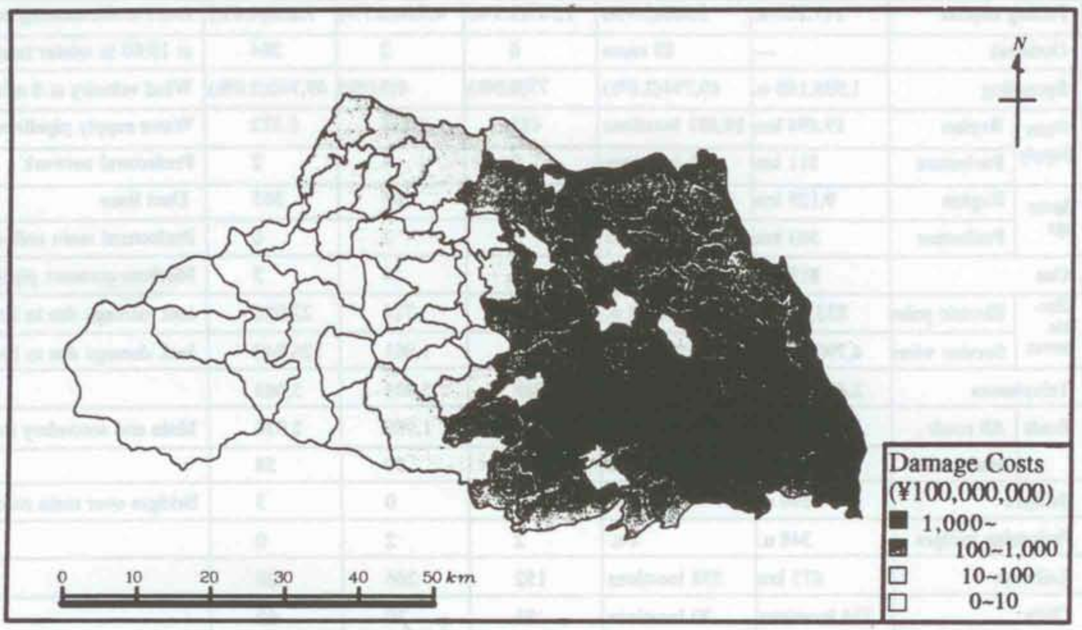

Figure V.20 Structural damage costs, including damage to wooden and nonwooden structure

Damage to lifelines and transportation systems cost ¥270 billion to repair (Figure V.21). This corresponds roughly to the prefecture's annual budget for civil engineering projects.

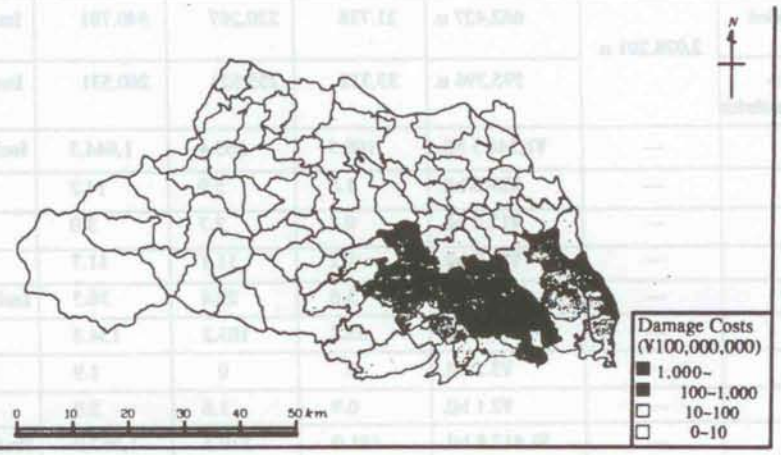

Figure V.21 Lifeline damage costs, including damage to roads

Item			Current Condition	Damage for Each Hypothetical Earthquake: Minami-Kanto	Nishi-Saitama	Ansei-Edo	Ayase-River	Remarks
Magnitude			—	7.9	6.9	6.9	7.4	
Damage description	Structures	Wooden buildings	1,936,180 u.	41,707(1.4%)	3,751(0.1%)	9,493(0.3%)	62,938(1.9%)	Damaged units = No. of severely damaged + moderately damaged units
		RC buildings	80,881 u.	1,026(1.1%)	1,435(1.0%)	474(0.5%)	2,351(1.7%)	Figure in parentheses:
		SF buildings	96,884 u.	1,644(1.5%)	840(0.7%)	308(0.3%)	2,983(2.3%)	Damage rate = Rate of severe damage + 1/2 rate of moderate damage
		Brick walls	678,000 u.	22,326(3.3%)	2,229(0.3%)	10,037(1.5%)	14,505(2.1%)	Include stone walls
		Falling objects	117,765 u.	5,988(3.4%)	1,907(1.1%)	4,736(2.7%)	7,852(4.4%)	From 3-or-more-stories-high buildings
	Fires	Outbreak	—	83 cases	6	2	264	at 18:00 in winter (max.)
		Spreading	1,936,180 u.	49,794(2.6%)	77(0.0%)	4(0.0%)	49,740(2.6%)	Wind velocity at 8 m/s
	Lifeline facilities	Water Supply – Region	19,494 km	10,881 locations	423	2,238	5,372	Water supply pipelines
		Water Supply – Prefecture	511 km	6 locations	0	1	2	Prefectural network
		Sewerage – Region	9,125 km	1,441 locations	9	295	365	Duct lines
		Sewerage – Prefecture	303 km	8 locations	0	2	6	Prefectural main collectors
		Gas	819 km	18 locations	0	4	5	Medium-pressure pipelines
		Electric power – Electric poles	835,781 u.	22,708 u.	135	714	22,021	Incl. damage due to fires
		Electric power – Service wires	4,790,749 u.	127,394 u.	451	1,961	126,843	Incl. damage due to fires
		Telephones	2,477,900 u.	8,860 u.	1,288	5,405	5,063	
	Transportation facilities	Roads – All roads	45,038 km	2,809 locations	1,252	1,969	2,936	Main and secondary roads
		Roads – Main roads	600 km	55 locations	21	39	58	
		Bridges	596 u.	8 u.	0	0	3	Bridges over main roads
		Pedestrian bridges	348 u.	4 u.	2	2	0	
		Railways	675 km	338 locations	152	266	320	
	Others	Cliffs	734 locations	70 locations	53	39	62	
		Reclaimed lands	52 locations	0 location	0	0	0	
		River banks	318 km	194 km	53	100	133	Flood-prevention sections
		Reservoirs	580 locations	0 location	0	0	0	
	Casualties and social impact	Deaths	6,319,639 pers.	1,580 pers.	50	150	1,540	
		Injuries		15,520 pers.	1,440	3,030	16,790	
		Homeless		162,930 pers.	1,610	10,840	150,340	
		Refugees		203,800 pers.	—	—	169,090	
		Water-suspended households	2,028,201 u.	662,427 u.	21,738	220,267	340,781	Immediately after earthquake
		Electric power-suspended households		595,396 u.	33,712	255,621	260,531	Immediately after earthquake
Losses		Buildings	—	¥1,346.5 bil.	108.5	165.4	1,644.3	Incl. damage due to fires
		Water supply	—	¥29.8 bil.	1.0	5.9	14.2	
		Sewerage	—	¥12.0 bil.	0.1	2.7	3.0	
		Gas	—	¥12.0 bil.	1.2	11.1	11.7	
		Electric power	—	¥62.7 bil.	3.6	29.4	36.5	Incl. damage due to fires
		Roads	—	¥147.5 bil.	65.7	103.2	154.3	
		Bridges	—	¥5.2 bil.	0	0	1.9	
		Railways	—	¥2.1 bil.	0.9	1.6	2.0	
		Total	—	¥1,617.8 bil.	181.0	319.3	1,867.9	Prefectural budget for 1990 was ¥1,212.6 billion

Table V.5 Comparison of damage for the four scenarios

Indirect losses such as reductions in industrial and commercial activity due to the seismic damage and social confusion also seriously impacted the economy.

4. FINAL REMARKS

The first step in a Japanese seismic microzoning study is to estimate the damage caused by a hypothetical earthquake. The earthquake's effects on people's daily lives and the activities of society are then assessed. In the example presented, the different types of seismic damage were estimated using vast amounts of data (Table V.5), experience gained from past earthquakes, and state-of-the-art modeling techniques.

