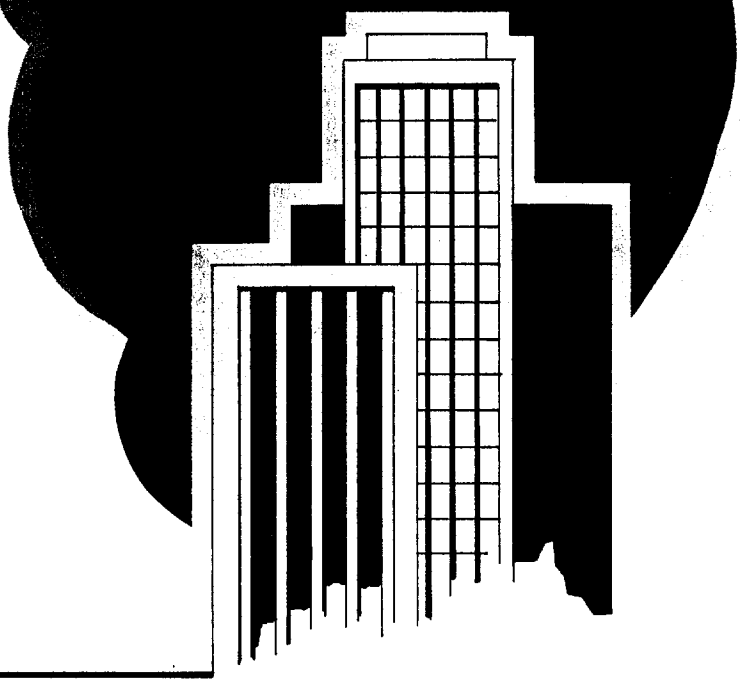
FIRE FOLLOWING EARTHQUAKE

Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco



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FIRE FOLLOWING EARTHQUAKE
Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco

Prepared for the All-Industry Research Advisory Council
By Dr. Charles Scawthorn
Dames & Moore
March 1987

This report, *Fire Following Earthquake*, is available from the All-Industry Research Advisory Council, 1200 Harger Road, Suite 222, Oak Brook, Illinois 60521. A single copy is free, 2-50 copies are $2 each, and more than 50 copies are $1.50 each. A listing of other AIRAC reports is provided at the end of this publication.

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EXECUTIVE SUMMARY

The principal findings of this study may be summarized as follows:

1. Major earthquakes in California's two largest population centers would be likely to touch off widespread conflagrations and cause fire damage in the billions of dollars.

2. Specifically, an earthquake similar to the 1906 earthquake on the northern San Andreas fault would produce an estimated $4 to $15 billion in fire damage to insured property in the San Francisco Bay area, depending primarily on wind conditions. In Southern California, a major earthquake on the Newport–Inglewood fault would produce fire losses estimated at $5 to $17 billion. These fire losses would be in addition to the damage caused by building collapse and other direct effects of seismic shaking and ground movement.

3. San Francisco faces the most serious conflagration risk. The study indicates that an earthquake similar to the 1906 event would cause fire damage of $2 to $5 billion to the city's homes and business property, representing 6% to 13% of San Francisco's total insured property values. The post-earthquake fire risk is three to four times higher in San Francisco than in other Bay area communities. Estimated fire losses for the Bay area as a whole are equivalent to 1.5% to 5% of total insured property at risk.

4. Even though the Newport–Inglewood fault runs directly beneath West-Central Los Angeles, the post-earthquake fire risk for the city as a whole is about the same as for other Los Angeles Basin communities. Estimated fire losses for the region are equivalent to 1% to 3.6% of total insured property at risk.

5. Fire following earthquake is a very serious threat to insurance companies. The fire losses shown in this study are substantially higher than the insured shake damage losses projected in a 1986 California Insurance Department study ($4.3 billion for insured shake damage in the San Francisco Bay area, $5.9 billion for insured shake damage in the Los Angeles region). The reason for this is that nearly all property is insured for fire, but fewer than 20% of homes and business properties in the two affected areas are insured for shake damage, even though California law requires insurers to offer shake coverage to property owners.

6. Substantial additional losses, many of them covered by insurance, would arise from earthquake-related injuries, damage to vehicles, lawsuits and business interruption. None of these additional losses has been taken into account in this study.

FOREWORD

This report is the result of two research studies to estimate the conflagration risk associated with major earthquakes in California. The first study was initiated by the National Science Foundation, which funded the consulting engineering firm of Dames & Moore to develop a methodology for estimating earthquake-related fire hazards, using the City of San Francisco.[1] The effort resulted in the development of a simulation model that enabled the principal investigator, Dr. Charles Scawthorn, to estimate fire losses for a wide variety of potential earthquake conditions. The model is able to take into account variations in earthquake intensities, wind speeds, disruption of water supplies, delays in discovery and reporting of fires, hindrances to fire department response, the width of streets and fire breaks, and other factors that could affect the number of fires and cause more or fewer of them to burn out of control.

The All-Industry Research Advisory Council subsequently retained Dr. Scawthorn to apply his simulation model to much larger areas, including the entire San Francisco Bay area and the Los Angeles Basin. He was asked to estimate the conflagration risk to property in those two large population centers, and to quantify the insured fire losses that might be expected to result.

The loss estimates prepared by Dames & Moore are a major contribution to understanding the magnitude of the earthquake risk faced by property owners and their insurance companies. Most previous research on the earthquake risk to insurance companies has been focused on the direct damage caused by seismic shaking and ground movement. Relatively little attention has been devoted to quantifying the risk posed by post-earthquake fires, even though fire caused the major part of the massive losses from the 1906 earthquake. The study makes it apparent that fire remains one of the most serious financial threats associated with earthquakes in heavily populated urban areas, despite improvements in building construction and firefighting techniques in recent years. Because fire is nearly always insured and shake damage frequently is not, fire is the most serious earthquake exposure quantified to date for insurers.

Readers of this report should keep in mind that individuals, property owners and their insurers also are subject to a number of earthquake losses other than fire and shake damage to homes and other buildings. The insured portion includes damage to vehicles, injuries covered by health and workers compensation policies, lawsuits arising from quake damage, and business interruption caused by damage to buildings and their contents. These types of insurance risk exposures were not taken into account in this study nor in the California Insurance Department's studies of shake damage.[2]

Business interruption losses, in particular, could be very large because of the massive disruption that would be caused by the destruction of entire sections of a city, plus widespread damage to power lines, water mains, streets, sewers and communications facilities. Shortages of building materials, architects, contractors and others needed for the reconstruction process would raise rebuilding costs and result in longer than normal reconstruction times. Repairs to industrial installations would have to await the fabrication of custom-built parts in some instances, and delays could be substantial if the supplier likewise sustained earthquake damage or was faced with orders from a number of damaged installations at the same time. About one-third of commercial property insurance policies contain coverage for business interruption losses.

For all of these reasons, the full magnitude of the earthquake risk has not yet been quantified. However, this study and the Insurance Department's earlier shake damage studies provide information on the two kinds of losses believed to pose the greatest threat to insurers.

To individual insurance companies wishing to use the data contained in this study for assessing their own risk exposures, be advised that AIRAC plans to do further work to make the findings more readily usable for risk assessment purposes. Because of the public significance of the overall findings, a decision was made to publish them as soon as possible without waiting for that additional work to be completed.

In the meantime, insurers and others can obtain a considerable amount of usable data from Appendix 4 (San Francisco Bay Area) and Appendix 7 (Los Angeles Basin). These tables assume the occurrence of major earthquakes accompanied by winds of about 10 mph, conditions fairly typical of those two regions. The extreme right hand column of each table shows the estimated percentage of insured building values likely to be destroyed by fire following an earthquake occurring under those wind conditions. The fire loss estimates shown in those two tables are thought to be roughly equivalent to the "Probable Maximum Loss" estimates for insured shake damage as shown in the California Insurance Department's research studies.

All-Industry Research Advisory Council

[1] Scawthorn, Charles, *An Investigation of Post-Earthquake Fire Risk: Final Report to the National Science Foundation*, 1987.

[2] California Insurance Department, *California Earthquake Zoning and Probable Maximum Loss Evaluation Program*, June 1986

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Wayne W. Sorenson
Chairman, AIRAC Fire Following Earthquake Committee

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CHAPTER 1
INTRODUCTION

The purpose of this report is to provide estimates of the potential losses that would occur today, due to fires following a large California earthquake.

Earthquakes have long been recognized as a serious threat to property in the United States. As the seismically active Western United States has experienced rapid economic growth in the years following World War II, the loss potential due to earthquakes has grown tremendously. This can be seen in the two maps on Figure 1, which compares population and seismicity for the contiguous United States. Much of the Western U.S. is sparsely populated and an earthquake in these areas is not likely to damage large amounts of property. However, the band of seismicity along coastal California associated with the San Andreas fault system[3] is in close proximity to the heavily populated Los Angeles and San Francisco urban areas, so that a large earthquake in these areas has the potential for catastrophic losses. This risk is exacerbated by the fact that in these areas much of the population and property value is concentrated in coastal and shoreline areas, or areas that were recently marsh or stream channels, areas that tend to amplify ground shaking and displacement.

Property losses associated with a large earthquake in these areas are potentially enormous, to the point where the Federal Emergency Management Agency has called them "potentially the worst catastrophe to strike the United States since the Civil War."[4]

While potential losses of this magnitude are of concern to everyone, they are of especial concern to the insurance industry. The occurrence of a large earthquake in a major urban area would cause enormous financial problems for insurers on a global scale. Although not all earthquake losses are covered by insurance, the insured losses might well be large enough to cause the failure of some companies.

Since underwriting is a multi-faceted process, with a great variety of coverages, deductibles, and limits, the consequences for the insurance industry of a large California earthquake depend to an unusual degree on the nature and distribution of the damage. Almost all California homeowners are insured for fire, but only about 15% to 20% of homeowners carry additional special coverage for earthquake shaking. The proportion of commercial property owners purchasing specific coverage for shake damage is thought to be similar.[5] In addition, shake damage is usually written with deductibles of 5% to 10% of the amount of coverage in force. The crucial point is that homeowners and commercial policies exclude coverage for earthquake shaking, unless specific shake damage coverage has been purchased at an additional premium, but they cover all kinds of fire damage including fire caused by earthquake shaking.

While many aspects of fire and earthquakes have been investigated in recent years, one aspect that has been little treated has been the subject of fire spread in an urban region following an earthquake. That fire following earthquake has been little researched or considered in the United States is particularly surprising when one realizes that the conflagration in San Francisco, following the 1906 earthquake, was the single largest urban fire and the single largest earthquake loss in American history. The earthquake of April 18, 1906, of magnitude[6] M 8+ was the result of the San Andreas fault rupturing along more than 200 miles of its length. The shaking damage in the City of San Francisco was considerable, especially in the soft

[3] The San Andreas and associated faults extend for many hundreds of miles from the Gulf of California in Mexico northwards to off Cape Mendocino, along the way passing through or close to the heavily populated Los Angeles Basin and San Francisco Bay areas. The faults form the boundary between the Pacific and North American plates, two of the largest crustal tectonic units on earth. In coastal California, the Pacific plate is moving northwards (or to the right when standing on the North American plate and looking at the Pacific plate) several millimeters a year. This movement is prevented in the immediate vicinity of the earthquake faults, due to friction and local irregularities of the crust which "lock" the faults. When sufficient decades have passed for the millimeter per year movement to add up to several feet or more, the friction and locking are overcome by the accumulated strain-energy, and the plates slide past each other. The vibrations associated with this sliding or bumping of large irregular blocks of earth are the shaking that we experience, and call earthquakes.

[4] FEMA, *An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake*, 1980.

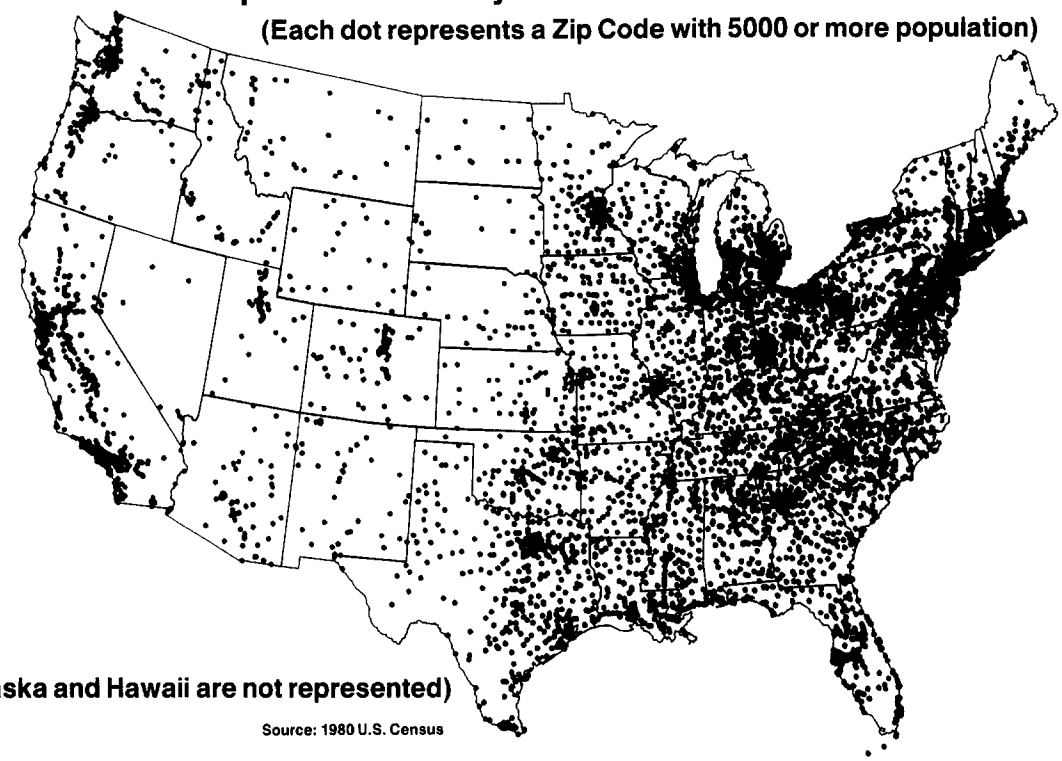
[5] The California Insurance Department's 1986 report on shake damage indicated that property insurers had about $33.3 billion in insured exposures for shake damage in San Francisco, San Mateo, Alameda and Contra Costa counties during 1985. That amounts to 22.4% of the insured fire exposures AIRAC estimated for the same area, using 1983 data. For Los Angeles and Orange counties, the Insurance Department estimated insured shake damage exposures at about $78.4 billion, or 17.5% of the insured exposures estimated by AIRAC for fire damage. All of these figures are for residential and commercial property combined.

[6] Magnitude can be thought of as a measure of the energy released by an earthquake. As originally defined by Charles Richter in 1935, it was the logarithm of the maximum amplitude measured in microns on the record of a standard torsion seismograph (Wood-Anderson) with a pendulum period of 0.8 sec., magnification of 280, and damping factor 0.8, located at a distance of 100 km. from the epicenter. This magnitude scale is now referred to as local magnitude M_L. There are now numerous magnitude scales in use. Herein, unless otherwise noted, where the term magnitude (or M) is employed we refer to surface wave magnitude, M_S, which is due to Gutenberg and Richter. On that scale, M 6 is often considered a large, M 7 a major and M 8 a great earthquake.

FIGURE 1

Population Density of The United States

(Each dot represents a Zip Code with 5000 or more population)



(Alaska and Hawaii are not represented)

Source: 1980 U.S. Census

Earthquakes in the United States

(Intensity V and above, through 1970)

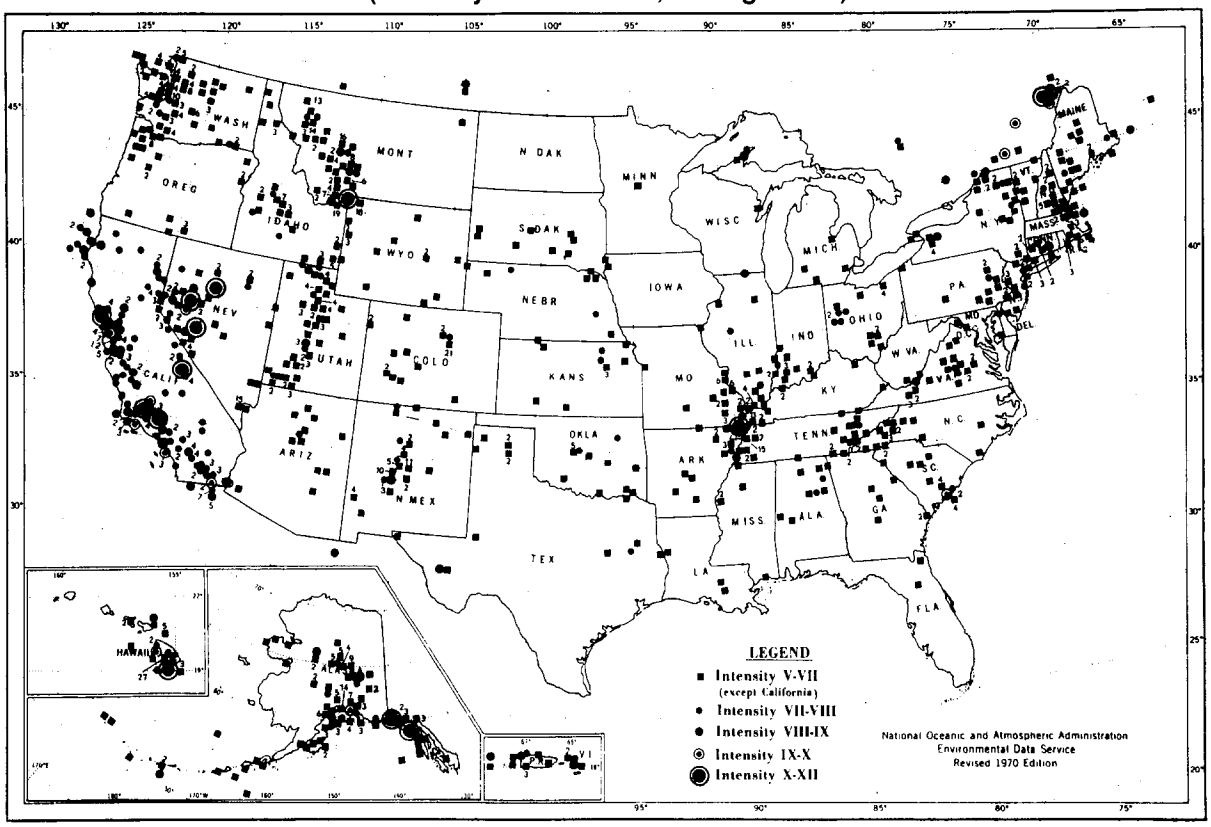
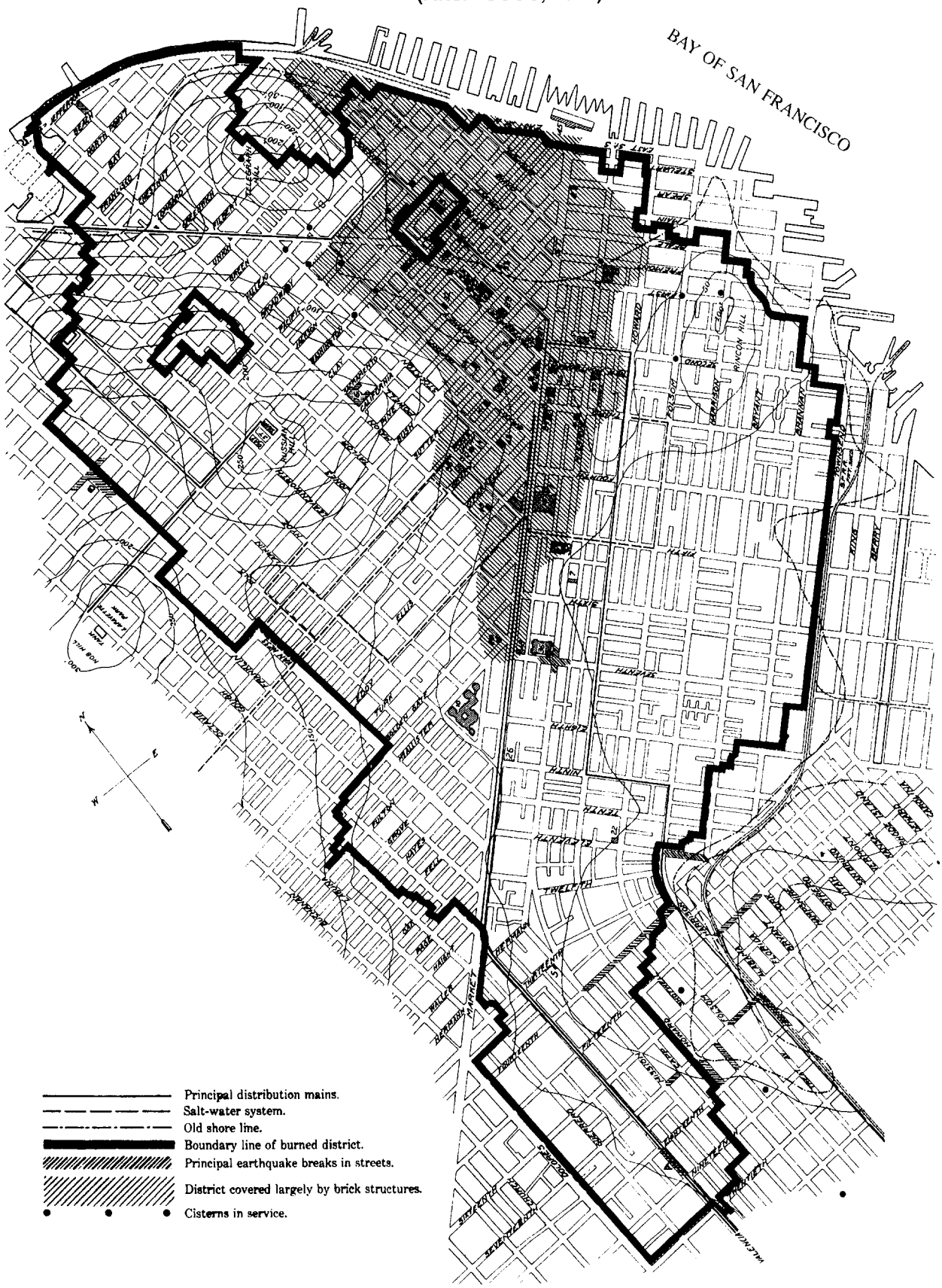


FIGURE 2

Map of San Francisco Showing District Burned in 1906

(After–USGS, 1907)



filled-in ground along the bay, on which much of the central business district was located, where permanent ground displacements of several feet were noted in numerous locations. Especially severely affected by these large ground displacements were the underground water pipes. The hundreds of breaks in these pipes resulted in loss of virtually all water in this densely built-up area, so that the fire department was helpless to stop the dozens of fires which ignited almost immediately following the earthquake. The result was one of the largest conflagrations the world had ever seen, with enormous destruction. The loss, in a city of about 400,000 persons, of over 28,000 buildings within an area of 4 square miles, in a period of three days, was staggering: $500,000,000 in 1906 dollars (USGS, 1907), or about $5.8 billion at today's prices (see Figure 2).

The fire following earthquake problem remains important today, especially in cities which have a large wood building stock, which is true of most cities in the U.S., particularly the seismically active West (e.g., Los Angeles, San Francisco). The hazard also exists with regard to industrial facilities, such as oil refineries, chemical plants, etc. The post-earthquake fire problem is complex and involves many diverse elements. The recent 1983 Coalinga and 1984 Morgan Hill earthquakes have pointed out some of these elements:

1. Fire departments functioned well but were inundated with numerous demands involving not only fire but structural damage, search and rescue, hazardous material incidents and medical aid,
2. Communications were seen to be extremely vital, but highly vulnerable, especially with regard to reporting initial fires to the fire departments,
3. Due to delays in reporting, fires rapidly grew larger, escalating demands on fire service resources.

The diversity, significance and complexity of fires following earthquakes are evident. This complexity requires simulation modeling, which has not been previously applied to this problem in the United States.

The present All-Industry Research Advisory Council (AIRAC) study is an application of newly available simulation modeling techniques, developed under National Science Foundation funding, to provide estimates of the potential losses that would occur today, due to fires following a large California earthquake. While the possibility exists of many different large earthquakes in California, two hypothetical but realistic earthquake scenarios were assumed for this study. These scenario earthquakes are discussed in the next section.

The firm of Dames & Moore, Consultants in the Applied Earth Sciences, was retained as a consultant for the project, in order to apply simulation modeling techniques they have developed to treat the problem of fire following earthquake. Data on insurance exposures in the affected regions of California was provided to Dames & Moore by AIRAC, based on data provided by major insurance companies and statistical organizations.

The next Chapter summarizes this report and its conclusions. Following that, Chapter 3 presents the methodology employed in providing the estimates of potential losses. Chapter 4 then discusses the application of this methodology to the scenario events. Lastly, Chapter 5 briefly discusses the application of these findings by individual companies.

CHAPTER 2
SUMMARY AND CONCLUSIONS

In the Spring of 1985, the All-Industry Research Advisory Council (AIRAC) began a Study to Quantify Monetary Losses Caused by Fire Following Earthquake, in an effort to determine how significant a problem post-earthquake fire might be for the insurance industry.

Of the many large earthquakes that might possibly occur in California, two scenario events were selected:

1. An M 8.3 event on the northern San Andreas fault—essentially a repeat of the 1906 earthquake, and
2. An M 6.5 event on the Newport-Inglewood fault zone, striking the central Los Angeles region.

Figures 3A, 3B and 4 show the shaking intensities, on the Modified Mercalli Intensity scale,[7] for the major urban areas affected by these two events.[8] These events were selected because they were among the most damaging that might credibly be thought to affect urban areas of either northern or southern California and result in large fires. The likelihood of the M 8.3 event occurring in the next few decades is considered moderate,[9] but will have more severe impacts when it does occur, compared to 1906, due to a much larger building inventory and population.

The occurrence of an M 6.5 event on the Newport-Inglewood fault zone also is considered of moderate likelihood, and is a very realistic planning scenario for the Los Angeles region (USGS, 1985). This event would be directly under west-central Los Angeles, and its occurrence would be very damaging, indeed potentially the most damaging earthquake for the United States since 1906. (An earthquake of M 7.0 or higher is considered possible on this fault zone but its occurrence is considered less likely.)

In summary, the methodology employed to estimate losses due to fire following an earthquake affecting an urban region begins with the estimation of shaking intensity (MMI) and resulting shaking damage to the buildings and other structures in the region. Shaking damage is estimated as a function of intensity and construction type, and is of interest only to estimate the deterioration in fire protection features of buildings (e.g., loss of facade increases the exposure). Damage and remaining functionality of the water supply system is also estimated, based on shaking intensity and likelihood of liquefaction.[10] Outbreaks of fires caused by the earthquake are then estimated, as a function of building square footage and shaking intensity. Only serious fires, which citizens are unable to suppress unaided and which require the response of the fire department, are considered. Growth of each of these fires is tracked during (a) the initial pre-fire department response period, while reporting of the fire and travel by the fire apparatus to the fire occurs under post-earthquake conditions, and (b) the suppression period, when extinguishment is attempted but may not be successful, due to inadequate apparatus, manpower or water. In tracking fire growth, building density, materials and post-earthquake condition, wind speed, average fire-break width, water supply functionality and available firefighting resources including mutual aid, are taken into account.

The result may be either a number of medium to large fires which are typically contained within the city block of incidence, or a few or more fires for which extinguishment is not possible. These fires grow out of control, cross city streets from block to block, and become conflagrations. Typically, these fires are found to burn for several or more blocks until encountering a large firebreak (e.g., a freeway, athletic field, park, etc.), where they are either stopped by the available firefighting resources or, in some cases, simply burn themselves out. Resulting regional fire losses are the summation of these fires. In the present study, due to the costs of data collection, data

[7] Intensity is a measure of the *effects* of an earthquake (as opposed to magnitude, which is a measure of the size of an earthquake). Any particular earthquake has only one magnitude, whereas the same earthquake has an infinite number of intensities, each intensity being particular to a specific site. Generally speaking, intensities decrease with distance from the epicenter, and increase with "poorer" (i.e., softer or weaker) soils. Thus, a very soft site at a substantial distance from an earthquake may have higher intensities than a better site closer to the earthquake, such as occurred in the 1985 Mexico City earthquake. Intensity is commonly enumerated in Roman numerals and, in the U.S., measured on the Modified Mercalli (MMI) scale, which is given in Table 1.

[8] These maps are based on the work of Dr. Jack F. Evernden of the U.S. Geological Survey (Menlo Park).

[9] That is, moderate as compared with certain other fault segments which are considered more likely to rupture, such as a portion of the San Andreas fault in southern California. See Lindh (1983) for an assessment of earthquake occurrence probabilities.

[10] Liquefaction is a phenomenon involving the loss of shear strength of a soil. The shear strength loss results from an increase in pore water pressure, caused by the rearrangement of soil particles induced by shaking or vibration. Liquefaction has been observed in many earthquakes, usually in soft poorly graded granular materials, i.e., loose sands) with high water tables. Liquefaction usually occurs in these soils during or shortly after a large earthquake. In effect, the liquefied soil strata behave as a heavy fluid. Buried tanks may "float" to the surface, and structures founded in the liquefied strata may "sink." Pipes passing through liquefiable materials typically sustain a relatively high number of breaks in an earthquake.

TABLE 1
MODIFIED MERCALLI INTENSITY SCALE
(ABRIDGED)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everyone 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 chinmeys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plum; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few (if any) masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

FIGURE 3A

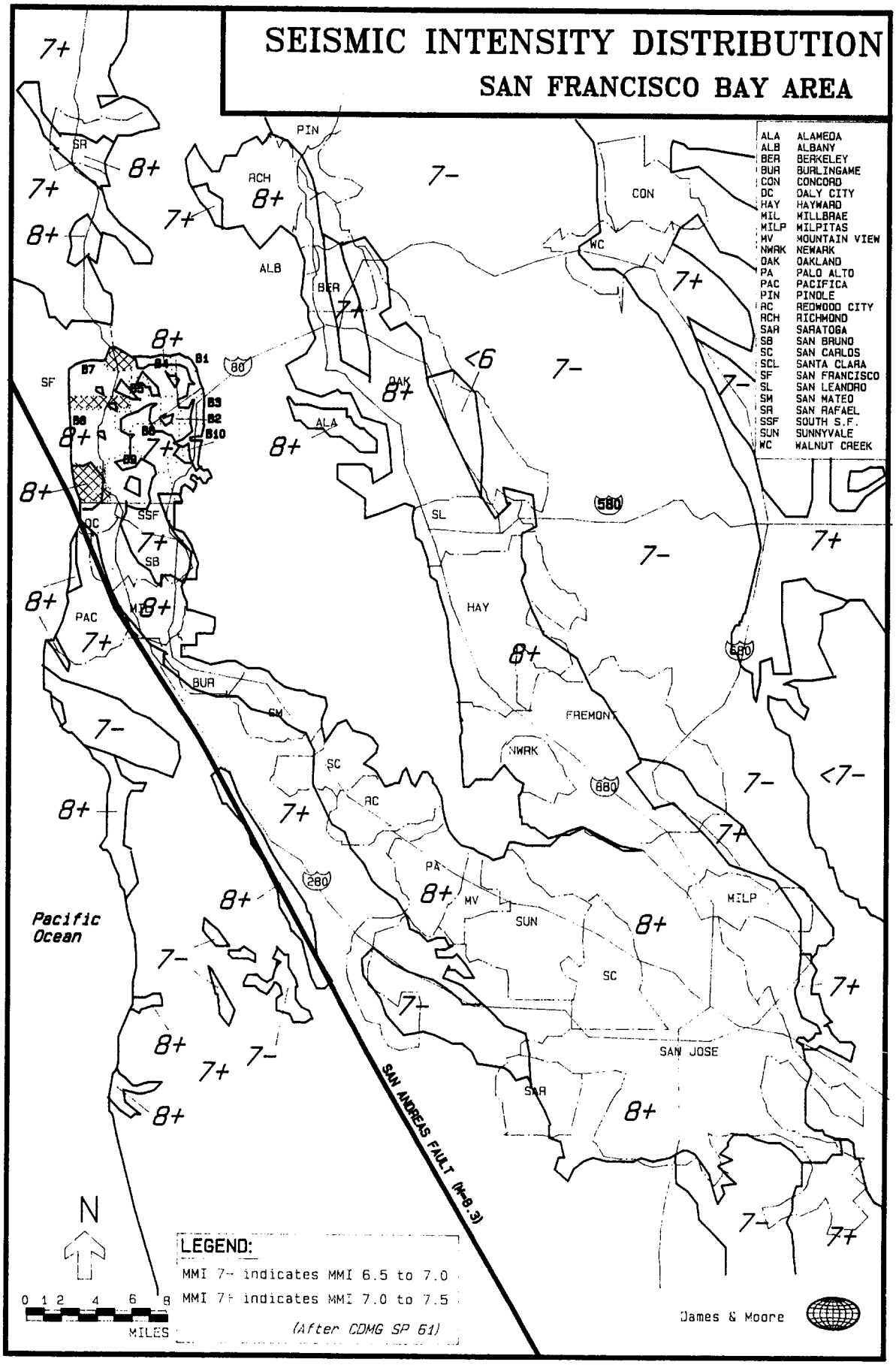

SEISMIC INTENSITY DISTRIBUTION
SAN FRANCISCO BAY AREA
ALA ALAMEDA
ALB ALBANY
BER BERKELEY
BUR BURLINGAME
CON CONCORD
DC DALY CITY
HAY HAYWARD
MIL MILLBRAE
MILP MILPITAS
MV MOUNTAIN VIEW
NWRK NEWARK
OAK OAKLAND
PA PALO ALTO
PAC PACIFICA
PIN PINOLE
RC REDWOOD CITY
RCH RICHMOND
SAR SARATOGA
SB SAN BRUNO
SC SAN CARLOS
SCL SANTA CLARA
SF SAN FRANCISCO
SL SAN LEANDRO
SM SAN MATEO
SR SAN RAFAEL
SSF SOUTH S.F.
SUN SUNNYVALE
WC WALNUT CREEK
Pacific Ocean
SAN ANDREAS FAULT (M=8.3)
LEGEND:
MMI 7- indicates MMI 6.5 to 7.0
MMI 7+ indicates MMI 7.0 to 7.5
(After CDMG SP 61)
0 1 2 4 6 8
MILES
N
James & Moore

FIGURE 3B

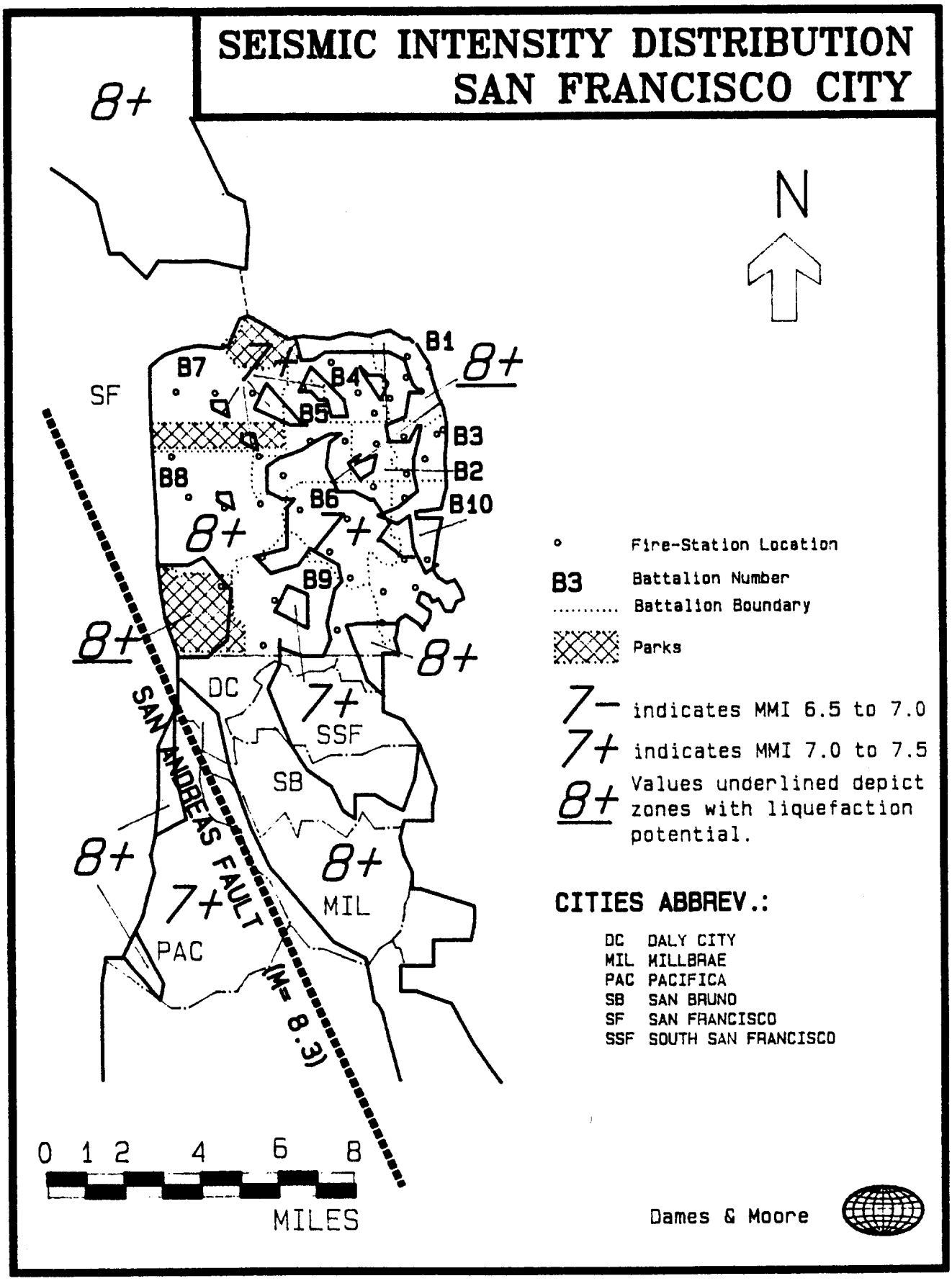
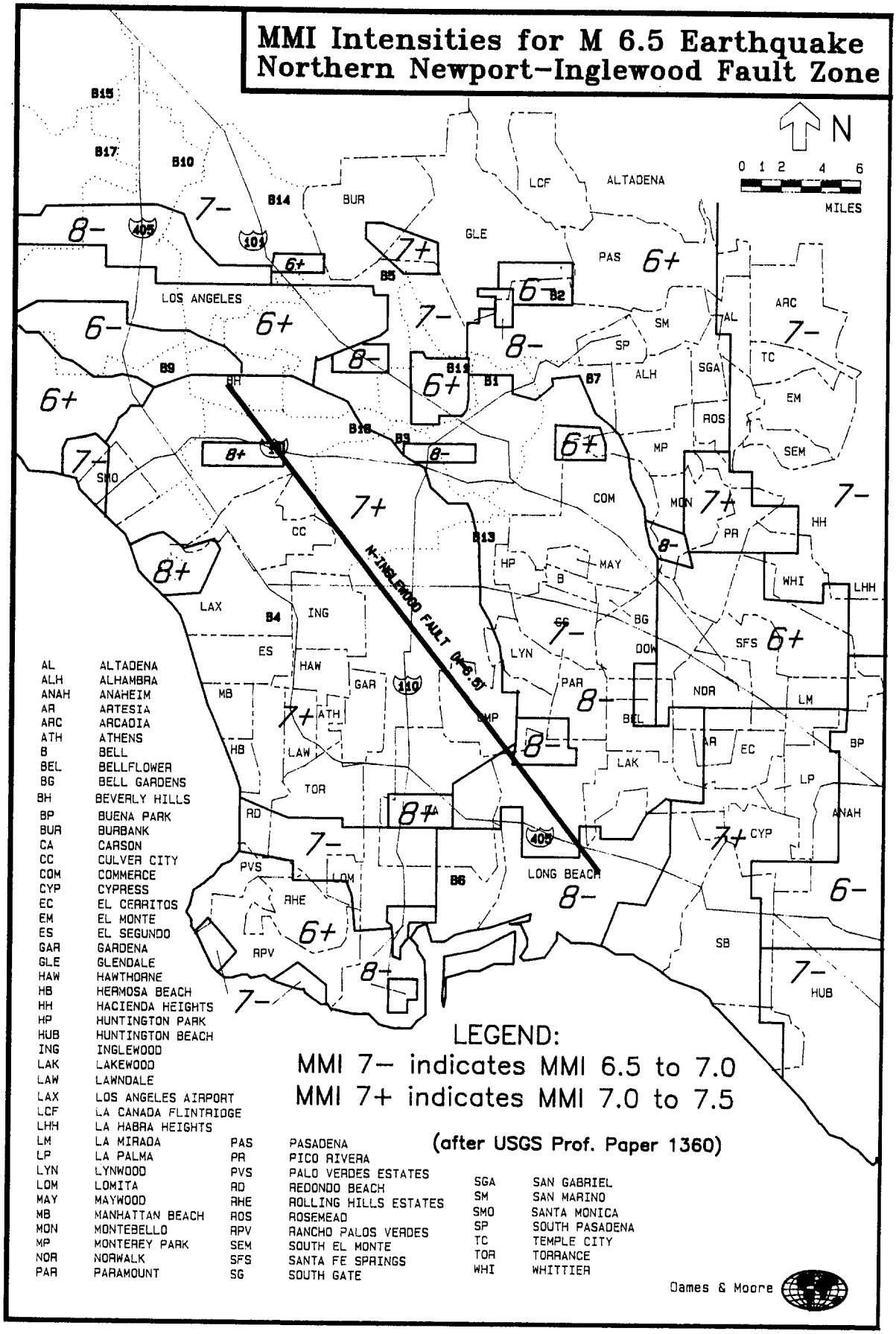

SEISMIC INTENSITY DISTRIBUTION
SAN FRANCISCO CITY
N
8+
B1
B7
B4
B5
B3
B2
B8
B6
B10
B9
SF
DC
SSF
SB
MIL
PAC
SAN ANDREAS FAULT
(M= 8.3)
0 1 2 4 6 8
MILES
Fire-Station Location
B3 Battalion Number
Battalion Boundary
Parks
7- indicates MMI 6.5 to 7.0
7+ indicates MMI 7.0 to 7.5
8+ Values underlined depict zones with liquefaction potential.
CITIES ABBREV.:
DC DALY CITY
MIL MILLBRAE
PAC PACIFICA
SB SAN BRUNO
SF SAN FRANCISCO
SSF SOUTH SAN FRANCISCO
Dames & Moore

FIGURE 4


MMI Intensities for M 6.5 Earthquake
Northern Newport–Inglewood Fault Zone
N
0 1 2 4 6
MILES
N-INGLEWOOD FAULT (M=6.5)
LOS ANGELES
ALTADENA
LONG BEACH
AL ALTADENA
ALH ALHAMBRA
ANAH ANAHEIM
AR ARTESIA
ARC ARCADIA
ATH ATHENS
B BELL
BEL BELLFLOWER
BG BELL GARDENS
BH BEVERLY HILLS
BP BUENA PARK
BUR BURBANK
CA CARSON
CC CULVER CITY
COM COMMERCE
CYP CYPRESS
EC EL CERRITOS
EM EL MONTE
ES EL SEGUNDO
GAR GARDENA
GLE GLENDALE
HAW HAWTHORNE
HB HERMOSA BEACH
HH HACIENDA HEIGHTS
HP HUNTINGTON PARK
HUB HUNTINGTON BEACH
ING INGLEWOOD
LAK LAKEWOOD
LAW LAWNDALE
LAX LOS ANGELES AIRPORT
LCF LA CANADA FLINTRIDGE
LHH LA HABRA HEIGHTS
LM LA MIRADA
LP LA PALMA
LYN LYNWOOD
LOM LOMITA
MAY MAYWOOD
MB MANHATTAN BEACH
MON MONTEBELLO
MP MONTEREY PARK
NOR NORWALK
PAR PARAMOUNT
PAS PASADENA
PR PICO RIVERA
PVS PALO VERDES ESTATES
RD REDONDO BEACH
RHE ROLLING HILLS ESTATES
ROS ROSEMEAD
RPV RANCHO PALOS VERDES
SEM SOUTH EL MONTE
SFS SANTA FE SPRINGS
SG SOUTH GATE
SGA SAN GABRIEL
SM SAN MARINO
SMO SANTA MONICA
SP SOUTH PASADENA
TC TEMPLE CITY
TOR TORRANCE
WHI WHITTIER
LEGEND:
MMI 7– indicates MMI 6.5 to 7.0
MMI 7+ indicates MMI 7.0 to 7.5
(after USGS Prof. Paper 1360)
Dames & Moore

such as building density, fire station spacing, etc., is averaged for each jurisdiction or handled statistically, instead of being modeled in detail for each jurisdiction. Where warranted, such as for the cities of San Francisco and Los Angeles, jurisdictions are modeled in greater detail (e.g., at the fire department battalion level).

Expected Number of Large Fires

Table 2 shows the number of post-earthquake fires likely to require fire department attention, and the number of those fires likely to be already out of control (i.e., too large to be suppressed by one fire engine) at first arrival. The research indicates that the San Francisco Bay area would experience an estimated 500 to 600 fires requiring fire department response under typical conditions (Levels I and II, fire factor 1.0). With winds calm to light, about 30% of those fires would become large fires by the time the first pumper arrived, and about 60% would become large fires if the earthquake were accompanied by winds of about 10 mph. For the Los Angeles Basin, the study estimates about the same number of fires but indicates that more of them would become large fires—about 60% with winds calm to light, and 80% with 10 mph winds. The Level III estimates, which assume 20% more initial fires plus winds of 20 mph or more, call for 70% of the fires to become large in the Bay area and 95% to become large in the Los Angeles area.

Note that the number of large fires increases with higher wind speeds, even when the number of ignitions remains constant. What is not evident from these figures alone is that the area ultimately burned by each large fire also gets larger at higher wind speeds, producing much higher dollar losses to property.

Estimates of Insured Losses

Table 3 displays our findings with regard to the estimated insured loss from fire following earthquake under three different sets of post-earthquake conditions. Level I conditions assume there is little or no wind and that there are no adverse factors present to increase the number of fires requiring a fire department response. Fires requiring such response are reported only 5 minutes after discovery, and fire engines are able to average 15 mph in traveling to the fires. Level II conditions are similar except that wind speeds average 10 mph, typical of the Bay area and

TABLE 2
ESTIMATED NUMBER OF FIRES CAUSED BY EARTHQUAKE
San Francisco and Los Angeles Regions

Earthquake Conditions	San Francisco Bay Area		Los Angeles Basin	
	Number of Fires Requiring Fire Department Response	Number of Large Fires[a]	Number of Fires Requiring Fire Department Response	Number of Large Fires[a]
Level I[b] (winds 0 mph, Fire Factor 1.0)	567	164	527	309
Level II[c] (winds 10 mph, Fire Factor 1.0)	567	321	527	440
Level III[d] (winds 20 mph, Fire Factor 1.2)	680	411	632	497

[a] Large fires are those out of control at first arrival (i.e., fires that cannot be suppressed by one fire engine).