Several recent local studies have used small-area units (down to the house-by-house level) and incorporated highly precise methodologies. Applying such highly detailed procedures to wider areas, however, would require huge amounts of data and work. Also, small changes in the assumed preconditions of an event would lead to large variations in scenario results. More effective estimation methods, therefore, are still needed.

Systematic and ongoing efforts to implement preparedness measures are needed to minimize seismic damage in earthquake-prone countries like Japan. In this context, earthquake scenarios and microzoning projects provide the basic information required for mounting effective seismic-disaster-mitigation programs.

A damage-estimation system capable of running on personal computers could facilitate future investigations and enhance the applicability of microzoning methods. Microzoning teams could then carry out both precise studies and rough but quick estimations of seismic damage. The former could be used for disaster-preparedness planning before the earthquake takes place, while the latter could facilitate emergency-response decision making after an earthquake's occurrence.

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SEISMIC DAMAGE ASSESSMENT WITH ENHANCED USE OF REGIONAL CHARACTERISTICS

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1. INTRODUCTION

In the past, seismic-damage assessments developed in Japan have generally been drawn from macroscopic regional data. Local governments have used these assessments to estimate both casualty figures and levels of damage to buildings and lifeline facilities. They have provided useful knowledge about levels of damage and helped local governments to prepare macroscopic contingency plans for assumed disasters. However, the scale of these estimates is usually too large to allow local residents to visualize damages clearly. Thus, such studies often fail to stimulate the development and implementation of much-needed earthquake-damage-mitigation measures.

This paper presents a seismic-damage-estimation method based on microscopic regional characteristics. The method can be used to estimate damage for a relatively small area, and employs a geographic information system (GIS). The detailed results that it produces help local residents to envision what will occur in their neighborhoods during an earthquake disaster. This, in turn, motivates them to help develop appropriate mitigation measures.

2. THE CONCEPT OF SEISMIC-DAMAGE ESTIMATION USING MICROSCOPIC REGIONAL CHARACTERISTICS

2.1 Microscopic Regional Characteristics

It is critically important to consider microscopic regional characteristics when determining the target area for a seismic-damage-estimation study. Important microscopic characteristics include number of stories, building structural type and use, location and width of principal and secondary roads, soil profile, geological and topographical information, and human resource statistics. Human resource statistics include population size during the day and night, age distribution, job categories, vulnerability to injuries in a disaster (e.g., weak, elderly, or handicapped persons and uninformed foreigners), ratio of permanent residents to total residents, and kinds of transportation used.

This information is entered into a GIS for processing and analysis and emerges in the form of digital maps. Compiling a data base of microscopic regional characteristics for an area can be difficult, but it is a necessary part of conducting a seismic-damage assessment based on microscopic regional data.

2.2 Seismic Damage Potential

Seismic ground intensity is determined using seismic-response characteristics of the ground based on topographical and geological information and soil profiles. An earthquake-response analysis then estimates the damage likely to be sustained by each building or other structure, and the likely effects of this damage on society. Special emphasis is placed on damage commonly experienced in houses, such as sliding and toppling of furniture. The danger of earthquake-triggered fires is evaluated by considering the types of structures, their use, and the proximity of fire-fighting facilities. A GIS displays the results of this evaluation on the computer screen.

2.3 Earthquake Damage Scenarios

Macroscopic damage estimates generated by local governments in Japan are typically summarized in tables and graphs. Although such results may be useful to local governments interested in preparing macroscopic disaster contingency plans, they appear technical and unengaging to local residents. These residents often cannot envision how earthquakes could affect them and their neighborhoods; consequently, they feel unmotivated to support or engage in earthquake-preparedness measures. To be effective in mobilizing public interest, damage estimates must give detailed, or microscopic, information about neighborhoods, such as the safety of commuting to specific schools, offices, and hospitals soon after an assumed earthquake.

3. ONE EXAMPLE OF DAMAGE ESTIMATION USING MICROSCOPIC REGIONAL CHARACTERISTICS

Microscopic geographical information can help to generate realistic, specific seismic-damage estimations. The case of the Azabu area in Minato, one of Tokyo's 23 wards, demonstrates this method. Existing methodologies for damage estimation have limitations; this example attempts to show the effectiveness and advantages of estimating seismic damage using microscopic geographical information, while highlighting the limitations of the various existing damage-estimation methodologies.

3.1 Regional Characteristics of the Azabu Area

The Azabu area has a total land area of 1,350 square kilometers; a day population of 22,324; a night population of 15,160; and 7,170 permanent residents. Other statistics are listed in Table V.6. The map on page 225 shows land-use (a GIS output). Most of the buildings in this area are one- or two-story houses, which are indicated on the map in pink and orange. Small shops and restaurants, shown in red, are concentrated along the three main streets that surround the area. There are also

11 embassies in the area. Based on these characteristics, the area can be considered upper-class and residential.

Index		Percentage
Small entrepreneurs		21.38%
Households:	Single member	35.44%
	Nuclear family	54.78%
	Extended family	9.78%
Population:	Inflow (in area since 1979)	16.50%
	Permanent (in area since 1964)	18.10%
	20-29 years old	16.64%
	Over 65 years old	9.52%

Table V.6 Statistics on the Azabu area

3.2 Structures and Uses of Buildings

Building types, numbers of stories, and uses are considered basic information for seismic-damage estimation. Digital maps stored in the computer are used to incorporate this information into damage-estimation calculations. The Azabu area comprises many reinforced concrete buildings and steel-frame reinforced concrete buildings, in addition to wooden buildings. Other regions of Japan, by contrast, have only wooden houses. Fire resulting from an earthquake will spread more quickly in these areas. Low-rise buildings (one to three stories) and medium-rise buildings (four to seven stories) constitute 90% of all buildings in the Azabu area. High-rise buildings (more than eight stories) exist along the main street. Buildings in the area have a range of uses (see page 227).

3.3 Seismic-response Characteristics of the Ground

The natural period of the ground, T_g (s), described by Formula V.1 was obtained for each of 54 points using microscopic topographical and geological information and data on soil profiles. The maps on page 229 and 231 show the ground height and topographical classification of the area. The spatial variation of T_g in the area is derived by the Kriging method for probabilistic interpolation (Formula V.1).

$$T_g = 4 \times \sum_{i=1}^{n} \frac{H_i}{V_i} \qquad (V.1)$$

where i is the order of the soil layer from the surface to the bedrock, H_i is the thickness (m) of the i'th soil layer, and V_{si} is the average shear wave velocity (m/s) of the i'th soil layer.

Using this spatial characteristic, the ground is classified into the following four categories (Formula V.2):

Hard Ground	$T_g < 0.2$
Medium Ground (a)	$0.2 \leq T_g < 0.4$
Medium Ground (b)	$0.4 \leq T_g < 0.6$
Soft Ground	$0.6 \leq T_g$ (V.2)

Plate 15 shows a map of ground classification by T_g. The dark blue area corresponds to the longest T_g; blue, the second longest; yellow, the third longest; green, the shortest. The dark blue and blue areas indicate soft ground where severe damage might occur during an earthquake. The longer T_gs and geographical classifications of the dark blue and blue areas correspond to the former course of a dried-up river. These areas had severe building damage during the Kanto Earthquake in 1923. The damage estimation for the Azabu area used this soil classification.

3.4 Damage Estimation for Wooden Houses

Wooden houses can be classified as "fully wooden" or "fire-resistant," for example, having fire-resistant roofs and walls. Research shows that most fully wooden houses in the Azabu area were constructed before 1960, while most fire-resistant wooden houses were constructed after this date. Pure wooden houses with one story have an average natural period, T_s, of 0.4 s, and those with two stories, a T_s of 0.55 s. Fire-resistant houses with one story have an average natural period of 0.25 s, and those with two stories a T_s of 0.35 s. These data and other microscopic information about wooden houses help to predict the seismic responses of different types of wooden houses.

First, the natural period of each wooden house is determined based on its age, type of structure, and number of stories. The ductility factor, which is an index of damage potential, is then calculated using Formula V.3,

$$\mu = \frac{1}{2}\left\{\left(\frac{S_A}{S_y}\right)^2 + 1\right\}$$

$$S_y = 0.25 \times \frac{980}{T_s} \qquad \text{(V.3)}$$

where S_a is the acceleration response of a house with a natural period T_s. S_a is obtained from the acceleration-response spectrum shown in Figure V.18, which is defined for each of the four ground classifications. The ductility factor has been determined for each wooden house in the area. These results can be used to determine relative levels of expected damage.