[b] Level I represents generally favorable post-earthquake conditions—calm to light wind conditions, an average number of fires requiring fire department response, reporting of fires only 5 minutes after discovery, and fire engine response times based on travel at 15 miles per hour.

[c] Level II assumes intermediate conditions involving moderate winds (approximately 10 mph), typical for San Francisco Bay and the Los Angeles Basin. Other conditions are similar to those for Level I.

[d] Level III assumes relatively adverse conditions, including stronger winds (20 mph or greater) and a 20% greater than average number of fires requiring fire department response. These are extreme conditions, but not the worst that could possibly occur.

NOTE: Although the simulation results shown in Table 2 are given to three significant digits, these are only estimates and should not be considered reliable beyond one or perhaps two significant digits.

TABLE 3
ESTIMATED INSURED LOSS FROM FIRE FOLLOWING EARTHQUAKE
San Francisco and Los Angeles Regions

Earthquake Conditions	San Francisco Bay Area: Estimated Fire Loss in Billions of Dollars	San Francisco Bay Area: Fire Loss As % of $264 Billions of Property Values At Risk	Los Angeles Basin: Estimated Fire Loss in Billions of Dollars	Los Angeles Basin: Fire Loss As % of $466 Billions of Property Values At Risk
Level I[a] (winds 0 mph, Fire Factor 1.0)	$4	1.5%	$5	1.1%
Level II[b] (winds 10 mph, Fire Factor 1.0)	$7	2.6%	$9	2.0%
Level III[c] (winds 20 mph, Fire Factor 1.2)	$9-$15	3.4%-5.7%	$13-$17	2.7%-3.6%

[a] Level I represents generally favorable post-earthquake conditions—calm to light wind conditions, an average number of fires requiring fire department response, reporting of fires only 5 minutes after discovery, and fire engine response times based on travel at 15 miles per hour.

[b] Level II assumes intermediate conditions involving moderate winds (approximately 10 mph), typical for San Francisco Bay and the Los Angeles Basin. Other conditions are similar to those for Level I.

[c] Level III assumes relatively adverse conditions, including strong winds (20 mph or greater) and a 20% greater than average number of fires requiring fire department response. These are extreme conditions, but not the worst that could possibly occur.

Los Angeles. Level III conditions are more adverse, involving 20 mph winds and other factors that increase the number of fires requiring professional firefighting by 20%.

For the $264 billion in property values at risk in the San Francisco Bay area, we estimate that favorable Level I conditions would result in fire losses of about $4 billion, or 1.5% of the value of homes and commercial property in that 1,245 square mile area. The intermediate Level II conditions would produce estimated losses of about $7 billion, or 2.6% of the values at risk. Losses for the more adverse Level III conditions would run about $9 to $15 billion, or 3.4%-5.7% of property values in the region. Much of this loss is concentrated in the City of San Francisco ($2.5 billion or 6% of the city's property values under Level I conditions, $3.5 billion or 8.5% of the value at risk under Level II conditions and $5.4 billion or 13.3% of value under Level III conditions.) This means the City of San Francisco has a post-earthquake fire risk three to four times higher than the Bay area as a whole.

For the $466 billion in property values at risk in the Los Angeles Basin, we estimate about $5 billion (1.1%) is likely to be lost due to fire following earthquake under Level I conditions. The estimate for Level II conditions is about $9 billion, or 2.0% of the value at risk. The more adverse Level III conditions would generate fire losses of $13 to $17 billion, the equivalent of 2.8% to 3.6% of value at risk in the Los Angeles region. Properties in the City of Los Angeles alone account for approximately $1.6 billion (1.2% of the value at risk) for Level I conditions, $3 billion or 2.2% of value for Level II conditions, and $5.4 billion or 4.1% of value for Level III conditions. That is, the City of Los Angeles as a whole has post-earthquake fire loss rates similar to those for the region.

The location of small, medium and large conflagrations is indicated in a general way on the accompanying maps depicting Level II conditions. For the San Francisco Bay area, the fires are clustered in the City of San Francisco and in the communities South along the Bay to San Jose (Figures 5 and 6). For the Los Angeles Basin (Figure 7), the largest conflagrations are shown in the Harbor area and in the vicinity of Torrance, but smaller conflagrations are distributed throughout Greater Los Angeles. Note that the black squares are not intended to pinpoint precise locations, but merely to indicate a general vicinity where conflagrations are likely.

It is of interest to compare estimates of losses due to

FIGURE 5

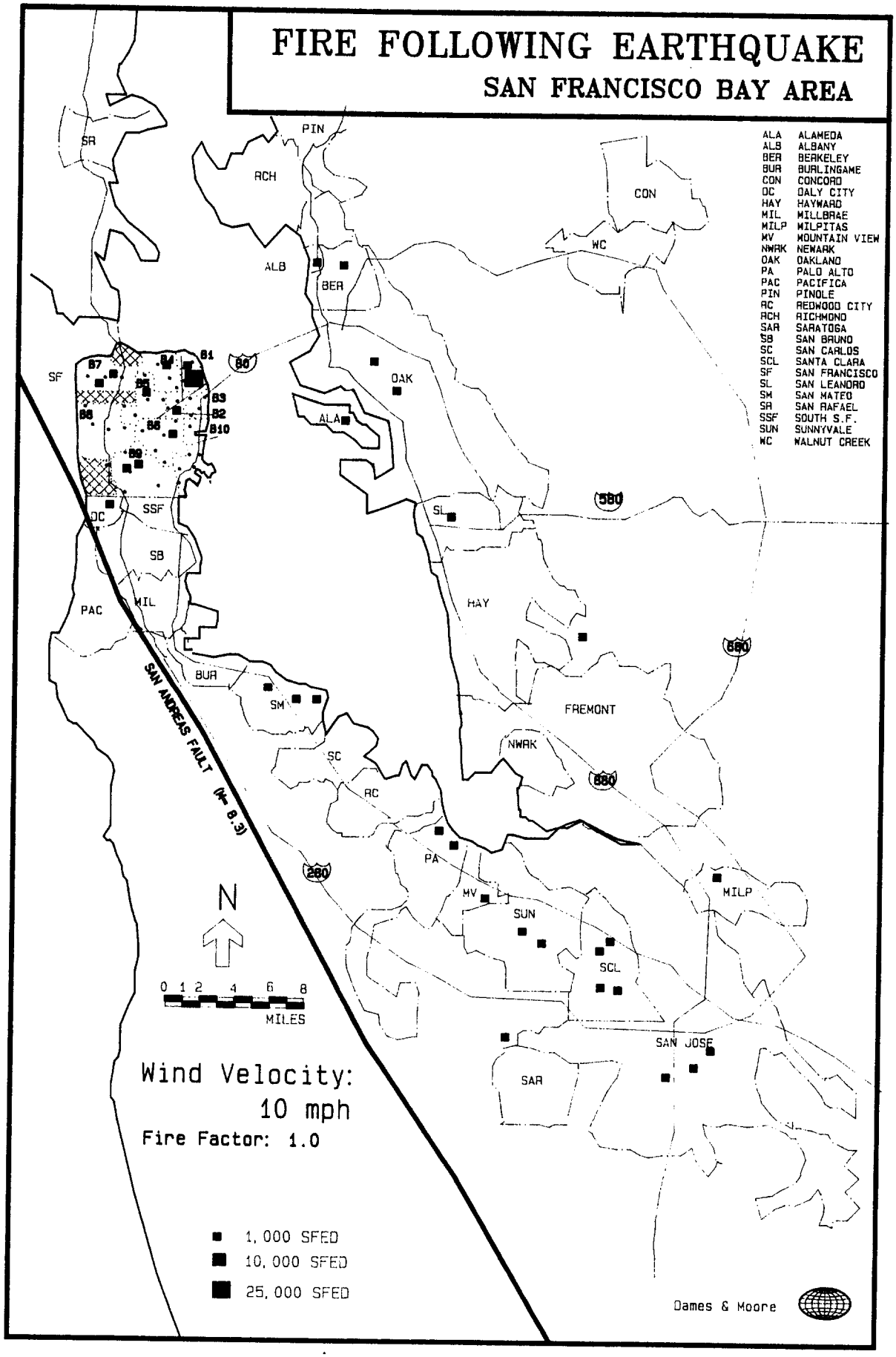

FIRE FOLLOWING EARTHQUAKE
SAN FRANCISCO BAY AREA
ALA ALAMEDA
ALB ALBANY
BER BERKELEY
BUR BURLINGAME
CON CONCORD
DC DALY CITY
HAY HAYWARD
MIL MILLBRAE
MILP MILPITAS
MV MOUNTAIN VIEW
NWRK NEWARK
OAK OAKLAND
PA PALO ALTO
PAC PACIFICA
PIN PINOLE
RC REDWOOD CITY
RCH RICHMOND
SAR SARATOGA
SB SAN BRUNO
SC SAN CARLOS
SCL SANTA CLARA
SF SAN FRANCISCO
SL SAN LEANDRO
SM SAN MATEO
SR SAN RAFAEL
SSF SOUTH S.F.
SUN SUNNYVALE
WC WALNUT CREEK
SAN ANDREAS FAULT (M= 8.3)
N
0 1 2 4 6 8
MILES
Wind Velocity:
10 mph
Fire Factor: 1.0
1,000 SFED
10,000 SFED
25,000 SFED
Dames & Moore

FIGURE 6

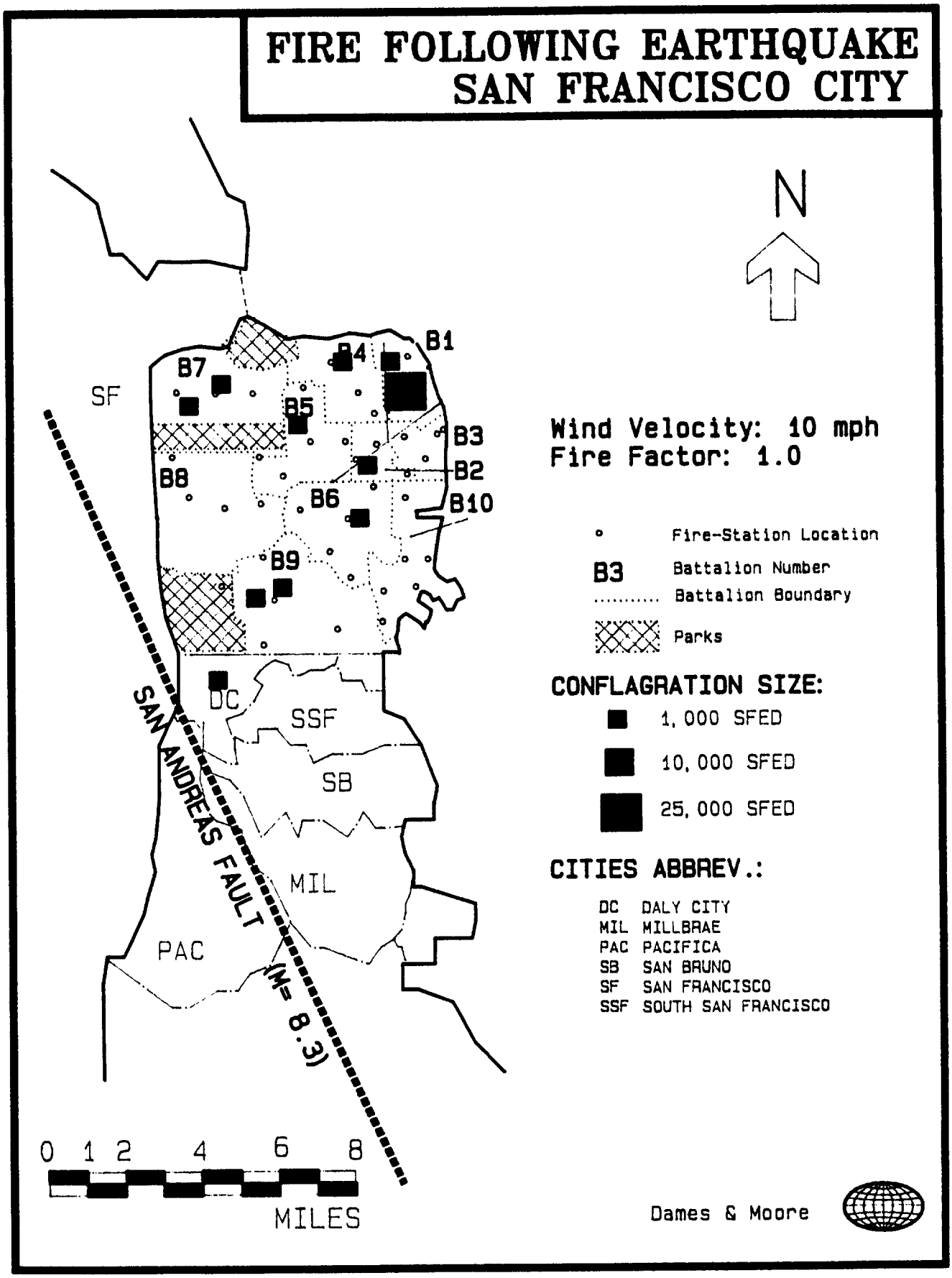
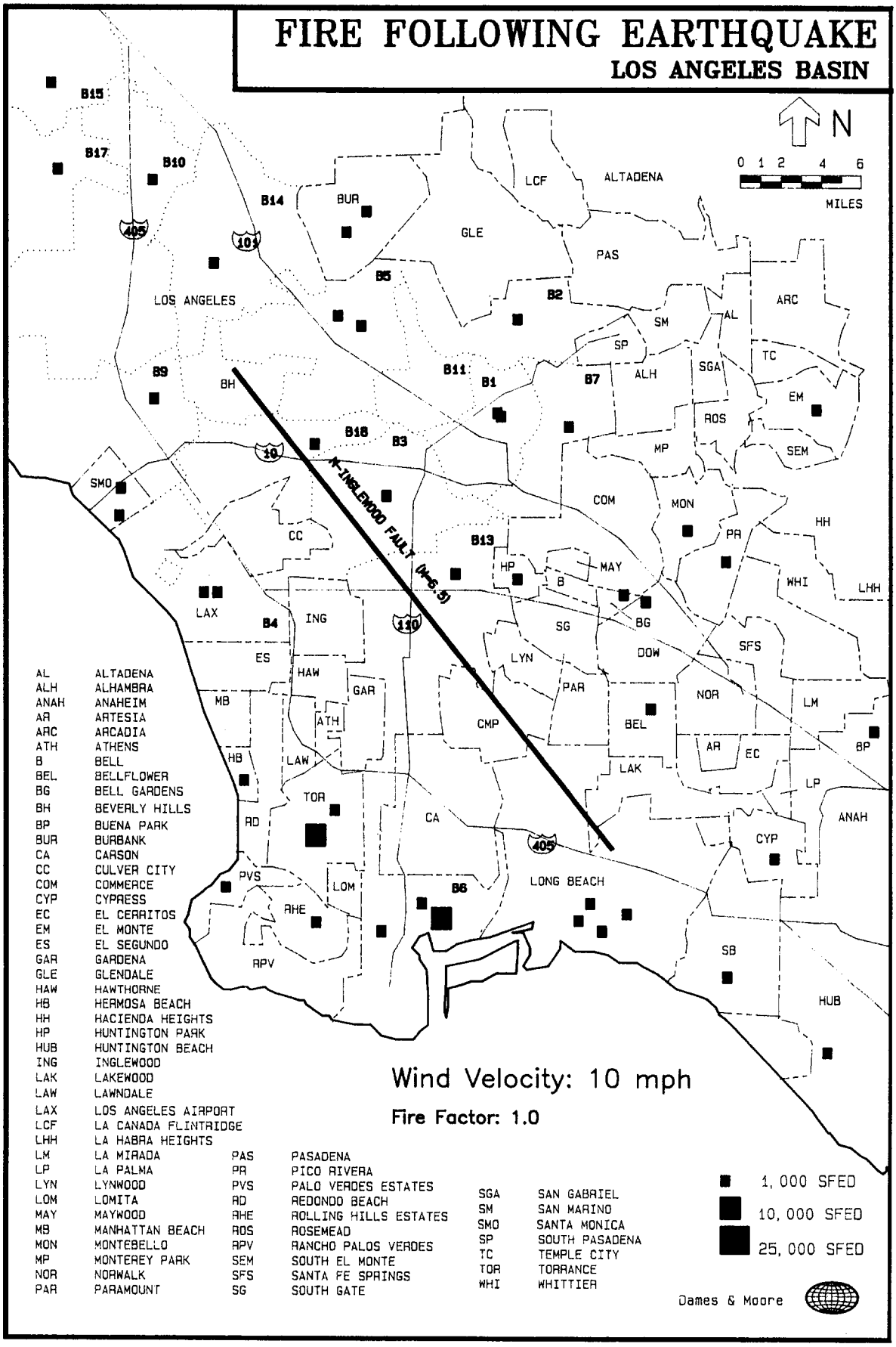

FIRE FOLLOWING EARTHQUAKE
SAN FRANCISCO CITY
N
B1
B4
B7
SF
B5
B3
B8
B2
B6
B10
B9
DC
SSF
SB
MIL
PAC
SAN ANDREAS FAULT
(M= 8.3)
Wind Velocity: 10 mph
Fire Factor: 1.0
Fire-Station Location
B3 Battalion Number
Battalion Boundary
Parks
CONFLAGRATION SIZE:
1,000 SFED
10,000 SFED
25,000 SFED
CITIES ABBREV.:
DC DALY CITY
MIL MILLBRAE
PAC PACIFICA
SB SAN BRUNO
SF SAN FRANCISCO
SSF SOUTH SAN FRANCISCO
0 1 2 4 6 8
MILES
Dames & Moore

FIGURE 7


FIRE FOLLOWING EARTHQUAKE
LOS ANGELES BASIN
N
0 1 2 4 6
MILES
B15
B17
B10
B14
B5
B2
B9
B11
B1
B7
B18
B3
B13
B4
B6
405
101
10
110
LOS ANGELES
BUR
GLE
LCF
ALTADENA
PAS
ARC
AL
SM
SP
ALH
SGA
TC
EM
ROS
MP
SEM
BH
SMO
CC
COM
MON
PR
HH
WHI
LHH
HP
MAY
B
BG
SG
DOW
SFS
LYN
PAR
NOR
LM
BEL
AR
EC
BP
LAK
LP
ANAH
CYP
LAX
ING
ES
HAW
GAR
MB
ATH
HB
LAW
TOR
RD
CA
PVS
LOM
RHE
RPV
LONG BEACH
SB
HUB
INGLEWOOD FAULT (M=6.5)
AL ALTADENA
ALH ALHAMBRA
ANAH ANAHEIM
AR ARTESIA
ARC ARCADIA
ATH ATHENS
B BELL
BEL BELLFLOWER
BG BELL GARDENS
BH BEVERLY HILLS
BP BUENA PARK
BUR BURBANK
CA CARSON
CC CULVER CITY
COM COMMERCE
CYP CYPRESS
EC EL CERRITOS
EM EL MONTE
ES EL SEGUNDO
GAR GARDENA
GLE GLENDALE
HAW HAWTHORNE
HB HERMOSA BEACH
HH HACIENDA HEIGHTS
HP HUNTINGTON PARK
HUB HUNTINGTON BEACH
ING INGLEWOOD
LAK LAKEWOOD
LAW LAWNDALE
LAX LOS ANGELES AIRPORT
LCF LA CANADA FLINTRIDGE
LHH LA HABRA HEIGHTS
LM LA MIRADA
LP LA PALMA
LYN LYNWOOD
LOM LOMITA
MAY MAYWOOD
MB MANHATTAN BEACH
MON MONTEBELLO
MP MONTEREY PARK
NOR NORWALK
PAR PARAMOUNT
PAS PASADENA
PR PICO RIVERA
PVS PALO VERDES ESTATES
RD REDONDO BEACH
RHE ROLLING HILLS ESTATES
ROS ROSEMEAD
RPV RANCHO PALOS VERDES
SEM SOUTH EL MONTE
SFS SANTA FE SPRINGS
SG SOUTH GATE
SGA SAN GABRIEL
SM SAN MARINO
SMO SANTA MONICA
SP SOUTH PASADENA
TC TEMPLE CITY
TOR TORRANCE
WHI WHITTIER
Wind Velocity: 10 mph
Fire Factor: 1.0
1,000 SFED
10,000 SFED
25,000 SFED
Dames & Moore

fire following earthquake with losses due to quake-related shake damage. The California Department of Insurance has surveyed property insurers with regard to their shake damage exposures since 1980 and published annual reports containing estimates of the "Probable Maximum Loss" to insurers due to shaking. The Insurance Department's PML figures are comparable to this report's Level II figures. The shake damage and fire damage estimates are shown together in Table 4.

TABLE 4

COMPARISON OF INSURED EARTHQUAKE LOSSES ESTIMATED FOR SHAKE AND FIRE DAMAGE

	Shake Losses*	Fire Losses
San Francisco Bay Area	$4.3 billion	$7 billion
Los Angeles Basin	$5.9 billion	$9 billion

*Table 4, *California Earthquake Zoning and Probable Maximum Loss Evaluation Program*, 1986.

Table 4 indicates that estimated insured fire losses following earthquake substantially exceed estimated insured fire losses due to shaking. That result stems in part from the fact that fire is a very serious part of the earthquake risk, and in part from the fact that property owners are much more likely to be insured for fire damage than for shake damage. Almost all buildings are insured for fire, but only about 15% to 20% of property owners are insured specifically for earthquake shake damage in the two areas studied. The loss estimates shown in Table 4 represent only that portion of the losses estimated to be covered by insurance.

It is important to note that no attempt has been made to account for overlaps between shake damage and fire damage in preparing the fire loss estimates contained in this study. This is not a major problem currently, since the amount of insurance coverage being written for shake damage is relatively low and we cannot assume that properties sustaining shake damage will burn nor that properties burned will have sustained severe shake damage. Fires are much more likely to start in shake-damaged buildings, as discussed earlier, but subsequent fire spread is likely to involve many buildings that sustained little or no significant shake damage. Any attempt to address the overlap between shake damage and fire damage would have to consider that issue, as well as account for the effect of insurance deductibles for shake damage. If the amount of shake damage insurance increases substantially over time, future research on insured fire losses will need to address the overlap problem. In the meantime, readers should be aware that neither this study nor the California Department of Insurance study fully accounts for all of the insured losses that would be caused by a great earthquake. Substantial additional insured losses would be incurred today under automobile, workers compensation, business interruption, health insurance, inland marine and other insurance coverages.

CHAPTER 3
ESTIMATION OF LOSSES DUE TO FIRE FOLLOWING EARTHQUAKE

Outline of the Fire Following Earthquake Problem

This Chapter presents our methodology for estimating fire losses following earthquake. Our basic methodology can be seen in Figure 8, Fire Department Operations Time Line, which depicts the main aspects of the fire following earthquake problem. In this figure, the horizontal axis is Time, beginning at the time of the earthquake, while the vertical axis presents a series of horizontal bars of varying width. Each of these bars depicts the development of one fire, from ignition through growth or increasing size (size is indicated by the width or number of bars).

Beginning at the left (that is, at the time of the earthquake), we see the occurrence of various fires or ignitions (denoted by the number of the fire in a square box, see the legend at the bottom of Figure 8). Some of these fires occur very soon after the earthquake, while others occur sometime later (due for example to restoration of utilities). These ignitions may be due to various causes, but are primarily due to open flame, electrical malfunction and/or chemical spill. The mechanism of these ignitions is no different following an earthquake than at other times, although the earthquake can create unusual circumstances for ignition to take place. The primary difference due to the earthquake is the large number of simultaneous ignitions.

Following this ignition, or Fire Initiation, phase there is a period during which the fire is undiscovered but grows. A typical rule of thumb in the fire service is that the rate of growth of an uncombatted fire in this phase will double each seven seconds. In Figure 8, the size of the fire is denoted by its number of bars. That is, each bar for a particular fire represents one engine required for control and/or suppression. Thus if, with time, a fire in Figure 8 proceeds from one bar to two and then three, this denotes that the fire is growing and now requires three Class A fire engines to control the fire (Class A fire engines have approximately 1200 gpm of pumping capacity).

Discovery of the fire is denoted by the letter "D." Discovery under the post-earthquake environment is often no different than at other times, although discovery may be impeded due to damaged detectors, or distracted observers. Upon discovery, citizens may themselves attempt to combat the fire, and will sometimes be successful. We are concerned herein only with ignitions that citizens cannot/do not successfully combat, and which require fire department response.

The letter "R" denotes receipt of the Fire Report by the fire department. Under normal circumstances, fires are reported to the fire department by one of four methods:

(i) telephone,
(ii) fire department street boxes (voice or telegraph),
(iii) direct travel to a fire station by a citizen (so-called "citizen alarms"),
(iv) automatic detection and reporting equipment, usually maintained by private companies.

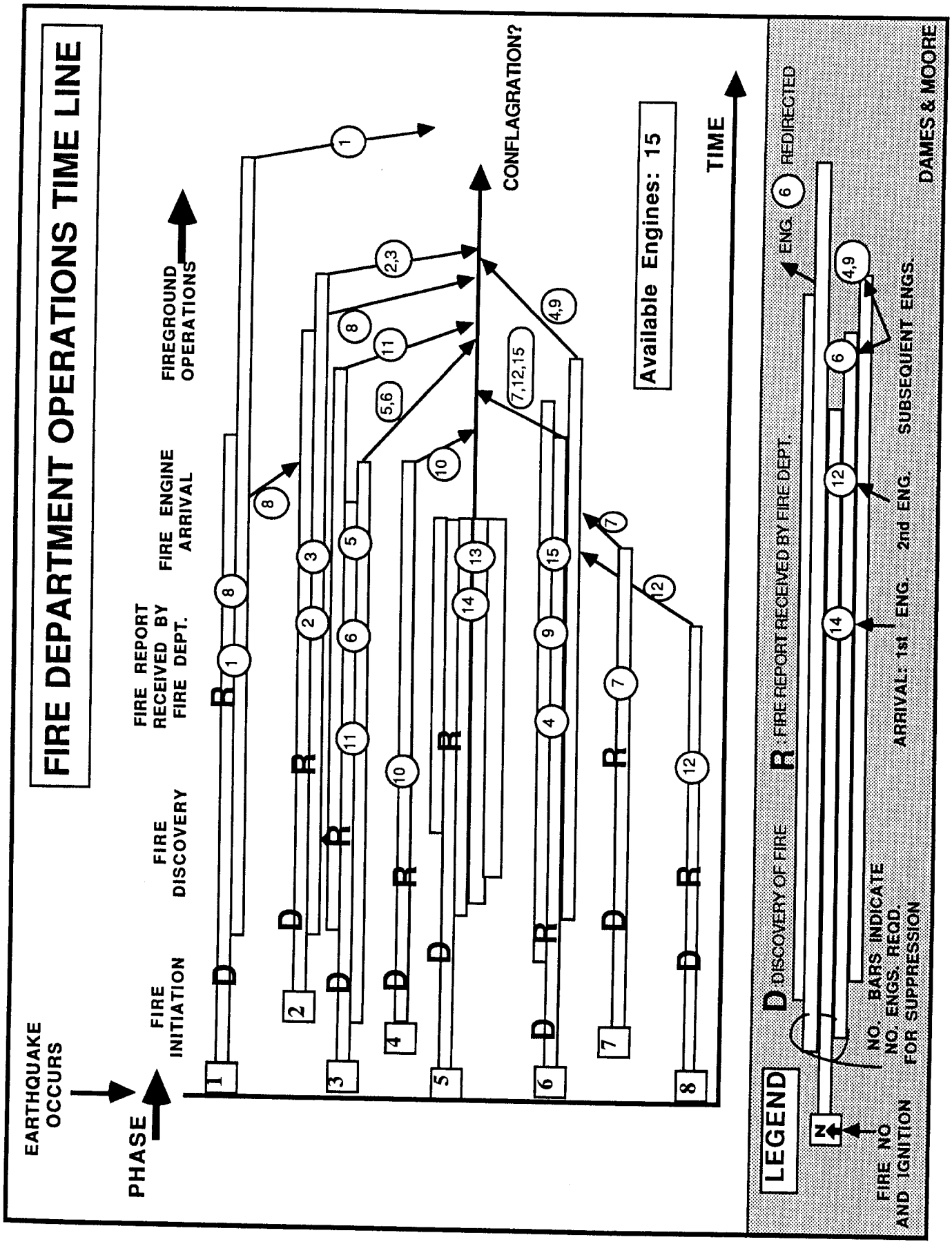
Under normal circumstances, with the exception of citizen alarms, these methods all communicate the occurrence of a fire within seconds, which is critical in the timely response and suppression of structural fires. In the critical minutes following an earthquake, review of earthquake experience has indicated that at present citizen alarms are likely to be the only feasible method for reporting fires, in areas of strong ground shaking. The telephone system may or may not sustain damage, but almost definitely will be incapacitated due to overload. Fire department street boxes are generally no longer in use (in California, only San Francisco maintains street boxes). Automatic detection and reporting equipment account for only a fraction of commercial property. They may be damaged in an earthquake, and will likely produce many false alarms, leading to lack of response to real fires, due to the inability to discriminate the real from the false alarms. Several other, unconventional, reporting methods may be employed. These include:

(i) amateur shortwave radio operators,
(ii) helicopter observation,
(iii) ground reconnaissance by police or fire personnel.

With regard to the last of these other methods, we have reviewed present post-earthquake damage reconnaissance planning on the part of several larger California fire departments and, in general, found them inadequate for identifying fires at a sufficiently early stage to prevent conflagration. A fundamental flaw in most of these plans is the performance of the post-earthquake damage reconnaissance by the fire personnel themselves, employing fire apparatus (i.e., engines and trucks).[11] The flaw lies in the fact that

[11] Basic fire service apparatus consists of two types: engines (or pumpers), which typically carry a pump of about 1200 gpm capacity, 2000 ft. of hose, 500 gal. of water, some tools and small ladders, and several firefighters. The second type are trucks (also termed ladders, aerials, hook and ladders, etc.), which carry large ladders of about 75 or 100 ft. length, a much larger variety of tools and ladders, and additional manpower. A ladder truck by itself cannot pump water so that the pumper is one basic measure of firefighting capacity. For typical non-earthquake structural fires however, the limiting factor is more often manpower, than pumping capacity.

FIGURE 8


FIRE DEPARTMENT OPERATIONS TIME LINE
EARTHQUAKE OCCURS
PHASE
FIRE INITIATION
FIRE DISCOVERY
FIRE REPORT RECEIVED BY FIRE DEPT.
FIRE ENGINE ARRIVAL
FIREGROUND OPERATIONS
CONFLAGRATION?
Available Engines: 15
TIME
LEGEND
D DISCOVERY OF FIRE
R: FIRE REPORT RECEIVED BY FIRE DEPT.
ENG. 6 REDIRECTED
FIRE NO AND IGNITION
NO. BARS INDICATE NO. ENGS. REQD. FOR SUPPRESSION
ARRIVAL: 1st ENG. 2nd ENG. SUBSEQUENT ENGS.
DAMES & MOORE

following an earthquake, these personnel and apparatus will almost immediately be redirected from the reconnaissance to actual fire or other emergency response.

Helicopter observation and amateur radio operators similarly will typically only be able to identify and report fires after they have reached greater alarm status (that is, when it is too late). Further, most fire officers have no special training in aerial observation or command.

Following receipt of the Fire Report by the fire department, apparatus will respond, if available (in Figure 8, arrival of apparatus at the fireground is denoted by the engine number within a circle—note that herein we only track fire engines, since only engines can suppress serious fires). Response may be impeded by blocked streets due to collapsed structures, or by traffic jams.

Upon arrival, the fire may be combatted per normal procedures or, if the general situation is sufficiently serious, minimal tactics may be all that is possible. Minimal tactics may constitute:

(i) deluge (so-called "flood and run" tactics),
(ii) abandonment of the burning structure and protection only of exposures,
(iii) recognition that exposed structures cannot be protected, with fall back to a defensible line (e.g., abandonment of a city block, with attempt to stop the fire at a wide street),
(iv) total abandonment, that is, recognition that either little or nothing can be done, that the fire will burn itself out at an identified firebreak with or without fire department intervention, or that other situations are more critical and demand the apparatus.

Water supply is a critical element, and earthquake damage to the water system may reduce supply, thus altering tactics. Due to the interconnectedness of a water supply system, earthquake damage at some distance from a fireground may still result in reduced supply.

In Figure 8, we denote increasing control of a fire by the reduction in the number of bars (i.e., engines required for control). As suppression progresses and control of the fire becomes near total, engines will be released by the incident commander for more pressing emergencies elsewhere. Movement of these released apparatus is denoted by a diagonal line showing travel of an engine from one fire to another. As fires are controlled, engines eventually converge on one or several large fires, or conflagrations. Growth and spread of conflagrations is a function of building materials, density, street width, wind, water supply and fire-fighting tactics.

In our methodology, the process depicted in Figure 8 has been coded on a VAX minicomputer (small cases can be handled on a microcomputer). An algorithm determines ignitions, assigns a number to each fire, and tracks fire growth. Algorithms also determine fire reporting time and fire engine arrival. Each fire engine is tracked from location to location. Damage to the water supply is determined on the basis of available information[12] and, in the case of reduced water supply, reduction in fire suppression capability is estimated.[13] Final burnt area for each ignition is thus calculated as a function of fire growth and applied fire suppression capacity. For a large city, this is a major computational effort, and regional size problems at this level of detail are prohibitive. This detailed methodology was run for several jurisdictions, and results were found to agree well at the jurisdictional level with a second computer code employing algorithms which track each fire but model fire department response with less detail. This latter code was used to provide mean estimates of fire loss for the regional study herein. We next discuss technical aspects of our methodology.

Ignition

We have reviewed available twentieth century United States earthquake experience and identified earthquake-caused ignitions requiring fire department response. A detailed review of this data is beyond the scope of this report. Based on our review, we have determined that post-earthquake ignitions are typically a random event due to (i) excessive motions, resulting in overturning or breakage of building contents (e.g., ignitions due to open flames or chemical reaction), or (ii) excessive structural deflections, resulting in abrasion or other damage to electrical wiring and consequent short-circuiting. Building collapse is an extreme example of (i) above, and will greatly increase the probability of ignition. Gas piping may be ruptured by either (i) or (ii). For example, a water heater may overturn, thus breaking the connection, or a building may slide on its foundation and shear connections. Less typical but observed modes of ignition are

[12] In the development of this methodology, detailed hydraulic modeling and damage estimation for the water system for the Case Study area of San Francisco was performed by a cooperating investigation at Cornell University (Prof. T.D. O'Rourke and Dr. C.H. Trautmann).

[13] In the Case Study, required fire flows were compared with the damaged system's ability to furnish water, and adjustments made accordingly. In the present study, detailed hydraulic modeling of the regional water supply, and seismic damage thereto, was not attempted. Rather, based on data on areas of severe ground displacements, major pipe breaks and impacts on fire suppression that would result were estimated, based on judgment.

heat due to friction or sparking due to pounding of structures.

While occupancy obviously affects building contents and hence probability of ignition, there are at present insufficient data to differentiate ignition probabilities on the basis of occupancy. For example, while chemical laboratories are an obvious source of chemical reaction ignitions, we do not have sufficient knowledge of the distribution of such laboratories in past earthquakes to perform meaningful analyses. Admittedly, existing earthquake-related data might be analyzed using judgment or non-earthquake fire frequency statistics. This is an avenue of promising future research. Also promising might be shaking/kinematics analysis of typical room contents combined with a statistical description of such room contents. However, neither approach has been explored to date.

We have normalized post-earthquake fire ignitions by building density, in units of SFED (Single Family Equivalent Dwellings = 1500 sq. ft. of floor area) and regressed the data against shaking intensity in terms of Modified Mercalli Intensity (MMI, see Table 1). SFED are chosen as a measure which is readily understandable by laymen (they can be thought of as detached "houses"). A large building of 1.5 million sq. ft. for example would be 1000 SFED.

Figure 9 shows normalized twentieth century fire ignitions as a function of MMI. A clear trend of increasing ignitions with increasing MMI can be seen. This trend may be stated as shown in Table 5.

TABLE 5
FIRE IGNITION RATE

MMI	ONE IGNITION PER
VI	Negligible
VII	7500 SFED
VIII	3500 SFED
IX	2500 SFED

While a substantial part of our data derives from the 1906 and 1971 events, note that this trend is not particularly sensitive to either event. Post-earthquake ignitions for a particular locality can thus be calculated as a random Poisson process with mean probability determined as a function of MMI and building inventory (i.e., SFED). For the study herein, the number of initial fires for each jurisdiction was estimated on the basis of average rates of ignition.

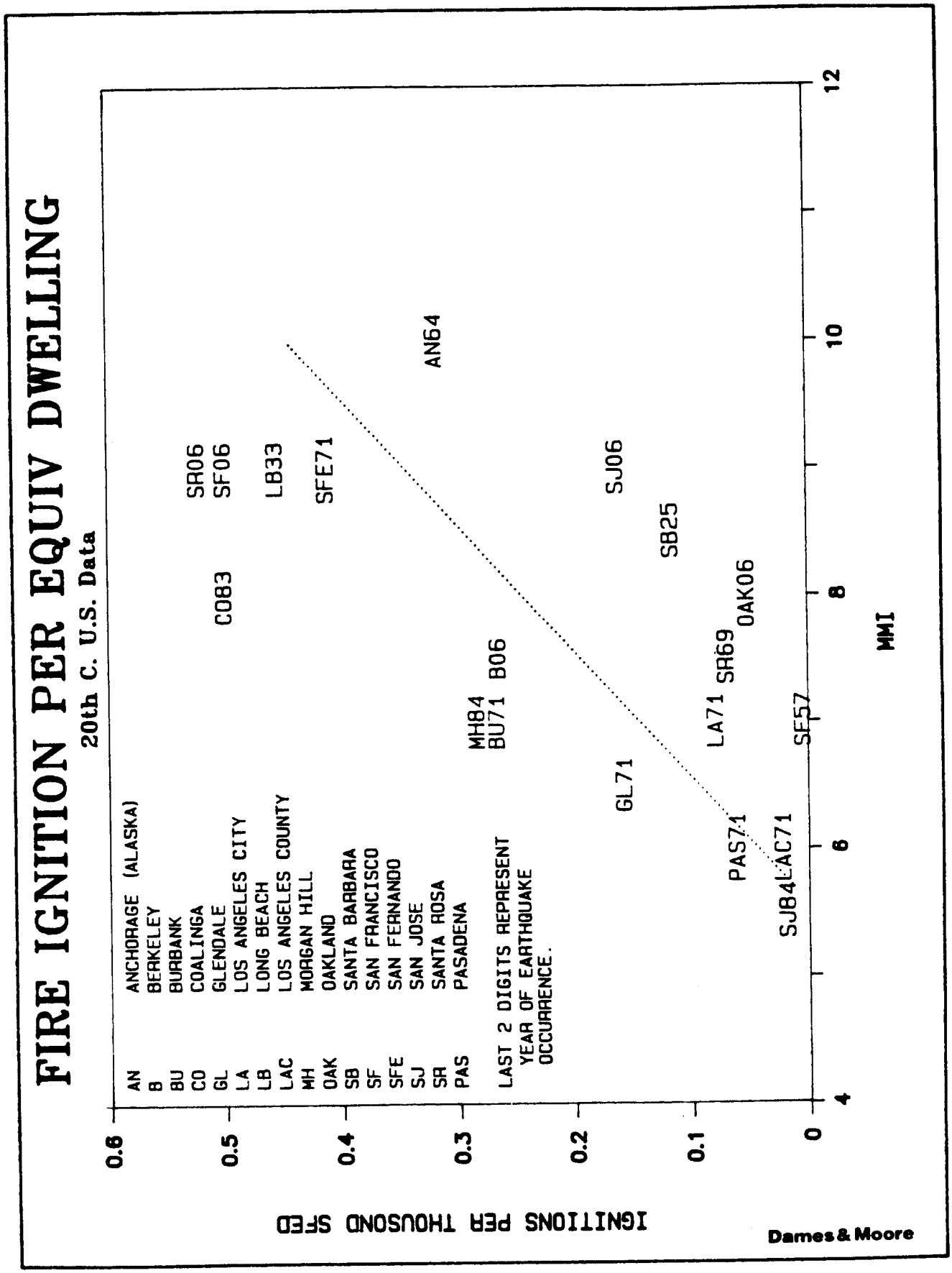
These rates of ignition do not account for possible intentional ignitions arising out of several motives (that is, arson). It can be argued that arson will be a significant problem, since property owners are in general aware that while they may not be covered for shaking damage, their fire coverage includes fire following earthquake. As will be seen, it takes only a relatively few additional ignitions to overwhelm fire department resources, with possible ensuing conflagration. Countering this is the point that, while past earthquakes have seen examples of arson, these appear to have been relatively few, and did not occur immediately after the shaking but rather days or weeks later. That is, in the immediate post-earthquake period (the first minutes to hours) of injury, emotion, confusion and multiple, simultaneous ignitions potentially leading to conflagration, people will be too overwhelmed by events to consider arson. Later, when this occurs to the relatively few persons who will actually commit this crime, the fires they set will occur in a period when the fire departments are back on a more normal footing, have been reinforced from outside the stricken area, and presumably will be able to handle these fires. We estimate that the latter scenario is more relevant, and hence have not included an allowance for arson in our methodology. Arson ignitions can be included by simply increasing the number of initial ignitions by a Fire Factor, and this has been studied and will be discussed below.

Fire Report and Response

As discussed above, citizen alarms are likely to be the dominant or only method of reporting fires in the minutes following a major earthquake. This means that, following discovery, a fire will be reported by a citizen running or driving to the nearest fire station. Thus, we determine time of reporting as a period of delay (herein termed Earthquake Delay, accounting for initial confusion, traffic difficulties, etc.) plus travel time from the location of the fire to the nearest fire station. In our model, travel time can be determined based on either direct or right angle travel, and vehicle speed is a variable.

Time of fire engine travel to the fire following receipt of report is similarly based on distance and vehicle speed. Under normal conditions, fire engines average between 15 and 20 mph in responding to a fire (i.e., if distance traveled is divided by total elapsed "roll-time," the result is in the range of 15 to 20 mph—of course, higher speeds are attained during certain portions of the travel). In our results below, we have typically used 15 mph, but examined faster and slower speeds. Delays are possible, due to detours or traffic jams. We have carefully considered debris

FIGURE 9


FIRE IGNITION PER EQUIV DWELLING
20th C. U.S. Data
AN ANCHORAGE (ALASKA)
B BERKELEY
BU BURBANK
CO COALINGA
GL GLENDALE
LA LOS ANGELES CITY
LB LONG BEACH
LAC LOS ANGELES COUNTY
MH MORGAN HILL
OAK OAKLAND
SB SANTA BARBARA
SF SAN FRANCISCO
SFE SAN FERNANDO
SJ SAN JOSE
SR SANTA ROSA
PAS PASADENA
LAST 2 DIGITS REPRESENT YEAR OF EARTHQUAKE OCCURRENCE.
IGNITIONS PER THOUSOND SFED
0.6
0.5
0.4
0.3
0.2
0.1
0
4
6
8
10
12
MMI
SJ84
LAC71
PAS71
GL71
MH84
BU71
B06
LA71
SF57
SR69
OAK06
SB25
SJ06
AN64
SFE71
LB33
SF06
SR06
C083
Dames & Moore

blockage of streets, and concluded that typically this should not be a major impediment although it may occur in selected districts. Depending on time of day, traffic jams may be a more critical factor. Based on our review of post-earthquake traffic conditions in U.S. earthquakes, we feel typical delays can be accounted for by the above Earthquake Delay factor. Their significance is explored below.

Fire Growth and Spread

Fire growth is a particularly complex phenomenon. Most research in the United States has concentrated on fire growth within one room (so-called "compartment fires"), and only very limited research has been performed on U.S. inter-building urban fire growth (Takata, 1968). More work has been performed on wild lands fire spread (Rothermel, 1983), but this work is of very limited applicability to the urban situation. We have reviewed available urban fire spread equations, and have employed the Hamada equations in our model (Hamada, 1951, 1975; Horiuch, n.d.; Scawthorn et al., 1981; Terada, 1984). These equations are based on Japanese experience in twentieth century conflagrations, both peacetime (e.g., following the 1923 Kanto earthquake) and wartime.

In order to explore the question of utility of these equations in the U.S. context, we have compared observed fire spread in various U.S. twentieth century fires with the fire spread predicted using these equations, Table 6 and Figure 10. In Figure 10, fire spread data from the fire following the 1906 earthquake in San Francisco are denoted by SFx, while other fire data are denoted X, where X indicates method of spread (B = branding, G = ground spread undifferentiated with respect to wind, U = ground spread upwind, D = ground spread downwind, S = ground spread side wind). With the exception of a group of data in the upper right hand corner of Figure 10 (corresponding to spread by branding among wood buildings under high winds), estimation agrees well with observation. Based on this comparison, we feel these equations provide reasonable, in some cases conservative (i.e., underestimation), estimation of fire spread.

Figure 11 is an example of fire spread estimated by these equations, for typical and dense residential and commercial California building conditions, at 20 minutes after first inter-building spread. Fire spread here is shown in terms of total SFED consumed as a function of downwind wind speed. These estimates are for typical low-rise construction. Single floor fire spread in modern mid- and high-rise construction typically differs little from this, for moderate expanses. Floor-to-floor fire spread in modern mid- and high-rise construction typically is slower however, and we have modeled this by using the above equations, reduced by a factor. Note that mid- and high-rise fire resistiveness varies substantially by jurisdiction, depending on local fire codes and enforcement.

These estimates are for fire spread within one city block or a built-up district, and do not account for fire spread across firebreaks, such as streets. We have reviewed World War II and other data (Bond, 1946), and developed estimates of the probability of a typical fully developed building fire crossing a firebreak, under various wind speeds and with and without active fire suppression efforts. Figure 12 for example shows such probabilities for various firebreak dimensions for a 10 mph downwind velocity.

Fire growth and spread then is modeled using these equations, taking into account probability of crossing a firebreak (with or without active fire suppression capability being present). Fires are tracked and merged where they meet (i.e., areas are not "burnt twice").

Fire Response and Suppression

As discussed above, fire growth and fire engine location are tracked concurrently. Under normal conditions, urban fire department response to a structural fire is usually a minimum of two fire engines and one ladder truck (additional apparatus responds in high value or extra hazard areas). This normal response will not be possible following a large earthquake, since fires may outnumber fire engines. Based on review of actual operations following earthquakes, and discussions with senior fire department officials, it is likely that following an earthquake, initially only one engine will respond to reported fires, to suppress the fire and/or size-up the situation. Thus, we have modeled initial response in this manner, initially allocating one engine to each fire, and additional engines as available. Where fires outnumber first line engines, we term the difference "excess fires."