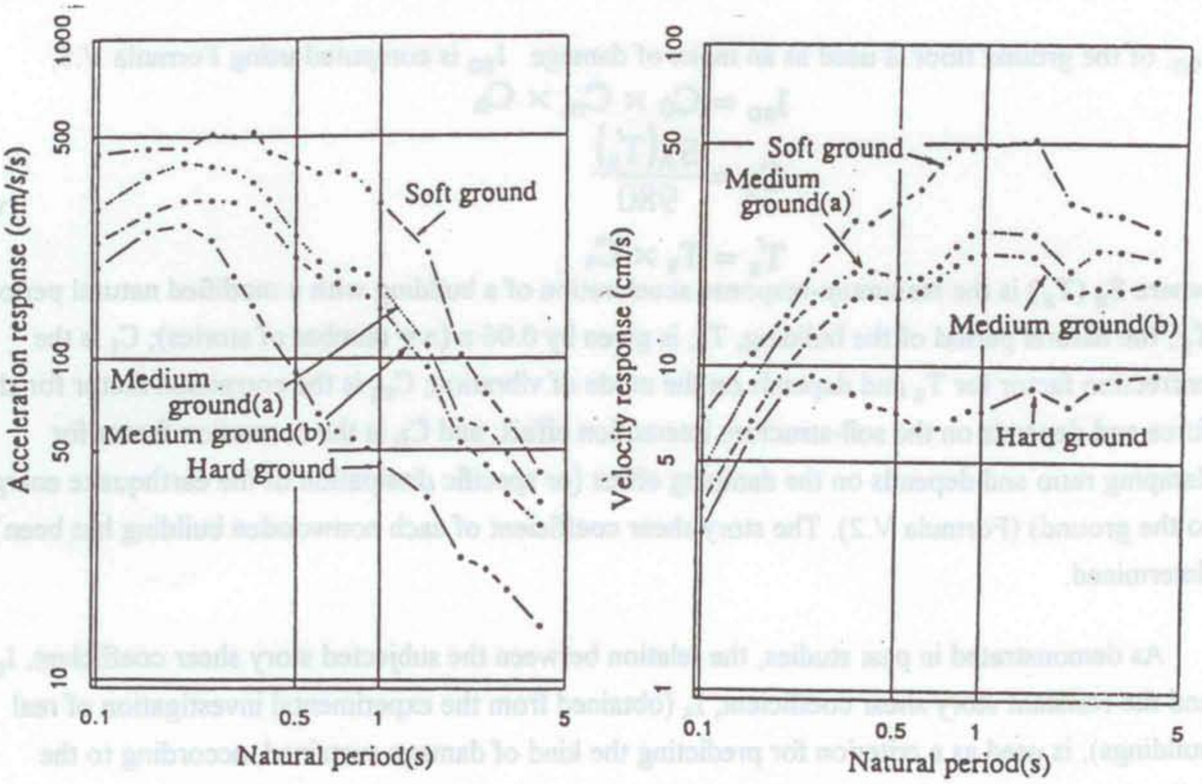

Figure V.22 Response spectrum of ground classifications

Past studies have demonstrated that the ductility factor can be used as a criterion for predicting levels of damage according to the following guidelines (Formula V.4),

$$\text{Total Collapse} \quad \mu_{ot} \leq \mu$$
$$\text{Partial Collapse} \quad \mu_{ot} \leq \mu < \mu_{ot} \qquad \text{(V.4)}$$

where "total collapse" means occurrence of permanent deformation greater than 10 centimeters, and "partial collapse" means permanent deformation of less than 10 centimeters. Typically, partially collapsed buildings can still be used after repairs and retrofitting. A previous investigation adopted the values $\mu_{OP} = 4$ and $\mu_{OT} = 6$.

Based on Formula V.4, the wooden houses in the area are not expected to sustain any damage during an earthquake.

3.5 Damage Estimation for Nonwooden Structures

Damage estimations must also be performed on nonwooden structures, including reinforced concrete (RC), steel-framed reinforced concrete (SRC), and steel-framed (S) structures. In this analysis, all nonwooden structures are assumed to be either RC or SRC, and RC and SRC damages are estimated using the conventional method (Formula V.4), whereby the story shear coefficient,

I_{so}, of the ground floor is used as an index of damage. I_{so} is computed using Formula V.5,

$$I_{so} = C_0 \times C_m \times C_h$$
$$C_0 = \frac{S_A(T_s')}{980} \qquad (V.5)$$
$$T_s' = T_s \times C_t$$

where S_a (T_s') is the maximum-response acceleration of a building with a modified natural period T_s'; the natural period of the building, T_s, is given by 0.06 n (n = number of stories); C_t is the correction factor for T_s and depends on the mode of vibration; C_m is the correction factor for shear force and depends on the soil-structure interaction effect; and C_h is the correction factor for damping ratio and depends on the damping effect (or specific dissipation of the earthquake energy to the ground) (Formula V.2). The story shear coefficient of each nonwooden building has been determined.

As demonstrated in past studies, the relation between the subjected story shear coefficient, I_{so}, and the resistant story shear coefficient, I_s (obtained from the experimental investigation of real buildings), is used as a criterion for predicting the kind of damage sustained, according to the following parameters (Formula V.6),

$$\text{Total Collapse} \quad 4\,I_s \leq I_{so}$$
$$\text{Partial Collapse} \quad 2\,I_s \leq I_{so} < 4\,I_s \qquad (V.6)$$

where "total collapse" means occurrence of severe damage to columns and structural walls, and "partial collapse" means occurrence of shear force cracks in columns and structural walls. Based on Formula V.6, the nonwooden houses in the area are not expected to sustain any damage during an earthquake.

3.6 Sliding and Toppling Furniture

The likelihood of furniture sliding and toppling is estimated using the matrix in Figure V.23.

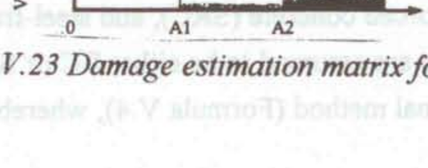

Figure V.23 Damage estimation matrix for furniture

Severe damage means that all furniture slides and more than half is toppled. Medium damage means that 20% to 30% of the furniture is toppled. Slight damage means that less than 8% of the furniture slides and almost no furniture is toppled. A_1 (cm/s^2), A_2 (cm/s^2), and V_0 (cm/s) in Figure V.19 are computed using the following formulas (Formula V.7),

$$A_1 = 2 \times B \times \frac{980}{H}$$
$$A_2 = 3 \times B \times \frac{980}{H}$$
$$V_0 = 25.6 \times \frac{B}{H} \qquad (V.7)$$

where B (cm) refers to vibrational direction thickness and H (cm) is the height of the furniture.

Objects commonly found in homes, for example, iceboxes, chests, bookshelves, and stoves, are used to estimate the occurrence of slides and toppling. Acceleration response and velocity response of buildings are estimated from the response spectrum shown in Figure V.22. Likely sliding and toppling patterns of furniture can also be established. Generally, the bookshelf is the most unstable piece of furniture. Almost all bookshelves that are not bolted to the wall will topple when subjected to an earthquake response of 300 cm/s^2. When buildings on soft ground were subjected to an earthquake response of 500 cm/s^2, almost all of the furniture inside will slide or topple.

4. SUMMARY

This paper describes the concept of seismic-damage estimation using microscopic geographical information and illustrates the method by applying it to an area of Tokyo. The results obtained by microscopic estimation are more detailed than those obtained by considering macroscopic regional characteristics. Moreover, these results enable local residents to visualize damage that might occur in their area and to understand how it will affect them.

Seismic-damage assessments based on microscopic regional data are a new concept, and certain aspects of this approach must still be refined. Particularly useful would be more accurate methodologies for estimating ground-motion intensity and quantifying soil or ground type. Better data are also needed on objects falling from buildings, liquefaction, landslides, and the incidence and spread of earthquake-triggered fires.