We assume that fire department resources will initially be totally and primarily devoted to fire suppression, although we recognize that other demands (search and rescue, hazardous material response, emergency medical treatment) will also be placed on these resources. Note that this assumption is optimistic, especially since building collapses and hazardous materials releases may involve large numbers of victims. We have discussed this aspect with senior officials of several fire departments, and their opinion is that some fire department resources will have to be

TABLE 6

URBAN FIRE SPREAD DATA FOR 20TH CENTURY NORTH AMERICAN FIRES

	FIRE, DATE:	TIME OF START FIRE	PERIOD OF SPREAD	RATE OF SPREAD (fpm)	WIND SPEED (mph)	BLDG TYPE	"BUILT-UP NESS"	NO. STORIES	METHOD OF SPREAD
1	OTTAWA/Hull '00	1030	1030-1300	18.7	30	2	0.35	1	B
2	OTTAWA/Hull '00	1030	1300-1930	26.2	30	1	0.25	6	B
3	BALTMORE, MD 04	1050	1050-2100	1.9	16	3	0.40	8	G
4	BALTMORE, MD 04	1050	2100-2200	4.8	22	4	0.40	12	G
5	BALTMORE, MD 04	1050	2200-2345	2.7	22	3	0.40	9	G
6	SF 18 April 06	530	1330-1530	4.1	20	2	0.35	2	SFg
7	(Earthquake/fire)	530	1300-1600	29.1	20	2	0.35	2	SFb
8	(Earthquake/fire)	530	0600-1200	1.9	6	2	0.35	2	SFg
9	(Earthquake/fire)	530	0900-1300	7.9	14	2	0.25	4	SFg
10	(Earthquake/fire)	530	2100-0030	6.7	5	3	0.35	0	SFg
11	(Earthquake/fire)	530	1000-1230	3.5	14	2	0.35	1	SFg
12	(Earthquake/fire)	530	0550-1730	4.1	10	2	0.35	3	SFg
13	(Earthquake/fire)	530	0550-1730	2.9	6	3	0.35	2	SFg
14	(Earthquake/fire)	530	0800-1000	10.8	7	1	0.35	2.5	SFg
15	(Earthquake/fire)	530	0900-2400	2.2	12	1	0.35	2.5	SFg
16	SF 19 April 06	day 2	1900-2200	2.2	20	1	0.35	2	SFg
17	SF 19 April 06	day 2	1130-1830	12.5	10	1	0.35	2	SFg
18	SF 20 April 06	day 3	0600-1800	5.5	26	2	0.35	2.5	SFg
19	ATLANTA, GA 17	1246	0400-0700	5.5	20	3	0.40	4	S
20	BERKELEY, CA 23	1420	1420-1500	34.9	25	1	0.25	2.5	B
21	BERKELEY, CA 23	1420	1500-1600	40.0	28	1	0.25	2.5	B
22	FALL R, MA 28	1700	1730-1900	3.3	15	3	0.40	6	D
23	FALL R, MA 28	1700	1730-1945	1.5	17	3	0.40	4	S
24	FALL R, MA 28	1700	1945-2015	6.7	18	3	0.40	5	G
25	FALL R, MA 28	1700	1945-2030	5.3	19	3	0.40	4	G
26	FALL R, MA 28	1700	2030-2300	1.3	22	2	0.40	1	U
27	CAMDEN, NJ 40	1305	1315-1730	1.2	18	2	0.40	5	G
28	W NY, NJ 61	1649	1649-1714	8.4	8	2	0.25	3	G
29	BOSTON, MA 62	1555	1555-1630	23.0	28	1	0.20	2	G
30	BOSTON, MA 62	1555	1600-1630	20.0	28	1	0.20	1	G
31	LYNN, MA 81	300	0300-0600	1.9	18	3	0.30	6	G
32	PHIL MOVE 85	1730	1730-2000	2.4	8	1	0.40	2	G

NOTES:

Type of Building:
1 Light Wooden
2 Heavy Wooden
3 Light stone or concrete
4 Heavy stone or concrete

Method of Spread:
B = Branding
G = Ground spread:
U = ground spread Upwind
D = ground spread Downwind
S = ground spread Sidewind
SFg = San Francisco data, branding
SFg = San Francisco data, ground spread

Built-up-ness: Percent of total ground area occupied by buildings

REFS: 1. Chandler, C.C. et al. USFS, 1963
2. Various fire journals, newspaper accounts.

FIGURE 10

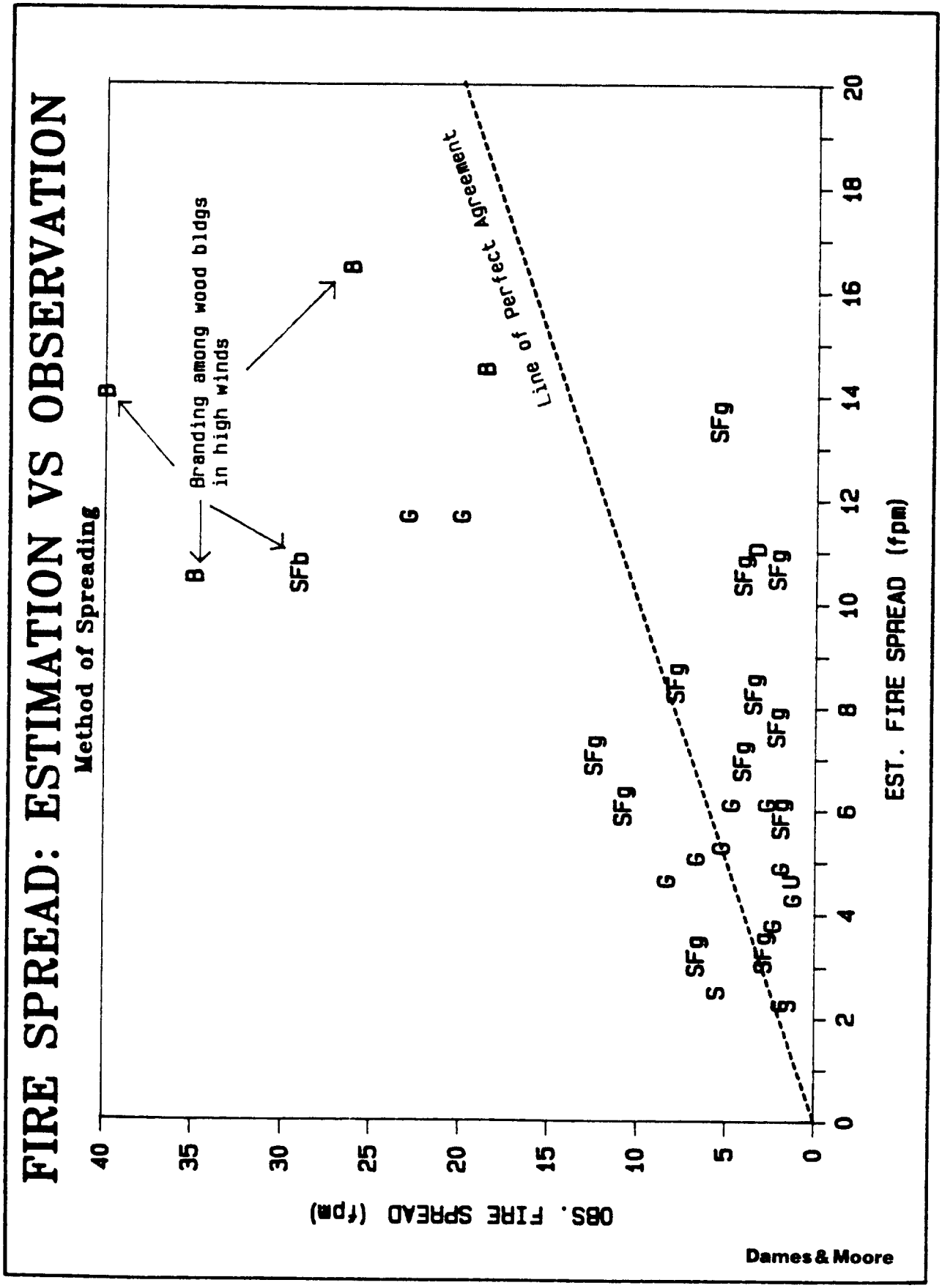

FIRE SPREAD: ESTIMATION VS OBSERVATION
Method of Spreading
Branding among wood bldgs in high winds
Line of Perfect Agreement
OBS. FIRE SPREAD (fpm)
EST. FIRE SPREAD (fpm)
Dames & Moore

FIGURE 11

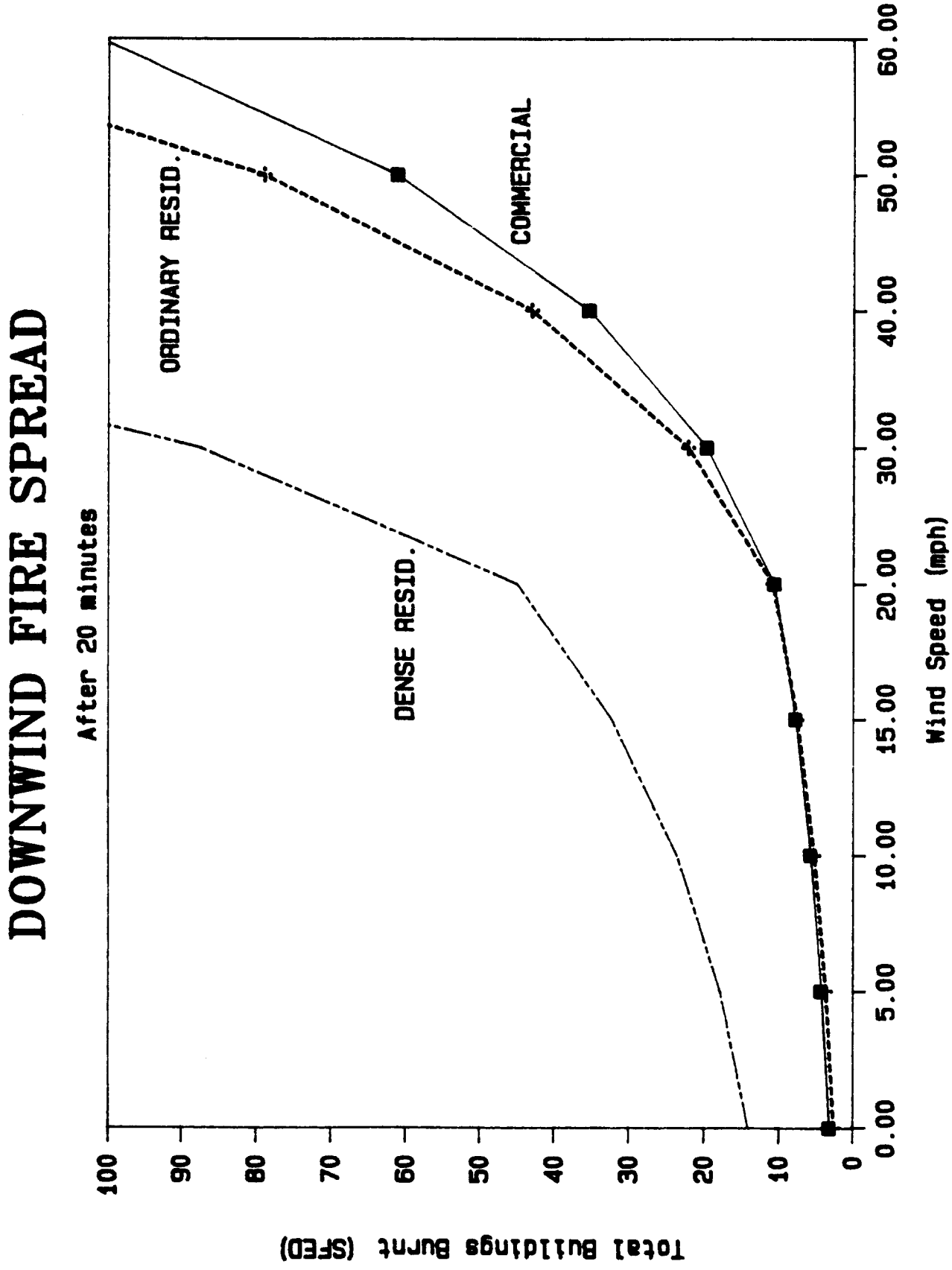
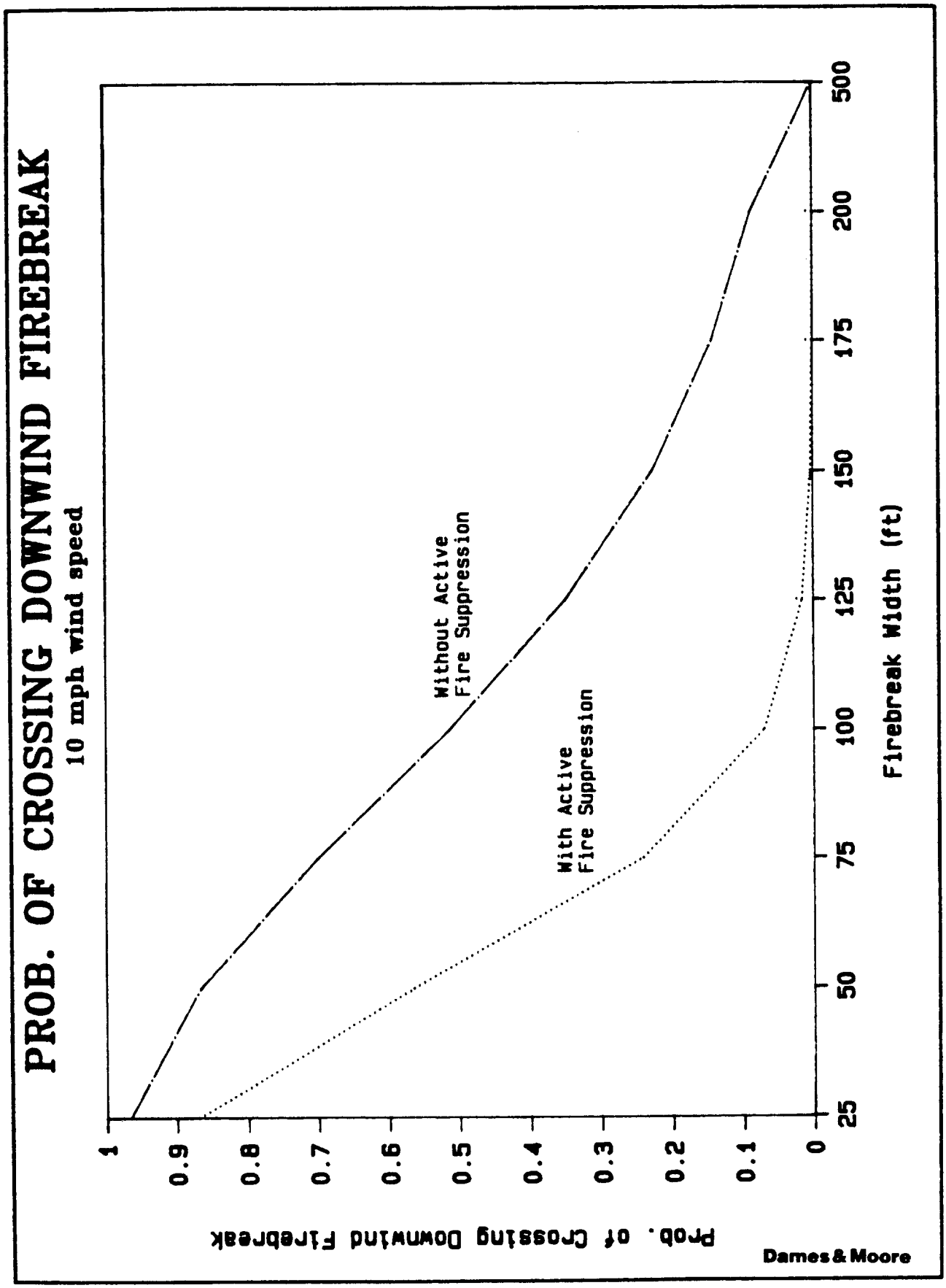

DOWNWIND FIRE SPREAD
After 20 minutes
ORDINARY RESID.
COMMERCIAL
DENSE RESID.
Total Buildings Burnt (SFED)
Wind Speed (mph)
0
10
20
30
40
50
60
70
80
90
100
0.00
5.00
10.00
15.00
20.00
30.00
40.00
50.00
60.00

FIGURE 12


PROB. OF CROSSING DOWNWIND FIREBREAK
10 mph wind speed
Without Active
Fire Suppression
With Active
Fire Suppression
Prob. of Crossing Downwind Firebreak
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25
50
75
100
125
150
175
200
500
Firebreak Width (ft)
Dames & Moore

diverted from firefighting to these other services. We have considered this, and feel that in the initial period following an earthquake, serious fires may receive first priority, for the following reasons: (a) fire service training and tradition, (b) fires are dynamic while building collapses are relatively static—that is, a fire situation will worsen if neglected, while the building collapse and rescue situation can often wait several hours (indeed often must await the arrival of heavy equipment), (c) ability of other services (police and others) to assist in building collapses, emergency medical treatment and hazardous materials management (via isolation and evacuation), while only the fire service is equipped to handle serious fires. Thus we have made the above assumption in our modeling, recognizing the above factors. The impact of this assumption is to decrease total expected losses due to fire following earthquake. Our methodology permits examination of the impacts of diverting resources to other needs, but we have not explored this at the present time.

In addition to each jurisdiction's fire suppression resources (i.e., the department's first line and reserve engines, other equipment and personnel), we model auto- and mutual aid, arriving somewhat later from more distant locations. Data on mutual aid arrivals is based in part on an exercise held by Region II of the Fire and Rescue Division, California Office of Emergency Services (OES) in April 1986, which Dames & Moore personnel observed.

We determine size of fire at first engine arrival time (in terms of actively burning SFED's, and water required for suppression) and compare this with that engine's suppression capability. Engine suppression capability is initially modeled using guidelines appropriate for typical structural fires under non-earthquake conditions, and modified to take into account reduced available water (due to earthquake damage to the water supply) and likely fire department use of minimal tactics (discussed above).

That is, given a burning area, we determine required fire flow under normal conditions on the basis of 4 gallons per minute (gpm) for each 100 cubic feet (cf) of occupancy directly involved in the fire or immediately exposed (Kimball, 1966). For larger fires, this volumetric calculation is based only on perimeter defense. Depending on construction and available manpower, a fire engine typically can apply up to 1500 gpm (using the monitor and or handlines, note however if 1500 gpm is to be applied entirely by handlines, additional personnel are needed). This may be reduced depending on the post-earthquake condition of the water supply system. Thus one engine can typically attack a maximum burning volume of 37,500 cf (typically, 3,000 to 4,000 square feet of floor area) if the monitor can be efficiently used, or half of this (about one SFED) if hand lines are used and additional personnel are not available. If minimal tactics are employed (i.e., no attack, perimeter protection only), then the capacity of one engine can be considered to be increased (e.g., up to three or four hundred linear feet of perimeter).

Damage to the water supply was of course of prime importance in the 1906 San Francisco earthquake, and will likely be critical in future earthquakes. It is not commonly realized that, although the main water transmission lines into San Francisco were severed by the earthquake, this was not critical—there existed sufficient water in reservoirs, etc., within the city itself, for initial firefighting needs. Rather, hundreds of breaks in the local distribution network, due to large ground displacements and liquefaction, resulted in the system hemorrhaging water and losing pressure. In order to account for damage to the water supply, a detailed hydraulic model of the system with estimated damage due to shaking, permanent ground displacements, etc., is preferred. This approach however was beyond the scope of the present investigation. The method employed herein involved review of regional water supply systems, and likely areas of liquefaction and permanent ground displacement. Based on this review, for areas where permanent ground displacements are determined to severely impact the water supply system, remaining water supply functionality and reduction in fire suppression capability are estimated judgmentally.

At the time of first arrival, if the fire (in terms of SFED's) is larger than the suppression capability (in terms of SFED's) of the allocated (one or more) engines, then we term this a "large fire." Large fires are assumed fought by available engines in a downwind perimeter defense, and to initially spread elliptically at down/up/side wind rates through a uniformly spaced gridwork of buildings. This assumption of a uniform gridwork of buildings has been used in all urban fire modeling to date, and is reasonable given our objectives. The spacing, story height, etc., of this gridwork are a function of building density and built-upness (the latter is the ratio of property devoted to buildings contrasted to the total area, including streets, parks, etc.). Fire spreading rates are decreased, and the initial elliptical shape altered, as the available firefighting capability increases. Eventually, for each fire, one of three things happens:

1. Fires are suppressed. That is, firefighting capability exceeds needs (either initially, or with build-up

of engines as other fires are suppressed and their engines redirected, and/or mutual aid engines arrive) and the fire is surrounded, controlled and suppressed.

2. The fire is too large and capability is exceeded by need. The fire burns relatively freely within a city block. At each street or other (down/up/side wind) firebreak, the fire crosses with crossing probability as discussed above. This probability is a function of firebreak width, wind direction and, especially, suppression capability. If sufficient engines and water are available, many fires will typically be stopped at the first wide street. Note that strong winds have an important effect on downwind firebreak crossing probabilities. In this context, branding (windborne transmission of flaming debris) is sometimes an important factor, especially where wood roofs are prevalent (these are banned in San Francisco, but are common in some other jurisdictions). In most cases, a fire is not expected to cross more than a few typical streets, so that most large fires will be stopped, or burn themselves out, within a few blocks. Again, moderate to strong winds will extend this stopping distance significantly.
3. The fire reaches an "ultimate" firebreak—that is, a large expanse of water, the edge of the urbanized area, etc. Available engines are sufficient to defend exposures along the remaining perimeter, and the fire is controlled and suppressed.

Final Burnt Area

The above method is followed for each fire. Fires are tracked and merged where they meet (i.e., areas are not "burnt twice"). Final burnt areas are summed, to arrive at total final burnt area. (This methodology ultimately was used to estimate final burnt area for 18 different combinations of wind conditions and other factors relevant to the conflagration risk. See Tables 8 and 9 in Chapter 4.)

Verification

In order to study the accuracy of this methodology, we have examined selected jurisdictions in several past earthquakes. These past earthquakes are directly relevant to this study's objectives, since the first two studied (the 1906 San Francisco and 1933 Long Beach) are prototypes for the earthquakes studied herein. Results are presented in Appendix 1. We discuss results for each earthquake in turn:

(i) 1906 San Francisco: Thirteen jurisdictions in the San Francisco Bay Area affected by this earthquake were examined using the above methodology, including San Francisco, Oakland, Berkeley, Alameda and Santa Rosa. The regional urban population in 1906 was approximately 600,000 (it is about ten times greater today), two-thirds of which were concentrated in San Francisco itself. In 1906 the urbanized portion of San Francisco was approximately 13 sq. miles, and this was protected by 45 engine and chemical companies, with a total pumping capacity of perhaps 34,000 gpm (today total engine pumping capacity is about twice this, although the number of companies has actually decreased, to 41). Because personnel in 1906 were on call 24 hours a day and lived near their fire stations, the immediately available manpower in 1906 (643) exceeded that at present (today there are approximately 350 per shift in San Francisco, with many personnel resident outside the city).

Two conflagrations occurred in this earthquake: the well-known fire in San Francisco resulting in a total fire loss of approximately $320 million (Steinbrugge, 1982; this would be about $3.2 billion in 1987 dollars), as well as a 4 to 5 city block fire in Santa Rosa. Although a few fires occurred in Oakland, Alameda and Berkeley (with a total population of about 100,000), conflagrations did not occur.

We have used the above methodology and estimate, for the 1906 building stock and fire suppression capabilities, a fire loss of $3 billion (1987 dollars) for San Francisco, compared with the historical $3.2 billion. For Santa Rosa we estimate a 1906 loss of $11 million, whereas a minimum loss of $40 million was experienced (our estimate, based on data in Lawson, 1908). While fires are estimated, and historically did occur in other communities (San Jose, Oakland, etc.), conflagrations are not estimated, and historically did not occur.