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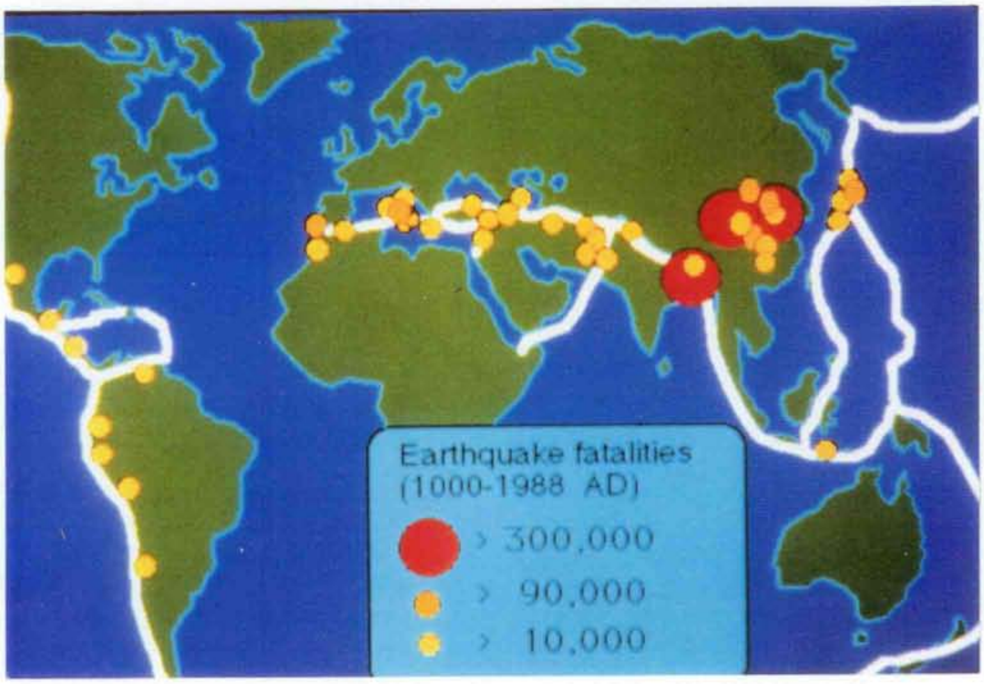
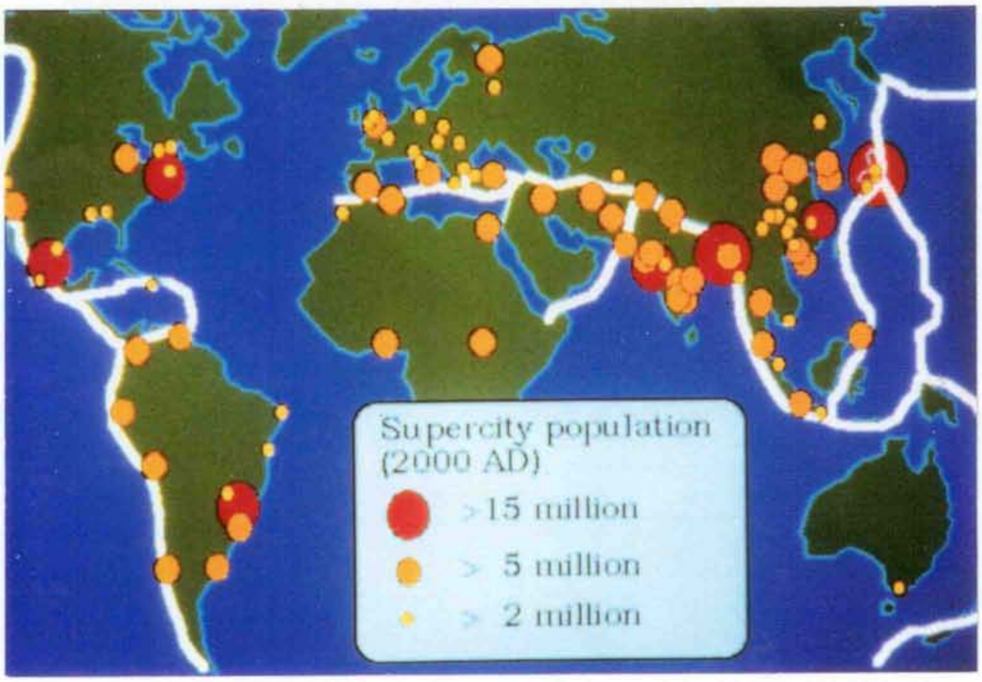
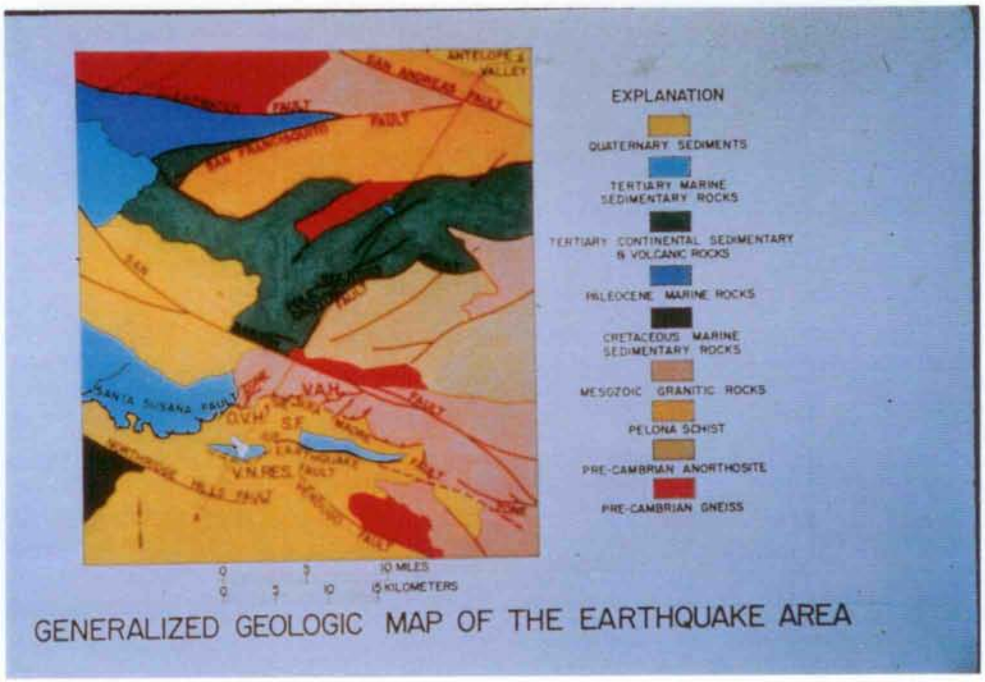
COLOR PLATES



Part I Earthquake fatalities, previous 1,000 years

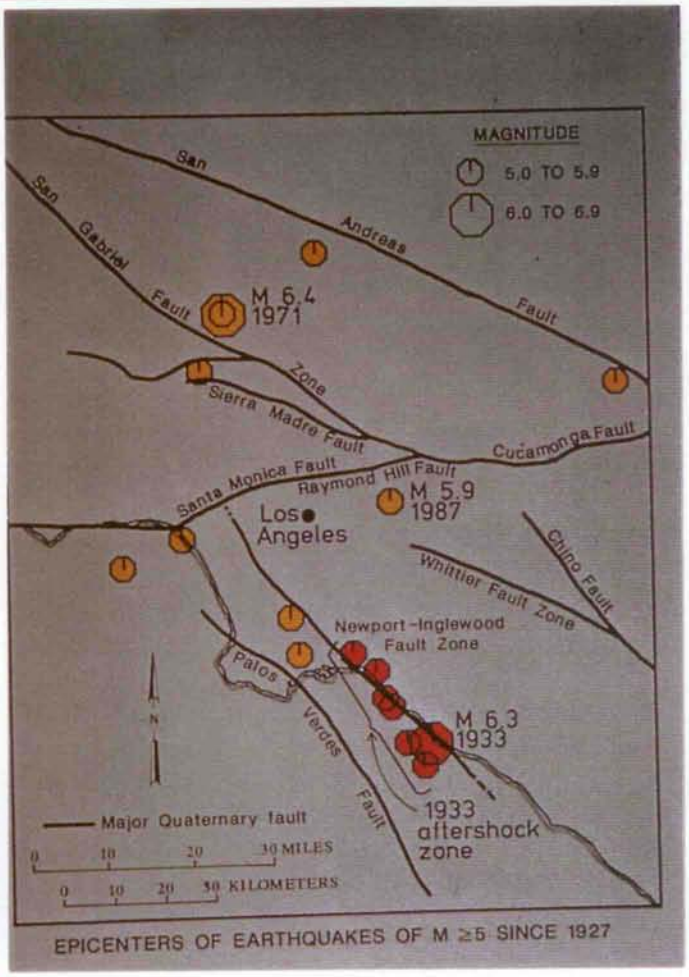


Part I Distribution and size of supercities, 2000

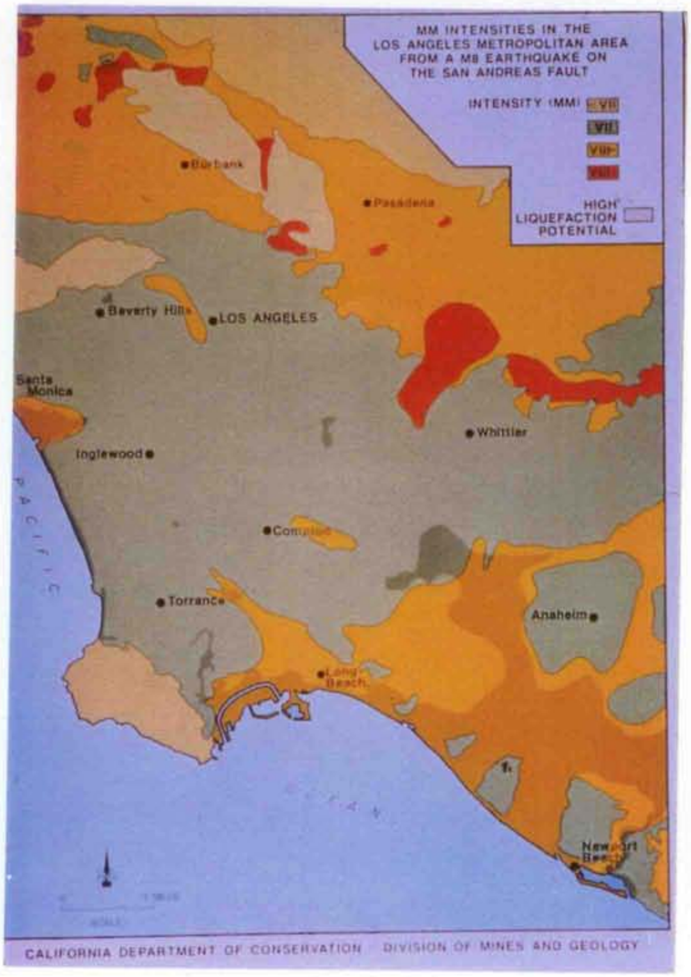


Part II Generalized Geologic map of the earthquake area

Part II Hayward Fault, California

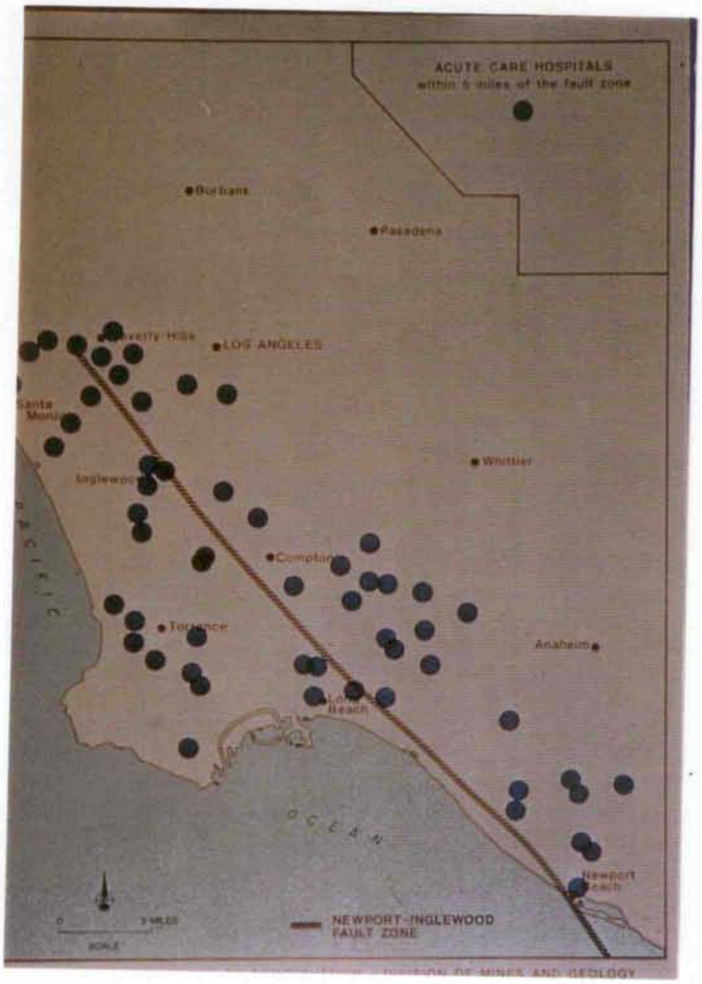


Part II Epicenters of MMI ≥ V earthquakes since 1927

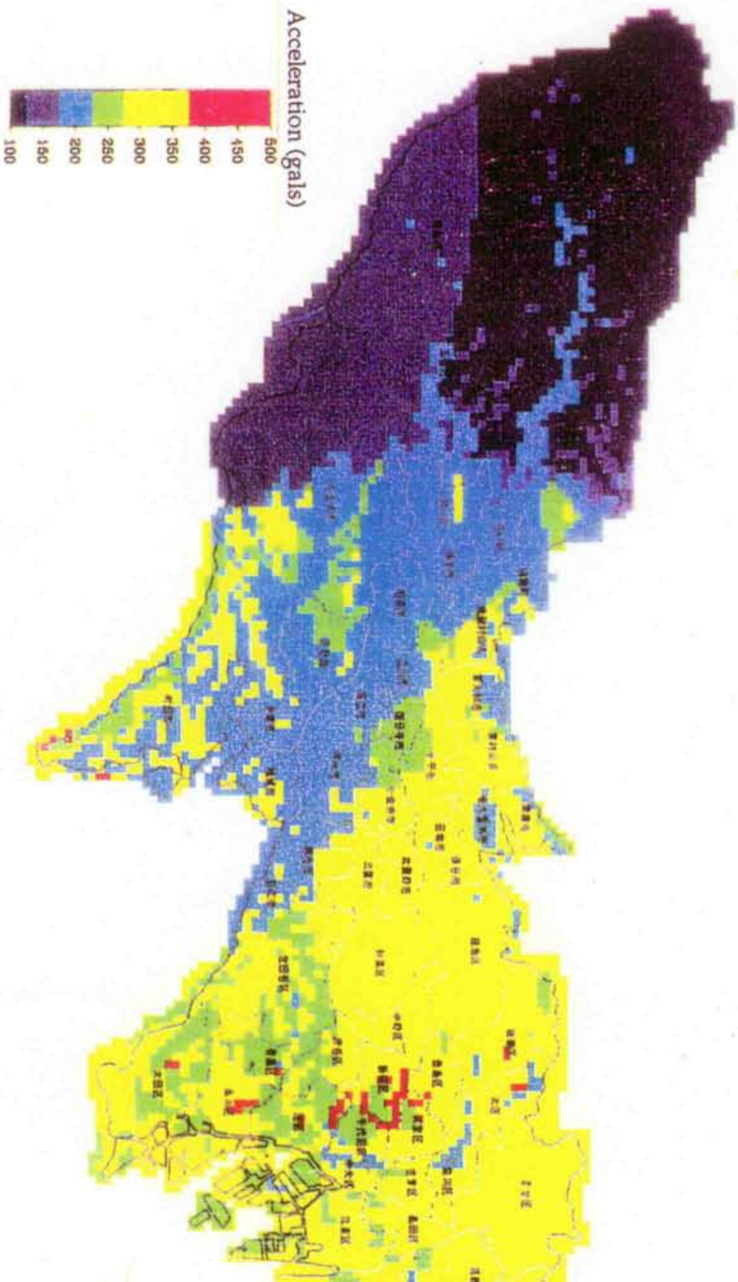


Part II Seismic intensity distribution, MMI VIII event (Source: CDMG)