(ii) 1933 Long Beach: We examined seven jurisdictions, breaking the City of Los Angeles into three portions (Central, Harbor and San Fernando Valley). Compton was especially badly damaged by shaking in this earthquake, and we estimate this jurisdiction should have had a two to four block conflagration. We also estimate that Long Beach should have had conflagration of twice this size. While Long Beach had a minimum of 16 fires, neither jurisdiction had a large fire loss. A factor which may account for overestimation compared with historical experience was the immediate loss of pressure in the gas system due to breaks (N.B.F.U., 1933; Du Ree, 1941) and the shutting off of the municipal gas supply following the

earthquake, per standing orders by the fire department (Smethurst, 1933).

(iii) 1957 San Francisco: This earthquake was the largest to affect San Francisco since the 1906 event, although it was still a relatively minor event (M 5.3). It caused no fires, with which our estimate agrees.

(iv) 1971 San Fernando: We examined seven jurisdictions, including the City of Los Angeles, which we broke into three portions as above. Although generally extensively documented, the fire aspects of this earthquake are not well documented in the City of Los Angeles, nor is there a detailed MMI map for this event. Our estimates agree rather well with the exception of the San Fernando Valley (the strongest shaken urbanized area), where we estimate the equivalent of a ten by ten city block area should have been burnt. Time of day (the earthquake was early in the morning), lack of wind and recent precipitation in this event are all factors which would tend to preclude large fires, relative to the average conditions employed in our model. Another factor which may account for our lack of agreement is that MMI in the Valley, away from the near-epicentral northeast corner, may have been lower than the MMI VII reported on the only available MMI map for this event (Scott, 1973), which is lacking in detail.

(v) 1984 Morgan Hill: We studied four jurisdictions for this event, including San Jose (population 700,000) which was on the edge of the strong shaking and which experienced a multi-alarm fire. Agreement is in general reasonable.

The above five earthquakes are typical of U.S. experience but unfortunately do not provide a broad enough basis for complete verification. Because of this, only fair agreement can be ascribed, based on the above. Based on these five examples, however, one point emerges: conflagrations and large fire loss are only likely to occur in the case of a large earthquake strongly shaking (i.e., MMI VII and above) a large metropolis, overwhelming local fire services. A moderate earthquake on the edge of a metropolis (e.g., 1971 San Fernando, M 6.4) may result in numerous fires, but the total number of fires will still be less than the total number of fire engines. In the 1971 event, for example, the total number of fires was about 109, while the City of Los Angeles alone had 132 fire engines in service.

CHAPTER 4
ESTIMATION OF LOSSES FOR SCENARIO EARTHQUAKES

This Chapter presents the data for and results derived from application of the above methodology, for the two scenario earthquakes.

Data Base on Insured Fire Risks

This section briefly discusses the data base on insured fire risks. The basic data were furnished by AIRAC for this study. The data base was derived from two kinds of inputs furnished to AIRAC by various insurance companies and organizations:

(i) A residential part by ZIP code, broken down by Forms 1, 2, 3 & 5 (one to four family dwellings) and Forms 4 & 6 (Tenants and Condominiums), and

(ii) A commercial part by ISO Territory, broken down by the following occupancies: Habitational, Mercantile, Manufacturing/Moderate Hazard Chemical, Manufacturing/High Hazard Chemical, Manufacturing/All Other, Non-Manufacturing, Warehouses and Yards, as well as a Total section. Each of these occupancies was further classified into Frame, Masonry and Other structural categories.

For the residential portion of the data base, AIRAC compiled data on insured fire exposures from State Farm, Allstate, Farmers Insurance Group and the Insurance Services Office (ISO). ISO is an insurance statistical and rating organization that collects information from several hundred insurers writing property insurance and other lines of business. An "insured fire exposure" is the amount of fire coverage provided by the policy—i.e., the amount an insurance company would have at risk in the event the insured property were destroyed by fire. Together, the three companies plus those represented in the ISO data accounted for 74% of the premiums written for property insurance coverages purchased by homeowners and tenants in California during 1983. AIRAC assumed that they also had 74% of the premiums and insured fire exposures in the San Francisco Bay Area and in the Los Angeles Region. Using that assumption, AIRAC projected the data to full industry exposure levels.

In developing the commercial fire exposure base, AIRAC obtained data from ISO, the Factory Mutual System, Industrial Risk Insurers and State Farm. The Factory Mutual System and Industrial Risk Insurers, like ISO, gather data on insured exposures from numerous member companies. Together, the four entities accounted for 54% of the commercial fire insurance premiums written in California during 1983, and are believed to provide a mix of business representative of insured properties in the two regions. Data provided by the four sources were used to project commercial fire exposures to full industry level. The residential and commercial data bases were then combined to provide estimates of total insurance industry exposure to fire losses in the San Francisco and Los Angeles regions. These data are summarized in Table 7 and detailed in Appendices 2 and 5.

For each jurisdiction of this study, this information was used, along with other information such as land use maps, assessor's files, etc., to estimate building square footage and density. Building square footage destroyed by fire is the direct measure of loss produced by our methodology, so that this in turn was

TABLE 7
SUMMARY OF INSURED FIRE RISKS
San Francisco and Los Angeles Regions

	Amount of Insurance Written ($ billions)
SAN FRANCISCO BAY AREA:	
City of San Francisco	
Residential:	$ 10.8
Commercial:	29.9
Remainder of region (AIRAC data)	
Residential:	118.1
Commercial:	85.9
Remainder of region (D&M Estimates)*	
Residential & Commercial:	19.1
TOTAL for San Francisco Bay area:	$263.8
LOS ANGELES REGION:	
City of Los Angeles	
Residential:	$ 56.4
Commercial:	76.4
Remainder of region (AIRAC data)	
Residential:	144.5
Commercial:	171.0
Remainder of region (D&M Estimates)**	
Residential & Commercial:	17.9
TOTAL for Los Angeles Region:	$466.2

*Estimates made for Solano, Santa Cruz, Sonoma, and Napa counties.
**Estimates made for Ventura county.

prorated back to insurance dollar loss, including contents loss. In general, the information furnished by AIRAC agreed well with other information (e.g., Bank of America, 1986; Means, 1983; Moselle, 1983), to the effect that average building value is approximately $50 per square foot of floor area and contents value half of this.

Our methodology does not directly account for certain special risks, such as high hazard chemical. These values were treated the same as other risks, and we may underestimate loss in this category. Note however that total high hazard chemical for the San Francisco Bay area is only about 1.2% of total commercial risk and 0.6% of total insured fire risk (for Los Angeles, the numbers are 2.0% and 1.1%, respectively) so that unless the relative losses in these categories are enormously higher than for other categories, the effect of neglecting the special nature of these risks should not have a major effect on the overall loss estimates.

EARTHQUAKE AND LOSSES IN SAN FRANCISCO BAY AREA

This section presents the scenario earthquake and the application of the above methodology to estimate losses due to fire following earthquake in the San Francisco Bay area.

Scenario Earthquake

The scenario earthquake for the San Francisco Bay area is a repeat of the 1906 San Francisco earthquake. That is, an earthquake of approximately M 8.3 on the northern portion of the San Andreas fault. Historical precedent for this earthquake is of course excellent (Lawson, 1908) and we shall not discuss the earthquake at length. The event represents a rupture of the San Andreas fault, with a total length of rupture of approximately 250 miles and a maximum right lateral offset of perhaps 21 feet. The faulting is within 10 miles of downtown San Francisco and runs along the San Francisco Peninsula, generally within 5 miles of the Peninsula cities with their manufacturing concentrations (''Silicon Valley'').

Effects of a postulated repeat of this event have been studied extensively (Davis et al., 1982; Evernden et al., 1981). For this event we use seismic intensities (MMI) generated by the California Division of Mines and Geology (Davis et al., 1982), Figure 3, which are based on work by Evernden at the U.S. Geological Survey. Mapping of liquefaction, Figure 13, estimates potential for liquefaction ''where cohesionless granular soils are present.''

MMI within the City of San Francisco vary considerably, from IX within parts of the downtown area, to less than VII on the firmest sites. Variation elsewhere in the Bay area is similar, being VI to VIII in Oakland, Berkeley, etc. Particularly hard hit, considering its size, is San Jose, within an average MMI of VIII.

Data Sources

For each relevant jurisdiction, estimates of exposed building square footage based on insured risk data furnished by AIRAC, population, assessor's files, traffic data and other information were compiled. In the San Francisco Bay area, a total of 119 jurisdictions in ten counties were considered, with a total population of 4.95 million persons. In the City of San Francisco for example, with a total population of approximately 720,000, total building square footage was estimated at approximately 544 million, with about 83 million of this in the Central Business District (CBD) alone. Building Density was estimated on the basis of total urbanized area, allowing for built-upness (the ratio of property devoted to buildings contrasted to the total area, including streets, parks, etc.).

Fire department resource data were made available to us by California OES Fire and Rescue Division. Post-earthquake water supply system functionality was estimated on the basis of zones of MMI and expected liquefaction (except in the City of San Francisco, no detailed studies were performed regarding damage to the water supply system—remaining functionality was simply estimated after reviewing MMI and liquefaction data—unique characteristics of individual water supply systems, such as local standpipes or pressure tanks, age and materials of piping, contingency plans, etc., were not considered). The data on building insured value, area, number of fire stations, etc., are summarized in Appendix 2.

Wind speed data were obtained from airport data (NOAA, 1977), and are presented in Figure 14. From this figure we can see that average wind speed in the Bay area is about 9 mph, while 90th percentile wind speed is close to 20 mph. Prevailing winds are dominantly onshore (i.e., from the west).

Findings for the San Francisco Bay Area

Based on the above methodology and data, we have made various estimates of the expected losses in the San Francisco Bay area due to fire following earthquake. Because of the large number of variable factors that can affect fire losses, such as wind, emergency preparedness, etc., we have prepared estimates based on several different combinations of factors. Results

FIGURE 13

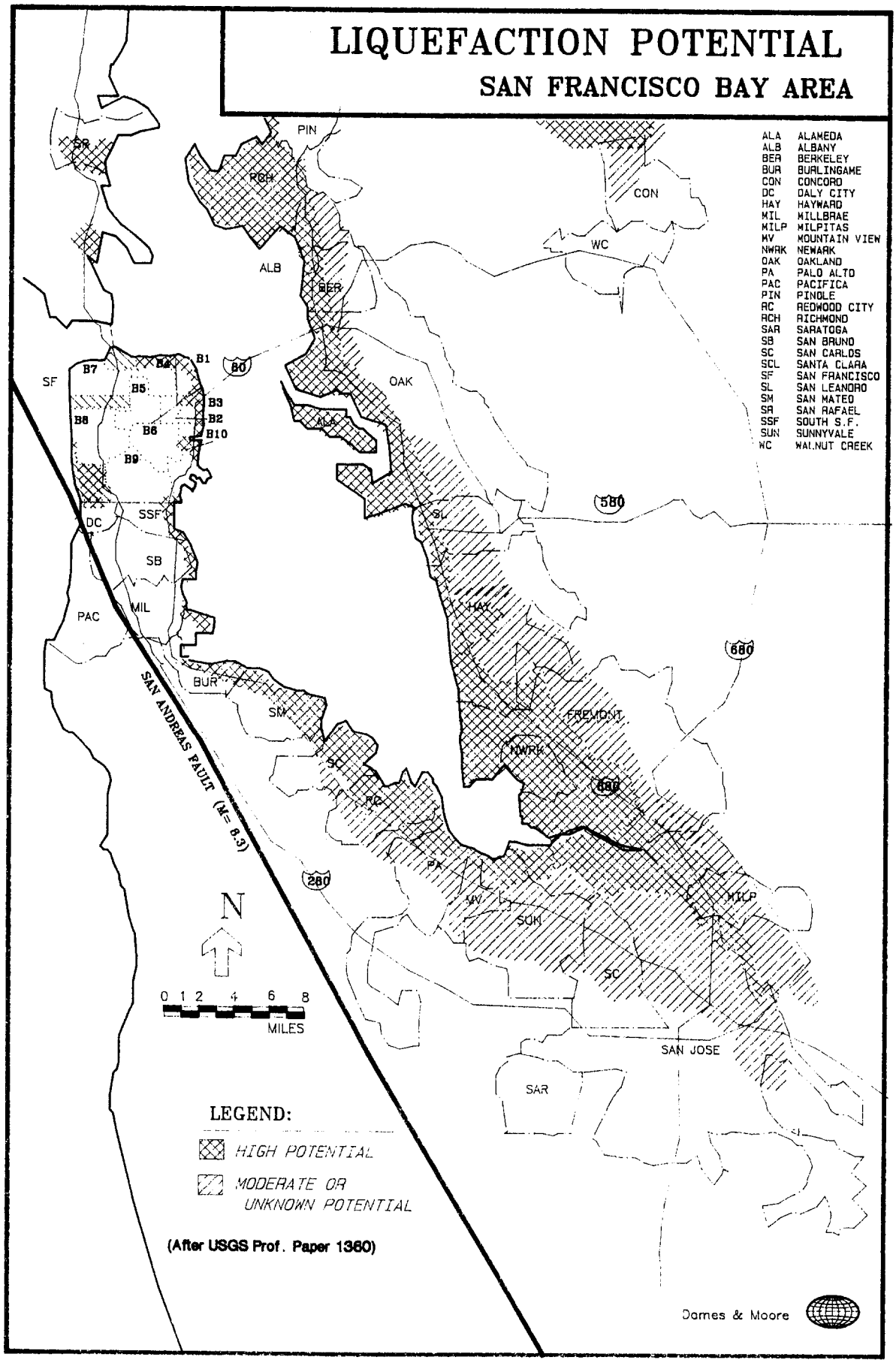
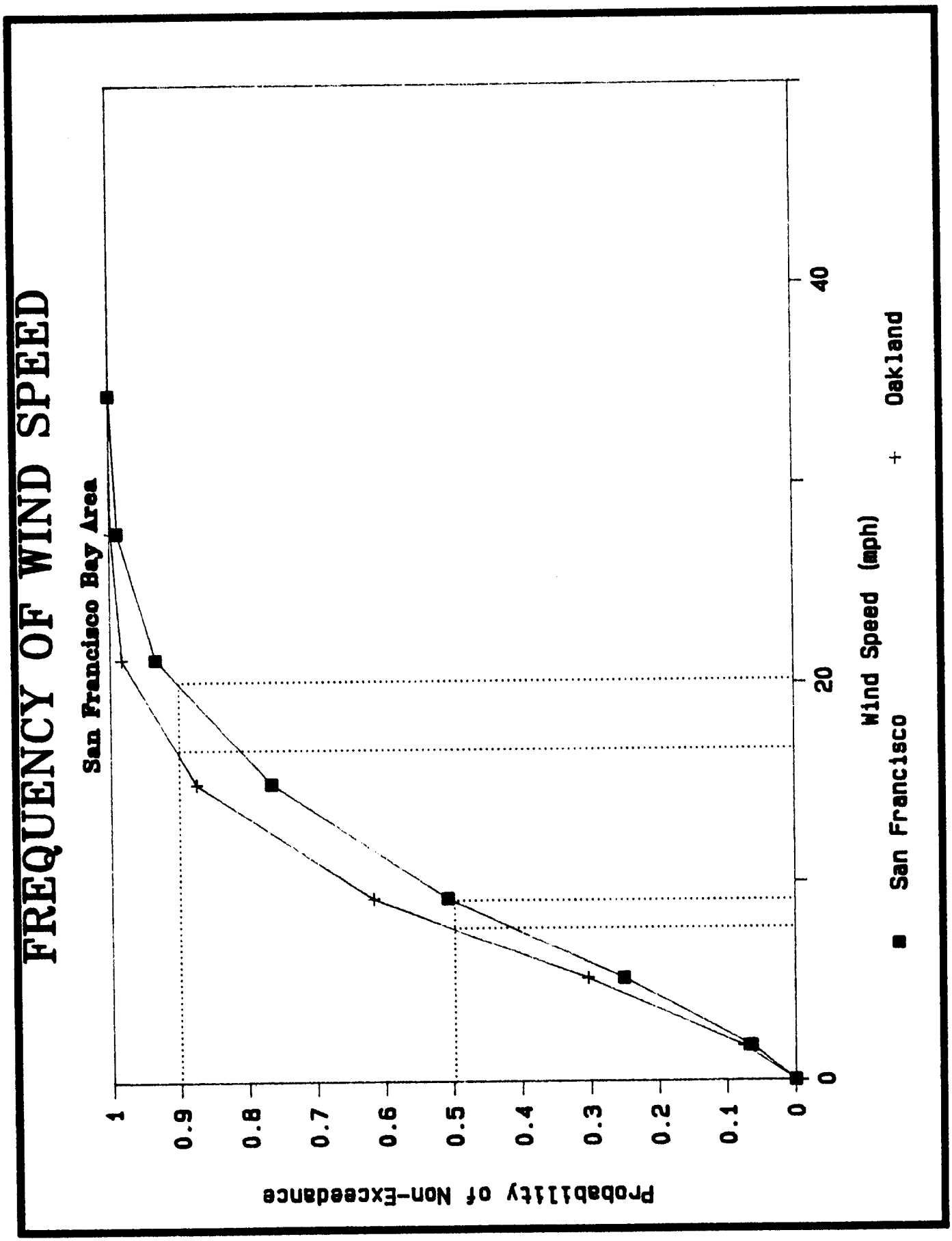

LIQUEFACTION POTENTIAL
SAN FRANCISCO BAY AREA
ALA ALAMEDA
ALB ALBANY
BER BERKELEY
BUR BURLINGAME
CON CONCORD
DC DALY CITY
HAY HAYWARD
MIL MILLBRAE
MILP MILPITAS
MV MOUNTAIN VIEW
NWRK NEWARK
OAK OAKLAND
PA PALO ALTO
PAC PACIFICA
PIN PINOLE
RC REDWOOD CITY
RCH RICHMOND
SAR SARATOGA
SB SAN BRUNO
SC SAN CARLOS
SCL SANTA CLARA
SF SAN FRANCISCO
SL SAN LEANDRO
SM SAN MATEO
SR SAN RAFAEL
SSF SOUTH S.F.
SUN SUNNYVALE
WC WALNUT CREEK
SAN ANDREAS FAULT (M= 8.3)
N
0 1 2 4 6 8
MILES
LEGEND:
HIGH POTENTIAL
MODERATE OR UNKNOWN POTENTIAL
(After USGS Prof. Paper 1360)
Dames & Moore

FIGURE 14


FREQUENCY OF WIND SPEED
San Francisco Bay Area
Probability of Non-Exceedance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
Wind Speed (mph)
San Francisco
Oakland

of those studies are summarized in Table 8. This table shows our estimates of aggregate losses due to fire following earthquake, in billions of dollars, for the City of San Francisco (rightmost column of numbers, denoted City), and for the entire San Francisco Bay area (next rightmost column of numbers, denoted Bay area). These estimates are for a variety of conditions that might exist at the time of an earthquake, notably:

(i) Wind Speed (minimum of 0 mph, maximum of 40 mph).

(ii) Fire Factor (a multiplicative factor to indicate the rate of fire ignitions. A Fire Factor of 1 indicates the average (mean) number of expected ignitions, 0.5 means half the average number of ignitions, 1.2 means 20% greater than average number of ignitions, etc. In terms of probabilities, an ignition rate of 1 is estimated to have a 50% chance of occurrence, while 0.5 and 1.4 each have a 10% chance of occurrence.

(iii) Earthquake Delay (delay in reporting fires to fire department, in minutes, as discussed above).

(iv) Fire Engine Speed (in mph, as discussed above).

We see that expected fire losses can range from negligible to about $17 billion for the region, depending on various combinations of these factors. For planning purposes, we have selected three particular combinations that represent relatively favorable, intermediate, and relatively severe conditions from the standpoint of generating fire losses, given the occurrence of the M 8.3 earthquake described earlier:

Level I is the term used to designate relatively favorable conditions at the time of the earthquake—calm to light wind conditions, an average number of fires requiring fire department response (Fire Factor 1), reporting of fires only 5 minutes after discovery, and fire engine response times based on travel at 15 mph. Our estimate of insured fire losses for the Bay area under Level I conditions is about $4 billion, of which about $2.5 billion or nearly two-thirds is sustained in the City of San Francisco.

Level II estimates assume intermediate conditions involving moderate winds (approximately 10 mph), conditions fairly typical for San Francisco Bay and the Los Angeles Basin. Other fire risk factors are similar to those for the Level I estimates. We estimate insured fire losses for the Bay area under Level II conditions at about $7 billion, with $3.5 billion (about 50%) in San Francisco itself.

Level III estimates assume relatively adverse conditions involving stronger winds (20 mph or greater) and

TABLE 8

SAN FRANCISCO BAY AREA: ESTIMATED LOSSES DUE TO FIRE FOLLOWING EARTHQUAKE ALONG THE NORTHERN PORTION OF THE SAN ANDREAS FAULT ZONE

WIND mph	FIRE FACTOR	EQ DELAY mins	ENGINE SPEED mph	SAN FRANCISCO TOTAL $ LOSS (billions) BAY AREA	CITY	
40	1.2	5	15	17,303	9,000	
40	1	5	15	14,738	7,988	
20	1.2	5	15	10,553	5,411	Level III, Figure 15
20	1	5	15	8,763	4,669	
15	1.2	5	15	9,044	4,703	
10	1.4	5	15	8,663	4,624	
10	1.2	5	15	7,469	4,073	Level II
10	1	5	8	6,919	3,510	Level II, Figure 5 and Appendix 4
10	1	5	15	6,131	3,465	Level II
10	1	5	30	5,108	3,409	
0	1.2	5	15	4,579	3,026	Level I
0	1	5	15	3,656	2,531	Level I, Appendix 3
10	1	0	15	3,600	2,700	Level I
10	1	0	30	2,486	2,486	
0	1	0	15	2,554	1,935	
0	1	0	30	0	0	
0	0.5	0	15	833	810	
0	0.5	0	30	0	0	

a 20% greater than average number of fires requiring fire department response (Fire Factor 1.2). An example of Level III conditions is the fire following the 1923 earthquake in Kanto, Japan, when ignitions probably were much higher than average due to the earthquake occurring exactly at cooking time (11:59 a.m.) on a windy day. Winds at the time were 25 mph. Our estimate of insured losses for the Bay area under Level III conditions is $9 to $15 billion, with about half of the loss occurring in the City of San Francisco.

The geographic distribution of Level II losses are shown in Figures 5 and 6 in Chapter 2. Comparable maps for Level III are shown in Figures 15A and 15B in this Chapter. Note that only the larger losses are shown in the maps, and that locations are not precise within a jurisdiction.

Detailed results by jurisdiction are presented in Appendix 3 (loss estimates for Level I conditions) and in Appendix 4 (loss estimates for Level II conditions).

In summary, we see that for the $264 billion at risk in the San Francisco Bay area, the relatively favorable Level I conditions would produce insured fire losses of about $4 billion, or 1.5% of the value of homes and commercial property in that 1,245 square mile area. Intermediate Level II conditions would produce estimated fire losses of about $7 billion, or 2.6% of the property value at risk. Losses for the relatively adverse Level III conditions would run about $9 to $15 million, or 3.4%-5.7% of property values for the Bay area. Much of this estimated loss is concentrated in the City of San Francisco ($2.5 billion or 6% of the city's property values under Level I conditions, $3.5 billion or 8.5% of the values at risk under Level II conditions, and $5.4 billion or 13.3% of value under Level III conditions. This means the City of San Francisco has a post-earthquake fire risk three to four times higher than the Bay area as a whole.

Note that the City of San Francisco since 1908 has had a special high pressure Auxiliary Water Supply System (AWSS) and cisterns dedicated to fire protection in the high value district. We have taken these special features into account in the estimates presented above. At present, the San Francisco Fire Department is planning to extend the AWSS and cisterns to other parts of the city, and to develop a Portable Water Supply System (PWSS). Funds for the PWSS have been allocated, and the AWSS extension was approved in the November 1986 ballot by an overwhelming majority. However, construction of AWSS will likely require a decade for completion. Implementation of these plans will significantly increase the post-earthquake capabilities of the department, and probably will decrease losses in San Francisco due to fire following earthquake. As implementation of these plans proceeds, revision of our fire loss estimates may be appropriate.

EARTHQUAKE AND LOSSES FOR THE LOS ANGELES REGION

This section presents the scenario earthquake and the application of the above methodology to estimate losses due to fire following the scenario earthquake in the Los Angeles Region.

Scenario Earthquake

The scenario earthquake for the Los Angeles Region is a magnitude 6.5 earthquake on the Newport–Inglewood fault. An earthquake of magnitude 7.5 for this fault zone has been used in previous studies of earthquake losses (NOAA, 1973). However, recent evidence (Anderson, 1979; Ziony and Yerkes, 1985) indicates that M 7.5 is a maximum credible event for this fault, and that a M 6.5 event is a credible earthquake for ordinary planning and design purposes for this fault zone (Ziony and Yerkes, 1985). An M 6.5 event does not necessarily represent the largest earthquake that might occur along the Newport-Inglewood zone (Ziony et al., 1985b), but larger events are judged to be very infrequent. This M 6.5 event was the subject of an extensive recent U.S.G.S. study (Ziony et al., 1985b), and we shall use their results herein.

Similar to the 1906 event, there is good historical precedent for our postulated earthquake. The 1933 Long Beach earthquake (M 6.3) occurred on this fault zone, somewhat southerly from this study's postulated epicenter. In that earthquake, cracked ground and broken water mains were observed in Long Beach, San Pedro, Watts and elsewhere (Barrows, 1974, citing Maher, 1933). Fires and building collapses occurred in Long Beach and surrounding communities. Compton was particularly hard hit.

The postulated event represents a rupture of the Newport-Inglewood fault zone, with a total length of rupture of approximately 20 miles and a maximum right lateral offset of perhaps 2 feet (Ziony et al., 1985b). The faulting is directly under west central Los Angeles, extending from about Gardena to about northern Culver City.

As mentioned above, effects of a postulated repeat of this event have been studied extensively by the U.S.G.S., and we use the Survey's maps of intensity generated by Evernden, and of liquefaction, generated by Tinsley and Youd (Ziony et al., 1985b). The intensity map is in terms of MMI, Figure 4 (taken from

FIGURE 15A

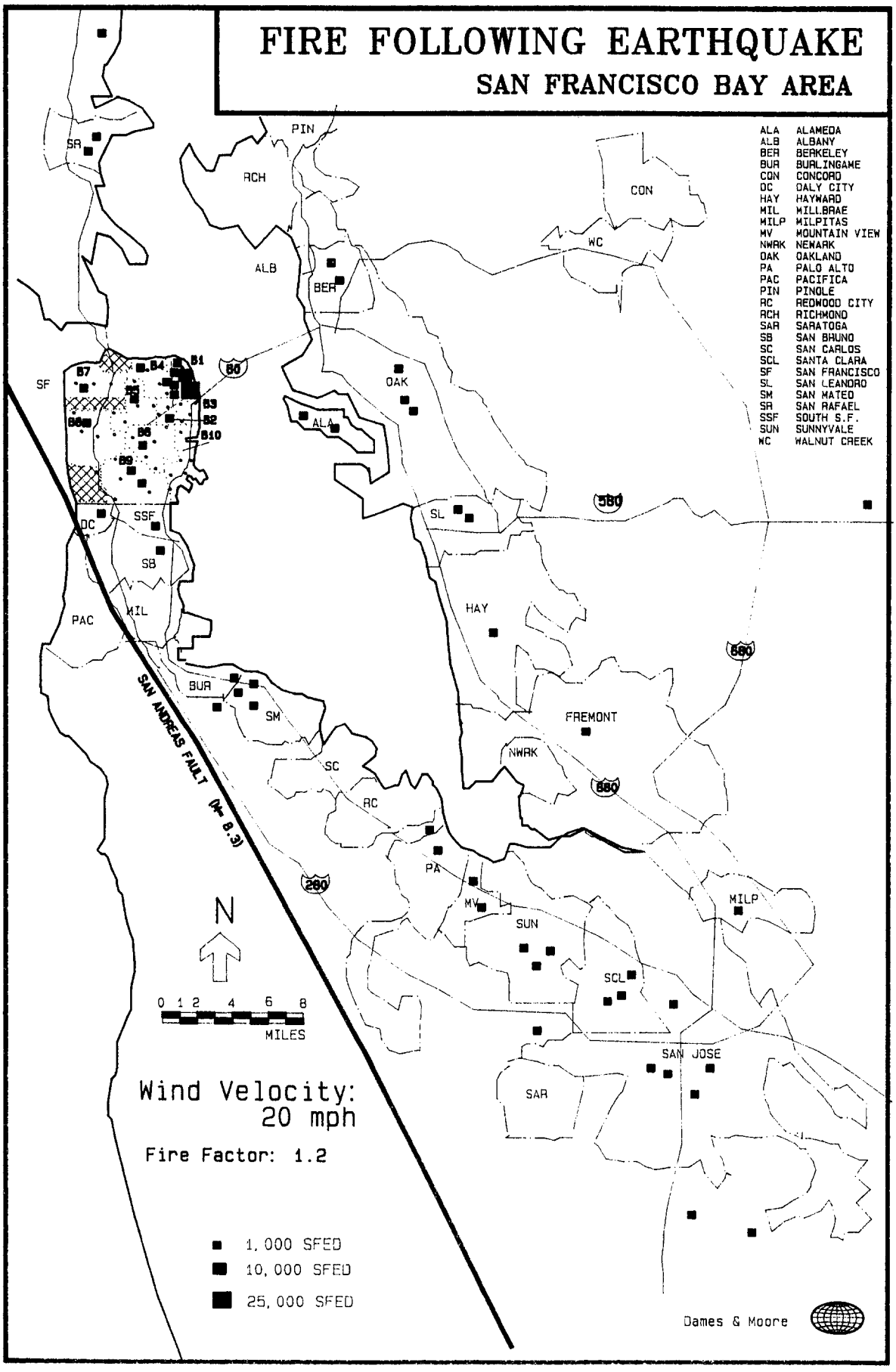
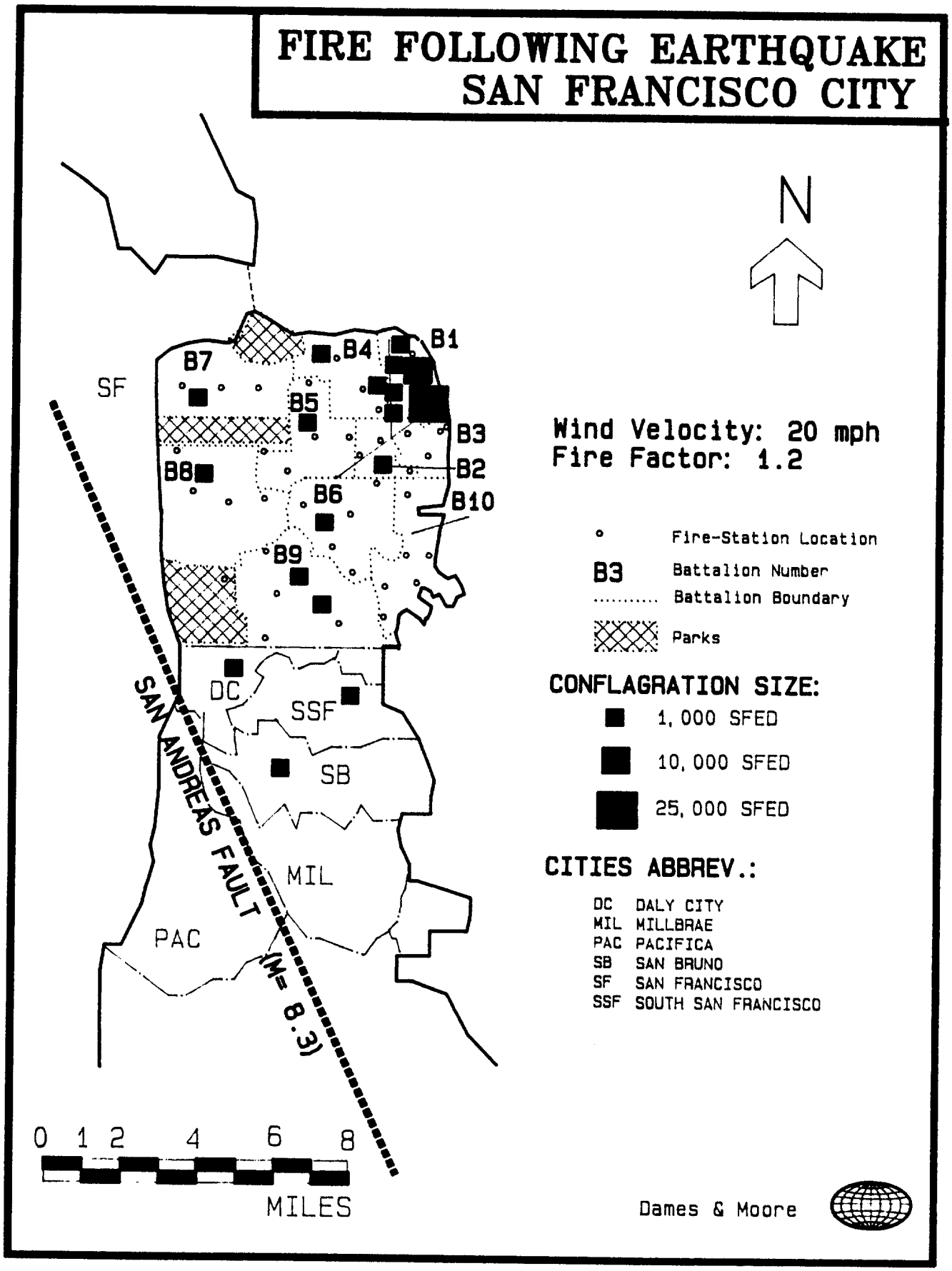

FIRE FOLLOWING EARTHQUAKE
SAN FRANCISCO BAY AREA
ALA ALAMEDA
ALB ALBANY
BER BERKELEY
BUR BURLINGAME
CON CONCORD
DC DALY CITY
HAY HAYWARD
MIL MILLBRAE
MILP MILPITAS
MV MOUNTAIN VIEW
NWRK NEWARK
OAK OAKLAND
PA PALO ALTO
PAC PACIFICA
PIN PINOLE
RC REDWOOD CITY
RCH RICHMOND
SAR SARATOGA
SB SAN BRUNO
SC SAN CARLOS
SCL SANTA CLARA
SF SAN FRANCISCO
SL SAN LEANDRO
SM SAN MATEO
SR SAN RAFAEL
SSF SOUTH S.F.
SUN SUNNYVALE
WC WALNUT CREEK
SAN ANDREAS FAULT (M= 8.3)
N
0 1 2 4 6 8
MILES
Wind Velocity:
20 mph
Fire Factor: 1.2
1,000 SFED
10,000 SFED
25,000 SFED
Dames & Moore

FIGURE 15B


FIRE FOLLOWING EARTHQUAKE
SAN FRANCISCO CITY
N
B1
B4
B7
SF
B5
B3
B8
B2
B6
B10
B9
DC
SSF
SB
MIL
PAC
SAN ANDREAS FAULT (M= 8.3)
Wind Velocity: 20 mph
Fire Factor: 1.2
Fire-Station Location
B3 Battalion Number
Battalion Boundary
Parks
CONFLAGRATION SIZE:
1,000 SFED
10,000 SFED
25,000 SFED
CITIES ABBREV.:
DC DALY CITY
MIL MILLBRAE
PAC PACIFICA
SB SAN BRUNO
SF SAN FRANCISCO
SSF SOUTH SAN FRANCISCO
0 1 2 4 6 8
MILES
Dames & Moore

Ziony et al., 1985b). Therein, MMI are presented in arabic numerals, for ease of reading. Mapping of liquefaction, Figure 16, estimates potential for liquefaction "where cohesionless granular soils are present."

MMI within the region vary from VIII+ in Marina del Rey (and elsewhere), to less than VI on the firmest sites. Particularly hard hit are the Harbor area (VIII−) and Marina del Rey (VIII+), both of which are indicated to have high liquefaction potential.

Data Sources

In general, data were compiled as discussed above for the San Francisco Bay area. In the Los Angeles Region, a total of 115 jurisdictions in three counties were considered, with a total population of 8.98 million persons. In the City of Los Angeles for example, with a total population of approximately 3.1 million, total building square footage was estimated at approximately 1.7 billion. Building Density and other data were estimated as discussed above.

Fire department resource data were made available to us by California OES Fire and Rescue Division, and were supplemented by additional data received from the fire departments of the City of Los Angeles and Los Angeles County. Post-earthquake water supply system functionality was estimated on the basis of zones of MMI and expected liquefaction. No detailed studies were performed regarding damage to the water supply system. Remaining functionality was simply estimated after reviewing MMI and liquefaction data. Unique characteristics of individual water supply systems, such as local standpipes or pressure tanks, age and materials of piping, contingency plans, etc., were not considered. The data on building insured value, area, number of fire stations, etc., are summarized in Appendix 5.

Wind speed data were obtained from airport data (NOAA, 1977), and are presented in Figure 17. From this figure we can see that average wind speed in the Region is about 5 or 6 mph, while 90th percentile wind speed is about 12 mph. With regard to wind, the Los Angeles Region has a somewhat unusual phenomenon, termed Santa Ana winds. These are occasional hot, dry, foehn-like desert winds, generally from the northeast or east, especially in the pass and river valley locales. They are most frequent in the fall, winter and early spring months, with an annualized probability of about 6% on any given day (i.e., Santa Ana conditions are observed about 22 days per year). Velocities in excess of 50 mph can develop over localized sections of the Los Angeles Basin, although even under these conditions average velocities for the region will be on the order of 20 mph or less (UCLA, n.d.).

Findings for the Los Angeles Region

Based on the above methodology and data, we have made various estimates of the expected losses in the Los Angeles Region due to fire following earthquake. As above, we present our findings in terms of the probable insured losses that would be expected to occur under various conditions that might exist at the time of the earthquake. Results of those studies are summarized in Table 9 for the City of Los Angeles (rightmost column of numbers, denoted City), and for the Los Angeles Region (next rightmost column of numbers, denoted Regional). Losses are in billions of 1987 dollars. These estimates are for various combinations of wind conditions (0 to 40 mph), fire factors (1 indicates the mean number of expected ignitions, 1.2 an ignition rate 20% greater than average, etc.), earthquake delays (in minutes, discussed above) and fire engine speeds (in mph, as discussed above).

We see that the estimates of insured fire losses can range from negligible to about $40 billion for the Los Angeles region, depending on the particular mix of factors present at the time of the earthquake. However, some conditions are more likely than others. For planning purposes, we have selected three particular combinations that represent relative favorable (Level I) conditions, intermediate (Level II) conditions, and relatively adverse (Level III) conditions. These terms and the headings used in Table 9 are described more fully in the section above titled "Findings for the San Francisco Bay Area."

For the relatively favorable Level I conditions, we estimate that the Los Angeles Region would sustain insured fire losses of approximately $5 billion, of which $1.6 billion or about one-third is sustained in the City of Los Angeles.

Intermediate Level II conditions would produce insured fire losses for the region of about $9 billion with about $3 billion or one-third of that total in Los Angeles itself.

The relatively adverse Level III conditions would generate estimated insured fire losses of $13 to $17 billion, again with about one-third of the losses in Los Angeles.

The geographic distribution of Level II and Level III losses is shown in Figures 6 and 18. Figure 19 depicts geographical distributions of large fires under even more extreme wind conditions (40 mph). Detailed results by jurisdiction are presented in Appendices 6 and 7.

FIGURE 16

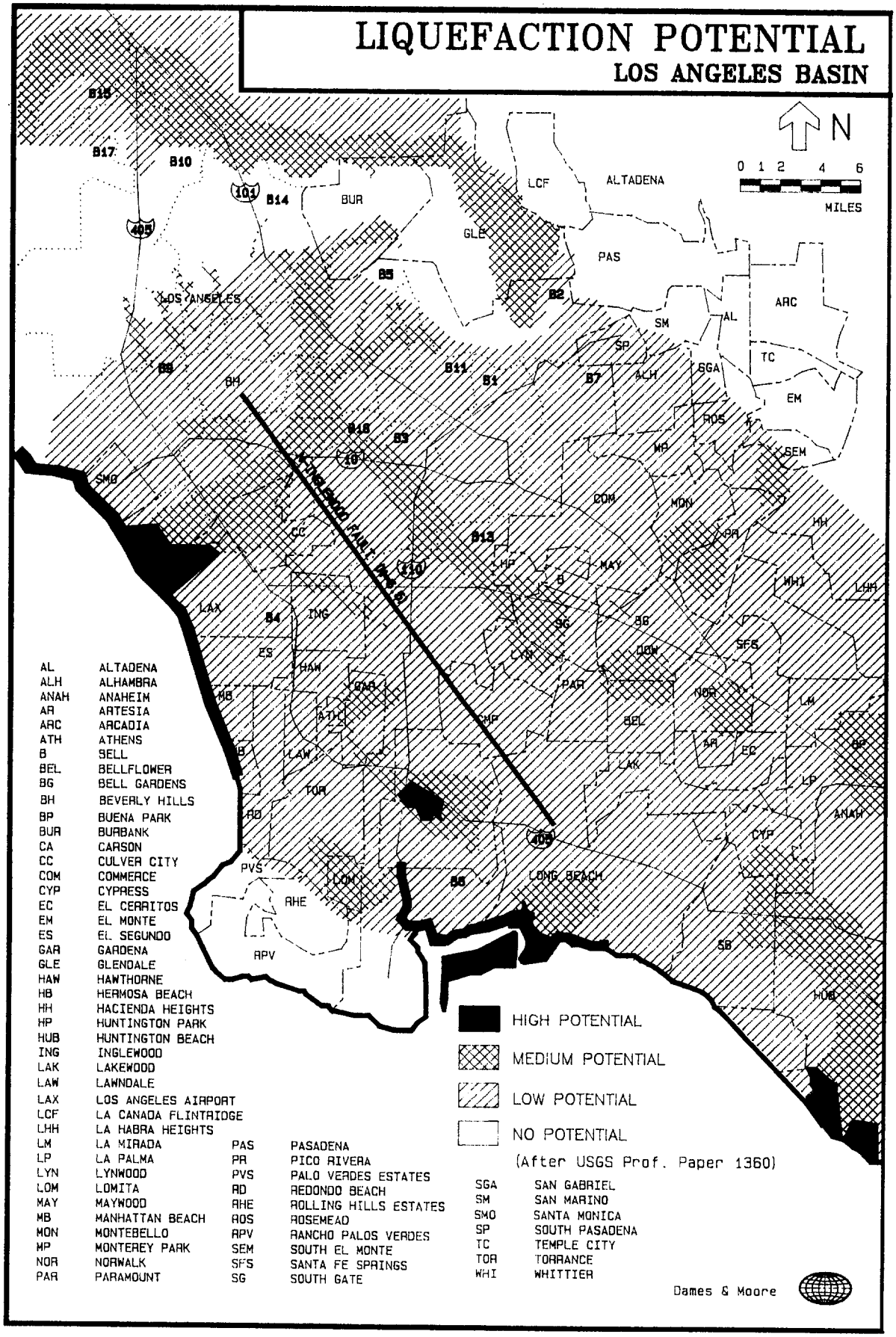
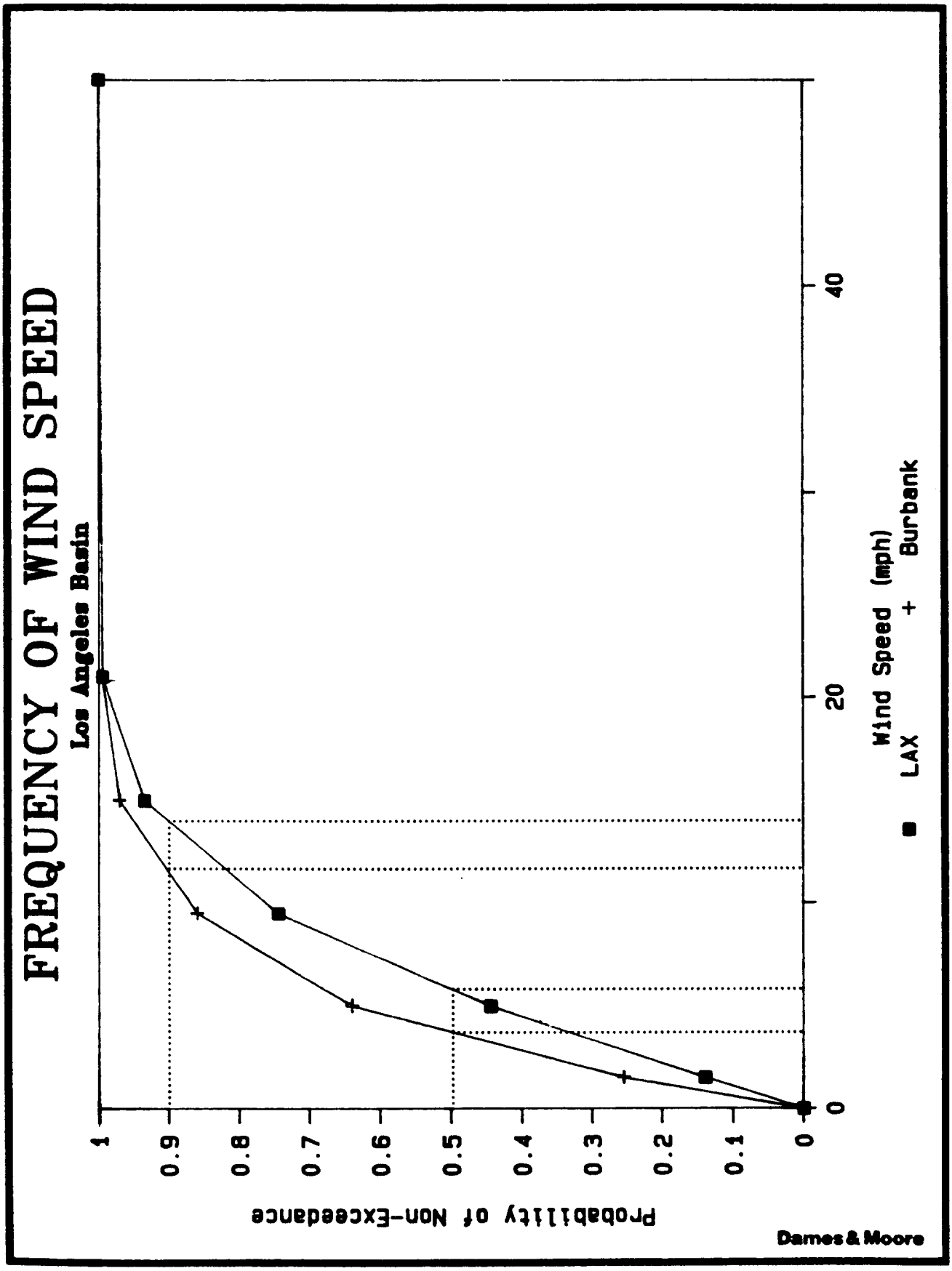