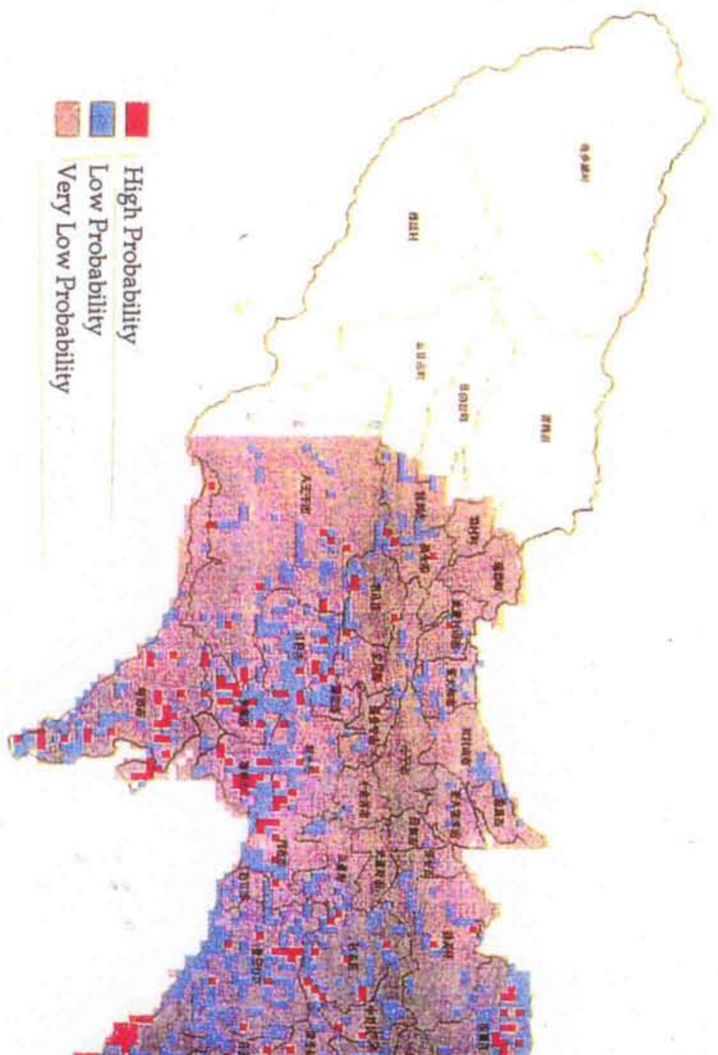
Part II Typical lifeline map (Source: CDMG)



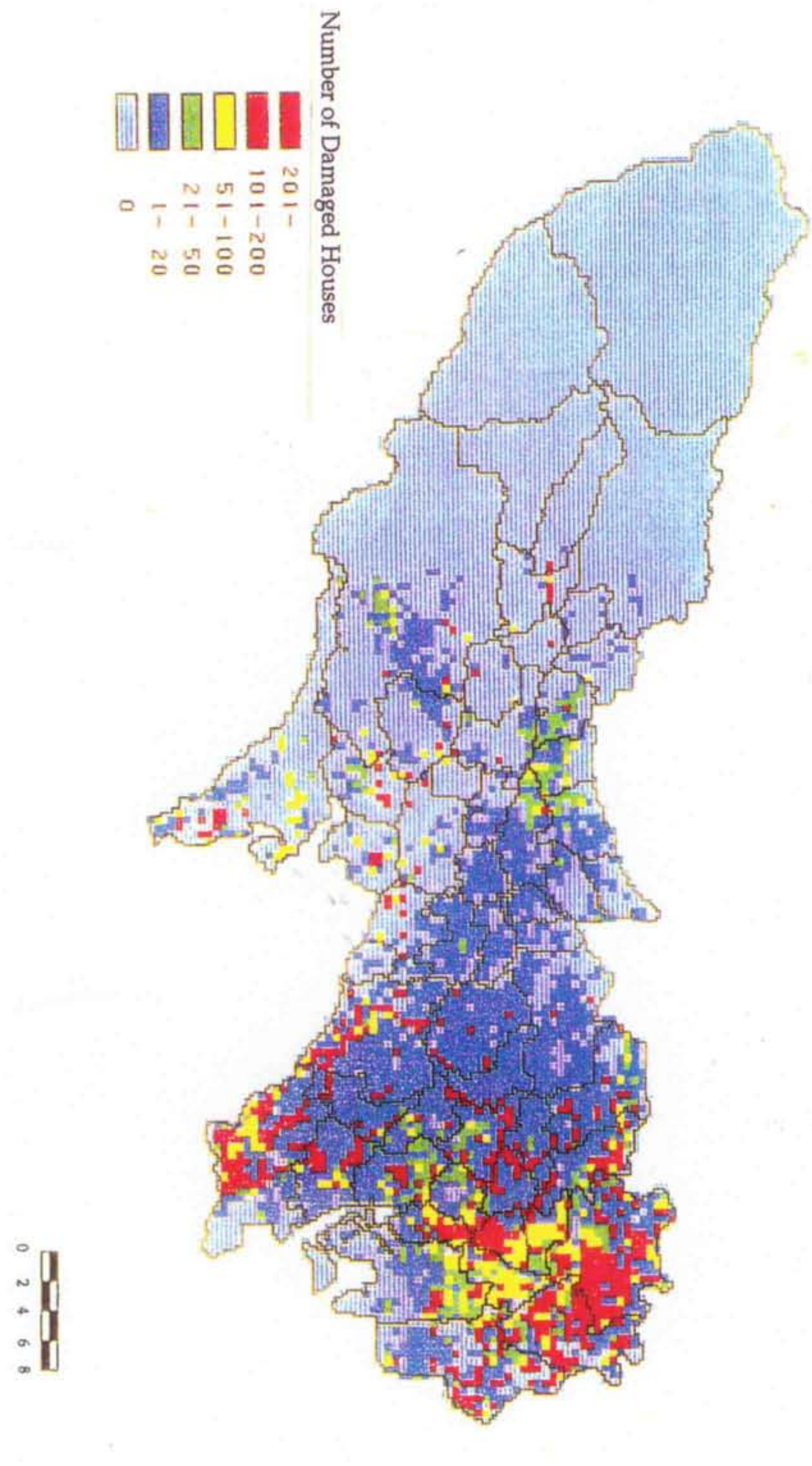
Part II Hospitals near the Newport-Inglewood Fault (Source: CDMG)