LIQUEFACTION POTENTIAL
LOS ANGELES BASIN
N
0 1 2 4 6
MILES
B15
B17
B10
101
B14
BUR
405
LCF
ALTADENA
GLE
PAS
B5
B2
LOS ANGELES
ARC
SM
AL
SP
TC
B9
BH
B11
B1
B7
ALH
SGA
EM
ROS
B16
B3
10
MP
SEM
SMO
COM
MON
CC
B13
PR
HH
HP
MAY
110
B
WHI
LHH
LAX
B4
ING
SG
BG
ES
LYN
DOW
SFS
HAW
PAR
NOR
MB
GAR
LM
ATH
CMP
BEL
AR
EC
BP
B
LAW
LAK
LP
TOR
RD
ANAH
405
CYP
PVS
LOM
B6
LONG BEACH
RHE
SB
RPV
HUB
AL ALTADENA
ALH ALHAMBRA
ANAH ANAHEIM
AR ARTESIA
ARC ARCADIA
ATH ATHENS
B BELL
BEL BELLFLOWER
BG BELL GARDENS
BH BEVERLY HILLS
BP BUENA PARK
BUR BURBANK
CA CARSON
CC CULVER CITY
COM COMMERCE
CYP CYPRESS
EC EL CERRITOS
EM EL MONTE
ES EL SEGUNDO
GAR GARDENA
GLE GLENDALE
HAW HAWTHORNE
HB HERMOSA BEACH
HH HACIENDA HEIGHTS
HP HUNTINGTON PARK
HUB HUNTINGTON BEACH
ING INGLEWOOD
LAK LAKEWOOD
LAW LAWNDALE
LAX LOS ANGELES AIRPORT
LCF LA CANADA FLINTRIDGE
LHH LA HABRA HEIGHTS
LM LA MIRADA
LP LA PALMA
LYN LYNWOOD
LOM LOMITA
MAY MAYWOOD
MB MANHATTAN BEACH
MON MONTEBELLO
MP MONTEREY PARK
NOR NORWALK
PAR PARAMOUNT
PAS PASADENA
PR PICO RIVERA
PVS PALO VERDES ESTATES
RD REDONDO BEACH
RHE ROLLING HILLS ESTATES
ROS ROSEMEAD
RPV RANCHO PALOS VERDES
SEM SOUTH EL MONTE
SFS SANTA FE SPRINGS
SG SOUTH GATE
SGA SAN GABRIEL
SM SAN MARINO
SMO SANTA MONICA
SP SOUTH PASADENA
TC TEMPLE CITY
TOR TORRANCE
WHI WHITTIER
HIGH POTENTIAL
MEDIUM POTENTIAL
LOW POTENTIAL
NO POTENTIAL
(After USGS Prof. Paper 1360)
Dames & Moore

FIGURE 17


FREQUENCY OF WIND SPEED
Los Angeles Basin
Probability of Non-Exceedance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
Wind Speed (mph)
LAX
+ Burbank
Dames & Moore

The above results for Level III losses reflect to some extent the possibility that Santa Ana conditions are present following a major earthquake. Figure 19 was added for the same reason. Note that even in Santa Ana conditions, high winds do not prevail uniformly throughout the Los Angeles Region. However, one aspect not dealt with directly in our loss estimates is the possible occurrence of an earthquake during an unusually hot, dry period, either in the summer months or during a Santa Ana condition in the fall, winter or spring, and the impact that might have on the fire risk in the areas which the Los Angeles Fire Department calls the Mountain Fire Zones (ISO Territory 08: Designated Brush Area). In hot, dry weather these are areas with a very high fire hazard, and in an earthquake we would expect numerous brush fire ignitions due to arcing of the many overhead power lines that transverse these areas. Such ignitions have been observed in recent earthquakes (Scawthorn and Donelan, 1983; Scawthorn et al., 1985) but they occurred in favorable spring weather and in sparsely populated areas, so that losses were nil. In hot, dry weather in the Los Angeles Region we would expect relatively high losses in the Mountain Fire Zones. Data currently available do not permit estimation of property values in these Zones. We recommend that this be done so that this aspect of the fire risk can be taken into account.

In summary, we see that for the $466 billion in property values at risk in the Los Angeles Region, we estimate that approximately $5 billion (1.1%) would be lost due to fire following an earthquake occurring under favorable Level I conditions. Under intermediate Level II conditions, the regional fire loss would be approximately $9 billion, or 1.9% of the value at risk. About $1.5 billion of the Level I loss is concentrated in the City of Los Angeles, or 1.1% of the value at risk. For Level II the Los Angeles portion is about $3 billion or 2.2% of the value at risk. That is, the City of Los Angeles as a whole has insured fire loss rates similar to the average loss rates for the entire region. Under more extreme Level III conditions the probable loss for the region is in the range of $13 to $17 billion.

TABLE 9

LOS ANGELES AREA: ESTIMATED LOSSES DUE TO FIRE FOLLOWING EARTHQUAKE ALONG THE NORTHERN PORTION OF THE NEWPORT–INGLEWOOD FAULT ZONE

WIND mph	FIRE FACTOR	EQ DELAY mins	ENGINE SPEED mph	LOS ANGELES TOTAL $ LOSS (billions) REGIONAL	CITY	
40	1.2	5	15	40,129	12,623	
40	1	5	15	34,796	10,935	Figure 19
20	1.2	5	15	16,661	5,400	Level III, Figure 18
20	1	5	15	13,691	4,534	Level III
15	1.2	5	15	13,466	4,343	Level III
10	1.4	5	15	12,848	4,050	Level III
10	1.2	5	15	11,036	3,533	
10	1	5	8	9,090	2,981	Level II
10	1	5	15	9,079	2,981	Level II, Figure 6 and Appendix 7
10	1	5	30	8,798	2,981	Level II
0	1.2	5	15	6,221	2,115	Level I
0	1	5	15	4,759	1,553	Level I, Appendix 6
10	1	0	15	2,408	844	Level I
10	1	0	30	2,194	844	
0	1	0	15	1,519	529	
0	1	0	30	1,395	529	
0	0.5	0	15	23	0	
0	0.5	0	30	23	0	

FIGURE 18

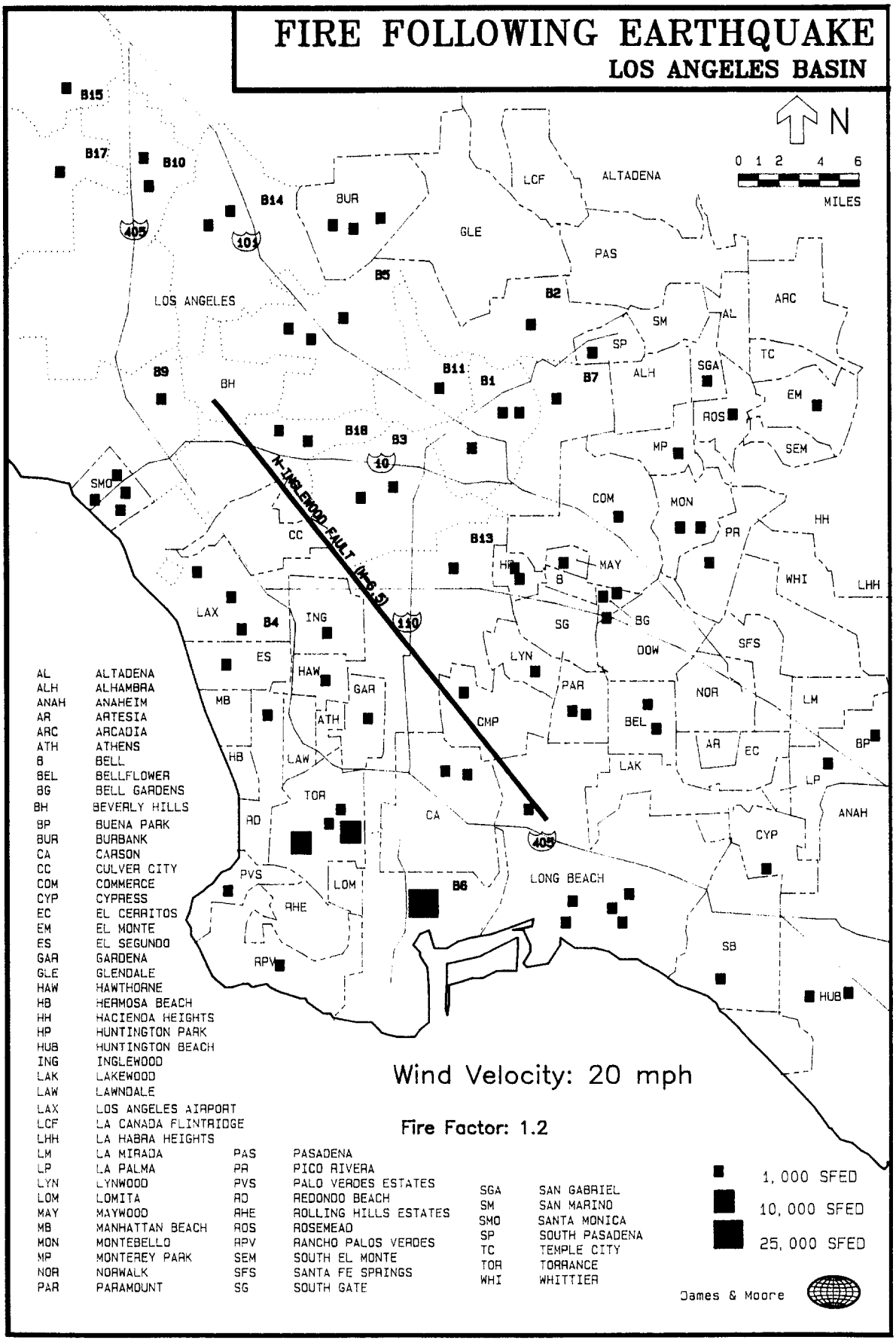
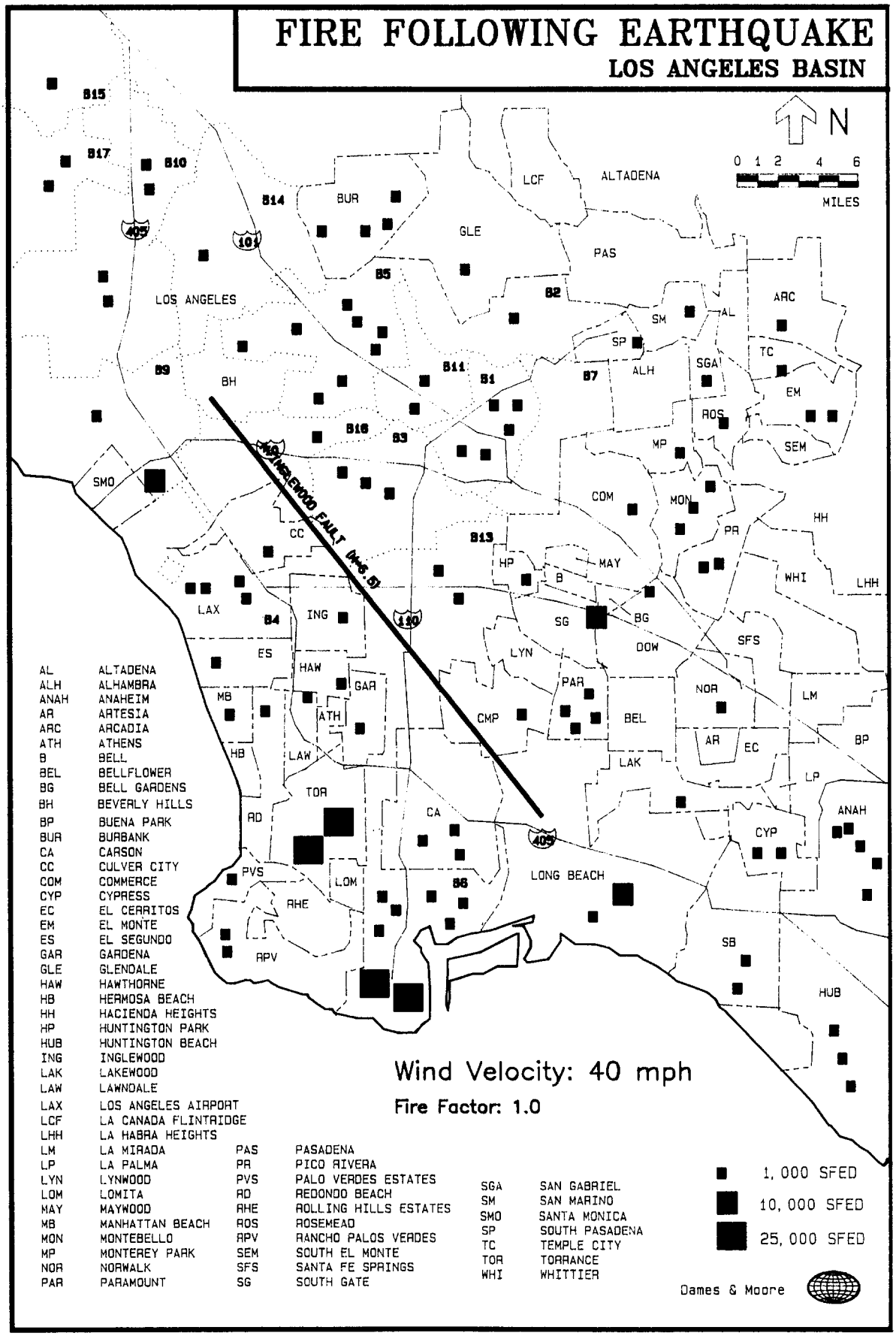

FIRE FOLLOWING EARTHQUAKE
LOS ANGELES BASIN
N
0 1 2 4 6
MILES
B15
B17
B10
B14
B5
B2
B9
B11
B1
B7
B18
B3
B13
B4
B6
405
101
10
110
LOS ANGELES
BUR
GLE
LCF
ALTADENA
PAS
ARC
AL
SM
SP
TC
SGA
ALH
EM
ROS
BH
MP
SEM
SMO
COM
MON
HH
PR
CC
HP
MAY
B
WHI
LHH
LAX
ING
SG
BG
DOW
SFS
ES
LYN
HAW
GAR
PAR
NOR
LM
MB
ATH
CMP
BEL
BP
HB
LAW
AR
EC
LAK
LP
TOR
CA
ANAH
RD
CYP
PVS
LOM
LONG BEACH
RHE
SB
RPV
HUB
Wind Velocity: 20 mph
Fire Factor: 1.2
1,000 SFED
10,000 SFED
25,000 SFED
Dames & Moore
AL ALTADENA
ALH ALHAMBRA
ANAH ANAHEIM
AR ARTESIA
ARC ARCADIA
ATH ATHENS
B BELL
BEL BELLFLOWER
BG BELL GARDENS
BH BEVERLY HILLS
BP BUENA PARK
BUR BURBANK
CA CARSON
CC CULVER CITY
COM COMMERCE
CYP CYPRESS
EC EL CERRITOS
EM EL MONTE
ES EL SEGUNDO
GAR GARDENA
GLE GLENDALE
HAW HAWTHORNE
HB HERMOSA BEACH
HH HACIENDA HEIGHTS
HP HUNTINGTON PARK
HUB HUNTINGTON BEACH
ING INGLEWOOD
LAK LAKEWOOD
LAW LAWNDALE
LAX LOS ANGELES AIRPORT
LCF LA CANADA FLINTRIDGE
LHH LA HABRA HEIGHTS
LM LA MIRADA
LP LA PALMA
LYN LYNWOOD
LOM LOMITA
MAY MAYWOOD
MB MANHATTAN BEACH
MON MONTEBELLO
MP MONTEREY PARK
NOR NORWALK
PAR PARAMOUNT
PAS PASADENA
PR PICO RIVERA
PVS PALO VERDES ESTATES
RD REDONDO BEACH
RHE ROLLING HILLS ESTATES
ROS ROSEMEAD
RPV RANCHO PALOS VERDES
SEM SOUTH EL MONTE
SFS SANTA FE SPRINGS
SG SOUTH GATE
SGA SAN GABRIEL
SM SAN MARINO
SMO SANTA MONICA
SP SOUTH PASADENA
TC TEMPLE CITY
TOR TORRANCE
WHI WHITTIER

FIGURE 19


FIRE FOLLOWING EARTHQUAKE
LOS ANGELES BASIN
N
0 1 2 4 6
MILES
LOS ANGELES
BUR
GLE
LCF
ALTADENA
PAS
ARC
AL
SM
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TC
SGA
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SG
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DOW
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LYN
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NOR
LM
BEL
AR
EC
BP
LAK
LP
ANAH
CYP
LONG BEACH
SB
HUB
LAX
ING
ES
HAW
GAR
MB
ATH
CMP
HB
LAW
TOR
RD
CA
PVS
LOM
RHE
RPV
INGLEWOOD FAULT (M=6.5)
405
110
Wind Velocity: 40 mph
Fire Factor: 1.0
1,000 SFED
10,000 SFED
25,000 SFED
Dames & Moore
AL ALTADENA
ALH ALHAMBRA
ANAH ANAHEIM
AR ARTESIA
ARC ARCADIA
ATH ATHENS
B BELL
BEL BELLFLOWER
BG BELL GARDENS
BH BEVERLY HILLS
BP BUENA PARK
BUR BURBANK
CA CARSON
CC CULVER CITY
COM COMMERCE
CYP CYPRESS
EC EL CERRITOS
EM EL MONTE
ES EL SEGUNDO
GAR GARDENA
GLE GLENDALE
HAW HAWTHORNE
HB HERMOSA BEACH
HH HACIENDA HEIGHTS
HP HUNTINGTON PARK
HUB HUNTINGTON BEACH
ING INGLEWOOD
LAK LAKEWOOD
LAW LAWNDALE
LAX LOS ANGELES AIRPORT
LCF LA CANADA FLINTRIDGE
LHH LA HABRA HEIGHTS
LM LA MIRADA
LP LA PALMA
LYN LYNWOOD
LOM LOMITA
MAY MAYWOOD
MB MANHATTAN BEACH
MON MONTEBELLO
MP MONTEREY PARK
NOR NORWALK
PAR PARAMOUNT
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PR PICO RIVERA
PVS PALO VERDES ESTATES
RD REDONDO BEACH
RHE ROLLING HILLS ESTATES
ROS ROSEMEAD
RPV RANCHO PALOS VERDES
SEM SOUTH EL MONTE
SFS SANTA FE SPRINGS
SG SOUTH GATE
SGA SAN GABRIEL
SM SAN MARINO
SMO SANTA MONICA
SP SOUTH PASADENA
TC TEMPLE CITY
TOR TORRANCE
WHI WHITTIER

CHAPTER 5
APPLICATION FOR INDIVIDUAL COMPANIES

We believe the methodology as presented in this report is directly applicable and usable by individual insurance companies. If an insurer is concerned about its exposure in a specific locality, the report provides loss estimates and damage rates for specific jurisdictions.

The information contained in Appendix 4 (San Francisco Area) and Appendix 7 (Los Angeles Area) is particularly recommended for insurance planning purposes. The fire loss estimates involved are thought to be roughly comparable in severity to the "Probable Maximum Loss" estimates for shake damage as shown in the California Insurance Department's research studies (see reference in Foreword). Insurers can make use of this information at whatever level of detail they have available about their own fire insurance exposures. If a company has exposure data only for the San Francisco Bay area as a whole, Appendix 4's bottom-line summary indicates that the probable loss from fire following earthquake is about 2.6% of the property values at risk. If the company can break out data for the City of San Francisco, the probable fire loss rate is 8.6% for that portion. And if it has data for its fire exposures in the city's central business district, the probable loss rate for that portion is 22.9%. All of these figures are taken from the rightmost column of Appendix 4, under the heading "Value Lost – %." Similar information for communities in the Los Angeles Area can be found in Appendix 7.

Several insurers have inquired about obtaining the fire damage rates by ZIP code, and AIRAC has indicated that it will undertake to obtain such information and make it available. Other "how to do it" information, such as a computational example, also is being prepared.

Going beyond the scope of this report, the methodology used in this study can be applied on a higher resolution basis for companies interested in obtaining more detailed fire loss rates. This would yield greater accuracy in estimating ignitions, fire spread, the number of available fire engines, fire personnel, water supply system functionality and the size of final burnt areas. These variables can be tracked and fire loss estimates obtained at the city block level if desired. However, it should be understood that the methodology is less concerned about estimating fire losses originating in a specific property than it is with estimating probable loss due to ignitions somewhere within a few city blocks and spreading to that property due to quake-related inadequacies in fire suppression capability. The methodology is suitable for both residential and commercial property, but special high value installations (e.g., oil refineries, tank farms, chemical plants) would require specific engineering review.

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EXPLANATION OF HEADINGS FOR APPENDICES

Appendices 2 and 5

Headings for the tables that appear in Appendices 2 and 5 are as follows:

Population—Estimated population for each jurisdiction, in thousands.

Area: Total and Urban—The area in square miles for each jurisdiction, in total and for the urbanized portions only.

MMI—Estimated intensity of earthquake shaking for each jurisdiction, measured on the Modified Mercalli Intensity (MMI) Scale (see Table 1 in Chapter 2).

Insured Value—The amount of fire insurance coverage in force for residential and commercial property within each jurisdiction, in millions of dollars (000,000 omitted). In Appendix 2, for example, the Central Business District of San Francisco has insured exposures of about $1.6 billion ($1,657,000,000) for residential property and about $11 billion ($10,928,000,000) for commercial property.

Firebreak Width—The average width of streets and other firebreaks, in feet.

Building Area—the aggregate amount of building floor space in each jurisdiction, in millions of square feet.

Number of Stations—The number of fire stations in each jurisdiction.

Number of Engines—The aggregate number of fire engines in each jurisdiction.

Water Supply—A measurement of water supply functionality following the earthquake. A figure 1 indicates little or no reduction, a zero would indicate complete loss of water supply.

Appendices 3, 4, 6 and 7

Headings for the tables contained in Appendices 3, 4, 6 and 7 are as follows:

Number of Fires—The number of fires that cannot be suppressed by ordinary citizens, and require fire apparatus response.

Average Distance—Estimated travel distance, in miles, for first arrival fire apparatus dispatched within that jurisdiction.

Average Response Time—Estimated time, in minutes, for arrival of first fire apparatus, based on distance, average speed, and earthquake delays in reporting.

Excess Fires—The number of fires requiring fire department response, in excess of the number of available fire engines.

Auto/Mutual Aid Response Time—Estimated time for neighboring jurisdictions to provide assistance, assuming they can.

Minimum Engines Required—The minimum total number of engines required for control of all fires within a jurisdiction, at first arrival of engines (either jurisdictional engines or auto/mutual aid engines).

Number of Large Fires—The number of fires that will be out of control at first arrival (i.e., fires that cannot be controlled by one engine).

Thousands Burnt: Land—Final gross burnt area for all conflagrations in the jurisdiction, in thousands of square meters, including buildings, streets, etc.

Thousands Burnt: Buildings—Gross burnt floor area for all buildings in the jurisdiction, expressed in thousands of Single Family Equivalent Dwellings (SFEDs), which are equal to 1,500 square feet per SFED. This unit of measurement applies to both residential and commercial property.

Value Lost—Value of property destroyed by fire following earthquake, in millions of 1987 dollars, and as a percentage of total property values at risk in the jurisdiction.

San Francisco County—The analysis for the City of San Francisco has been performed along fire department battalion boundaries (B1 through B10). Each battalion district has been identified by a geographic label as well. For example, Battalion 1 includes the Central Business District (CBD), Battalion 3 is for the area South of Market Street, etc. Other jurisdictions in the San Francisco Bay area have been analyzed by county and by town or city.

Los Angeles County—The analysis for the City of Los Angeles likewise has been performed along fire department battalion boundaries (B1 to B18), with geographic labels added. For example, Battalion district 4 denotes the Los Angeles International Airport area. Other jurisdictions within Los Angeles, Orange and Ventura Counties have been analysed by town or city, with summaries for each county as a whole.