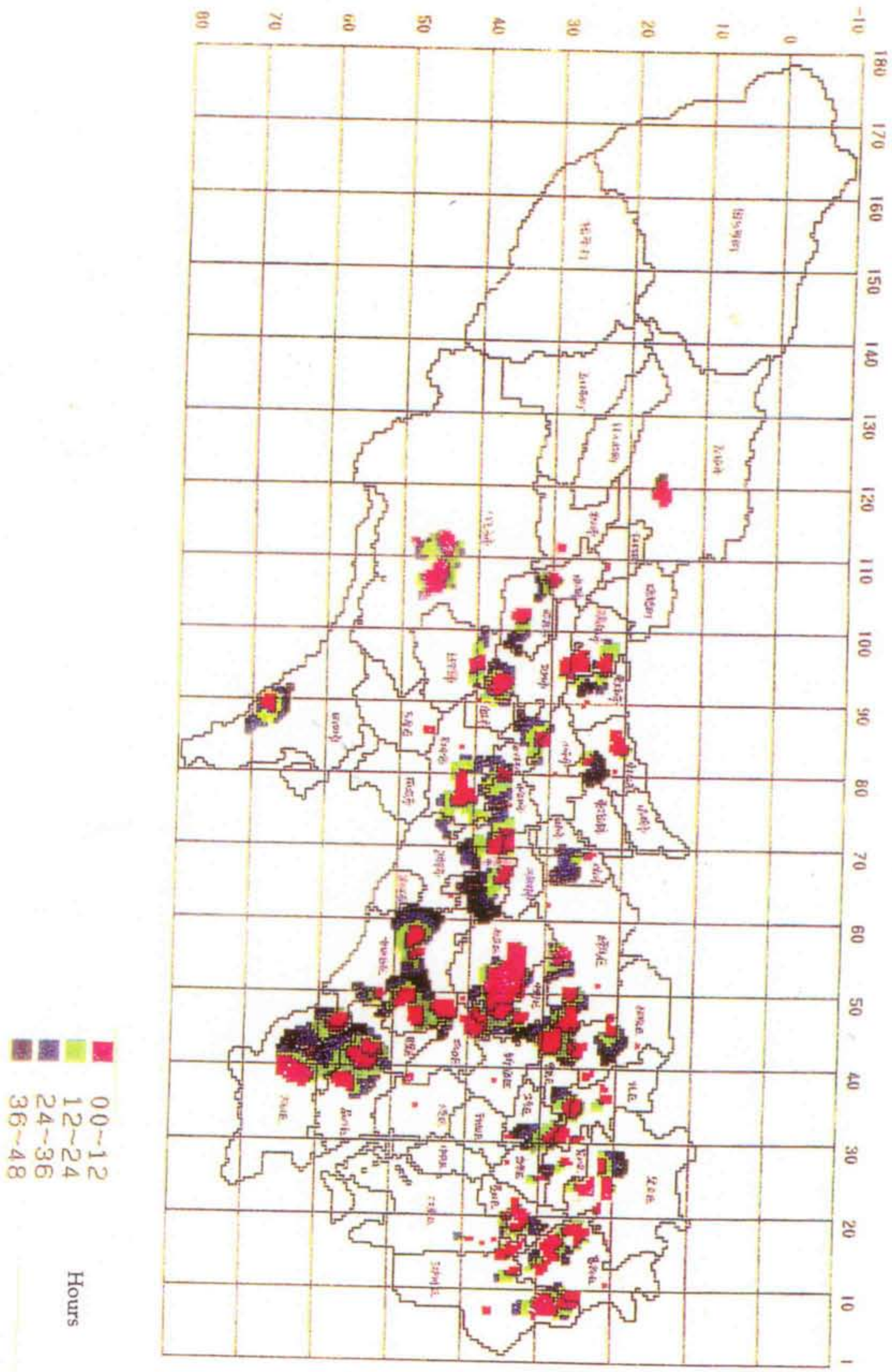
Part II Peak acceleration distribution



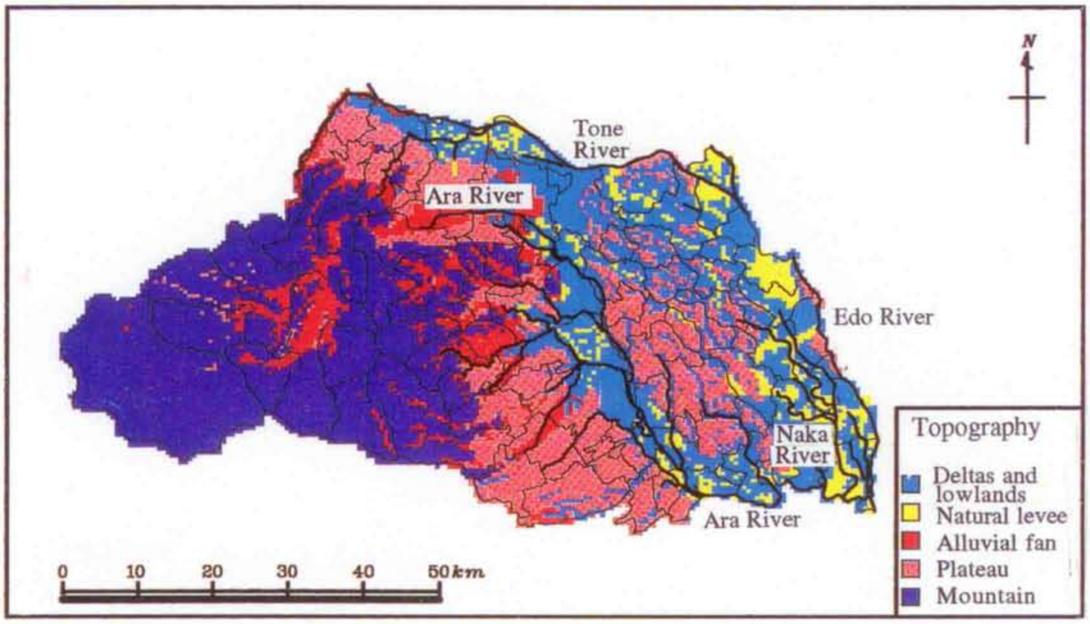
Part II Projected liquefaction



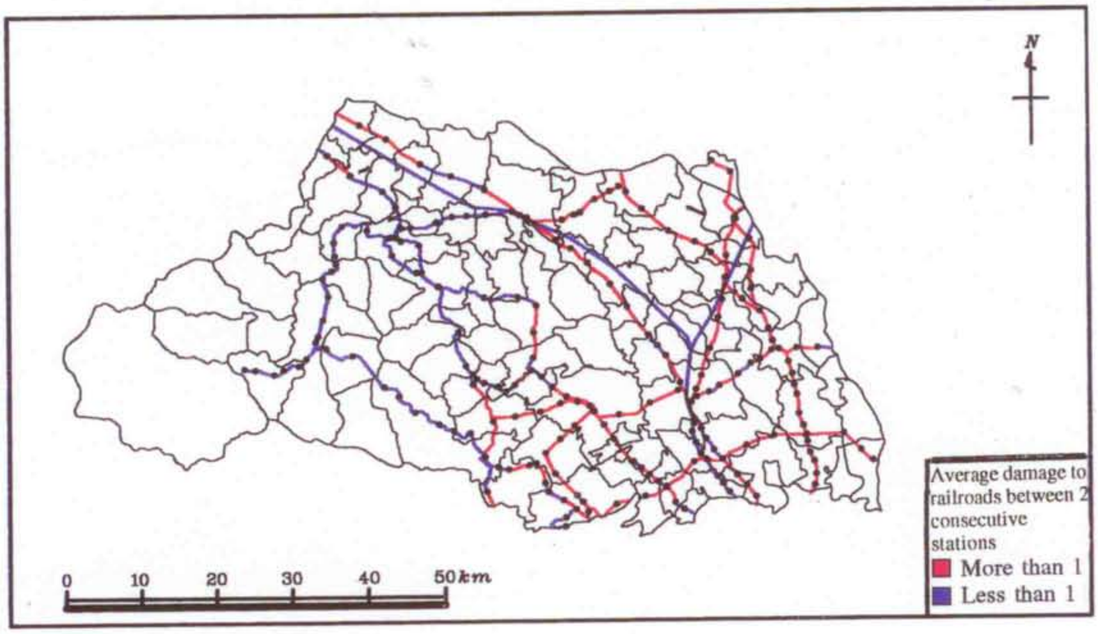
Part II Projected Building Damage



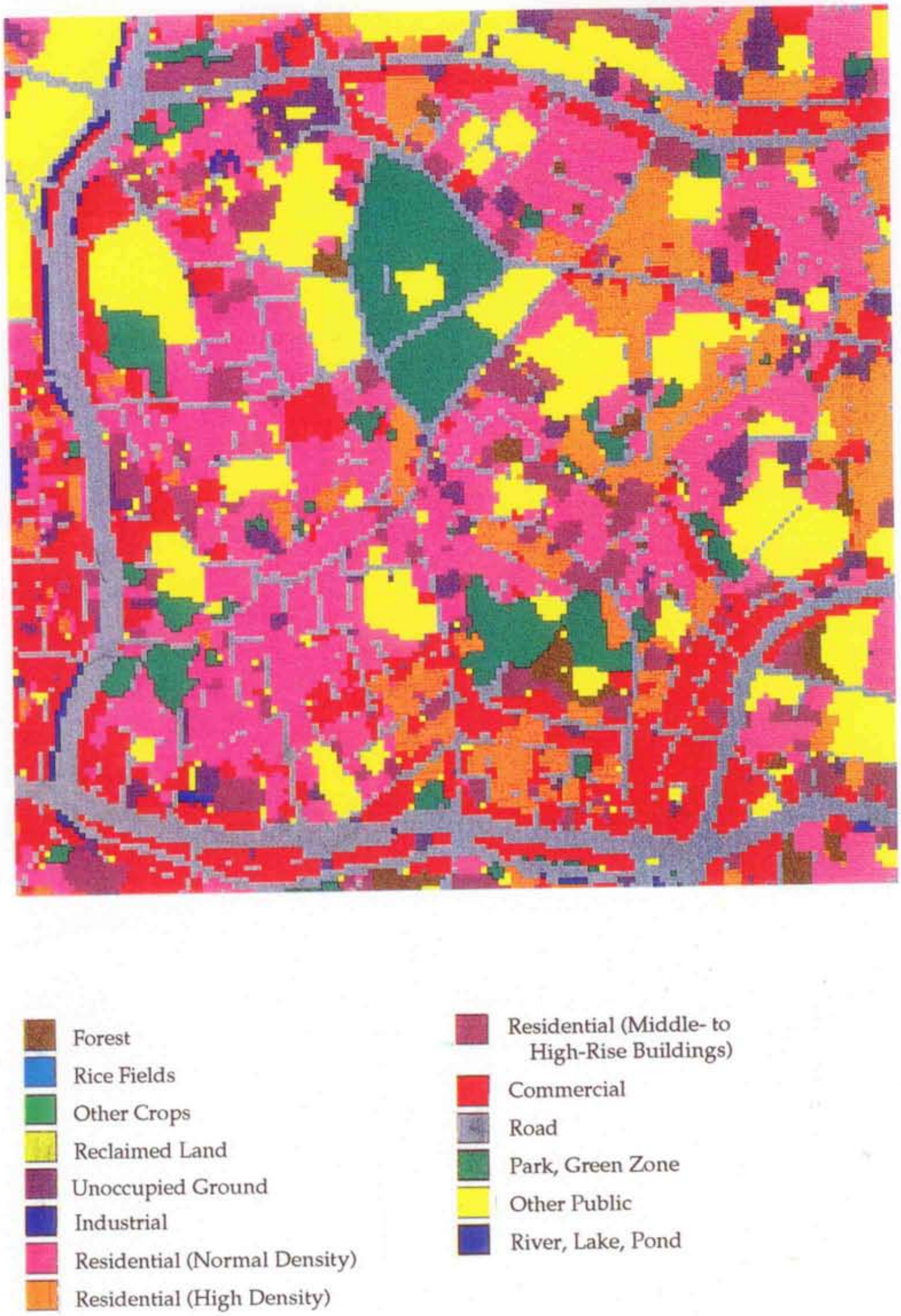
Part II Conflagration



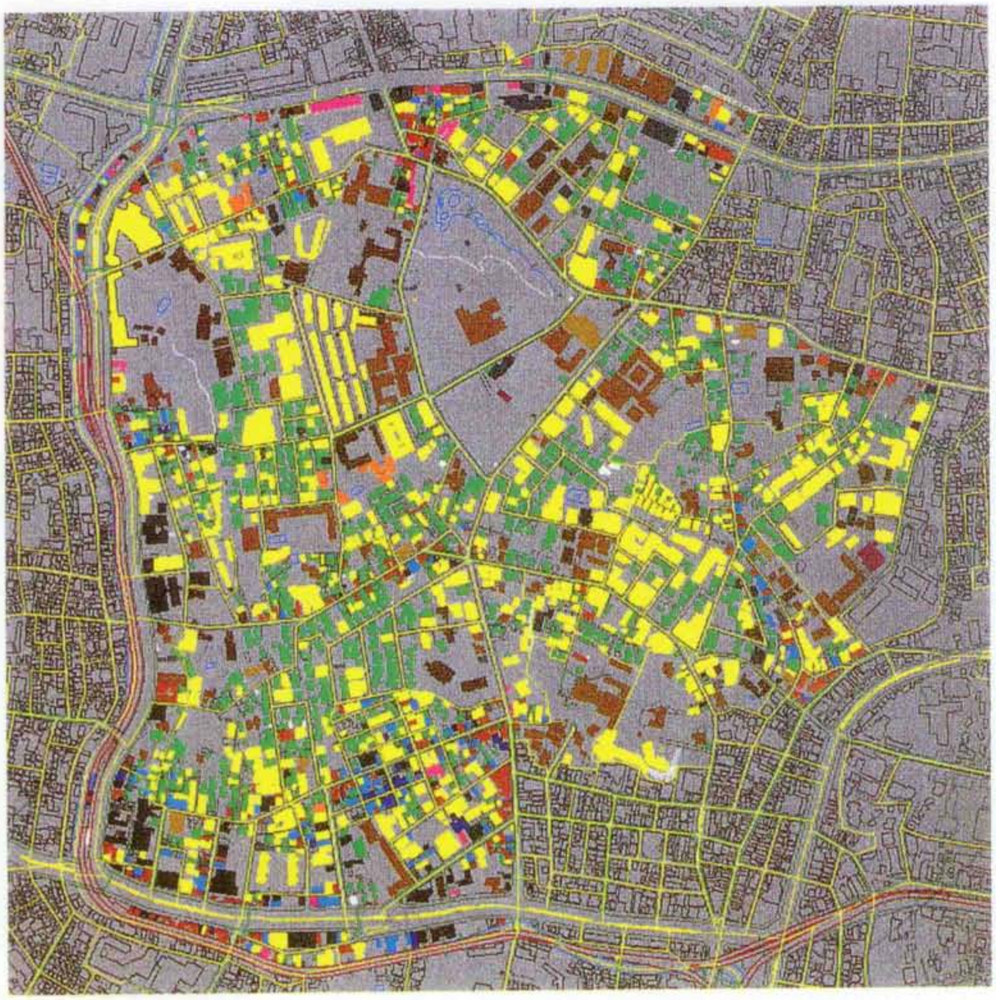
Part V Geomorphic characteristics of the Saitama prefecture



Part V Damage to railways



Part V Land use in Azabu area



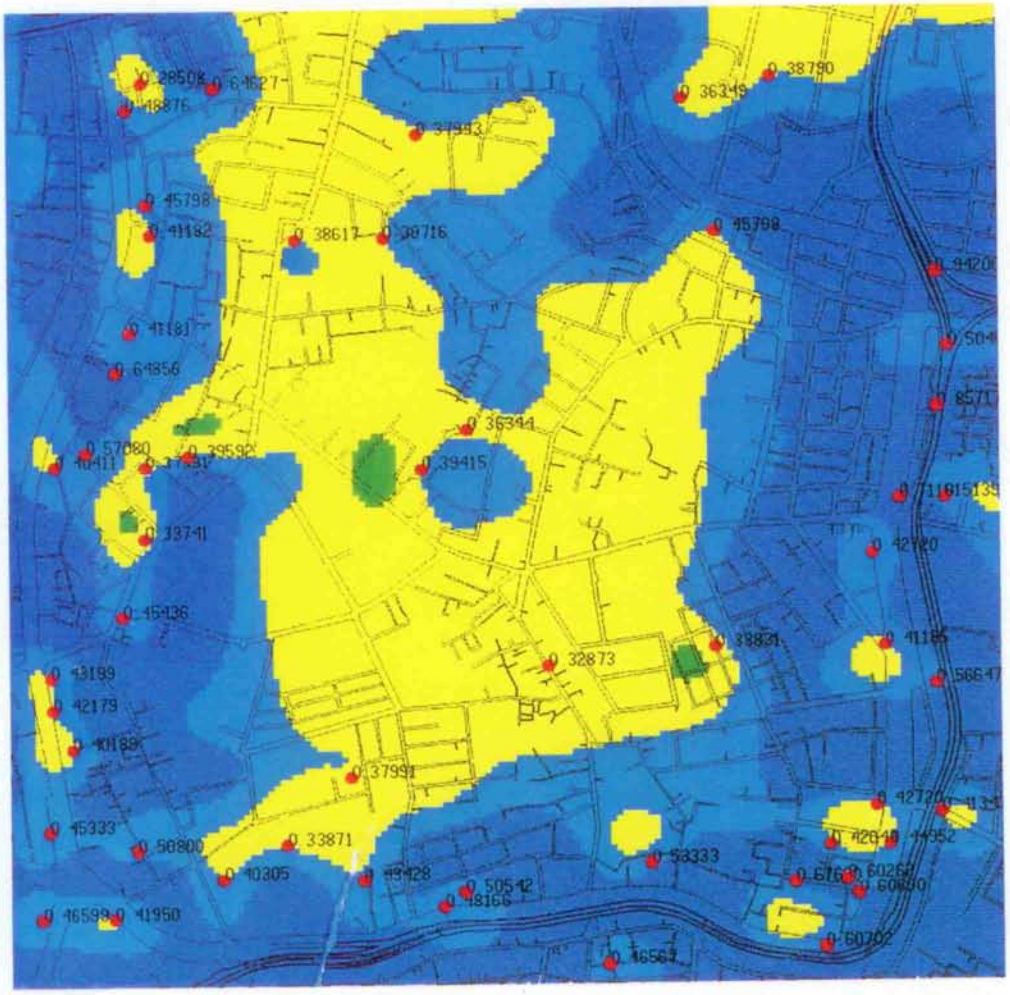
- Public Offices
- Educational Facilities
- Welfare and Medical Facilities
- Lifeline Facilities

- Offices
- Commercial Facilities (Stores)
- Residential and Commercial
- Lodging Facilities (e.g., Hotels)
- Amusement Facilities
- Private Residences
- Condominiums

- Factories
- Factories with Dormitories
- Warehouses

Part V Function of buildings

Part V Ground height



- Firm Ground ($T_g < 0.2$)
- Medium Ground ($0.2 \leq T_g < 0.4$)
- Medium-Soft Ground ($0.4 \leq T_g < 0.6$)
- Soft Ground ($0.6 \leq T_g$)

Part V Ground classification by T_g