NSF/ENG-88019

PB89-148035 2020.1

FIRE IGNITIONS FROM THE WHITTIER NARROWS EARTHQUAKE OF OCTOBER 1, 1987

Prepared for:

THE NATIONAL SCIENCE FOUNDATION

Grant No. CES-8803595

NOVEMBER 8, 1988

By:
JOHN H. WIGGINS, Ph.D., P.E.

CRISIS MANAGEMENT corporation

1650 South Pacific Coast Highway
Redondo Beach, California 90277 U.S.A.
(213) 316-2257
FAX (213) 316-2389

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/ENG-88019	2.	3. Recipient's Accession No. PB89 148035/AS

4. Title and Subtitle
Fire Ignitions from the Whittier Narrows Earthquake of October 1, 1987

5. Report Date November 1988

6.

7. Author(s)
J.H. Wiggins

8. Performing Organization Rept. No. 2020.1

9. Performing Organization Name and Address
Crisis Management Corporation
1650 South Pacific Coast Highway
Redondo Beach, CA 90277

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) CES8803595

12. Sponsoring Organization Name and Address
Directorate for Engineering (ENG)
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The purpose of the investigation was to examine the fire ignitions that took place as a result of the Whittier Narrows earthquake and determine ignition rates as a function of Modified Mercalli Intensity. Using this information and a complex fire modeling algorithm, the potential for conflagration can be developed. The objectives of the study were to: (1) count the number of ignitions; (2) describe them as to intensity region and location about the epicenter; and (3) identify the sources of the ignitions, such as electrical, gas, or flammable liquid spills.

17. Document Analysis a. Descriptors

Earthquakes	Fires
Algorithms	Ignition
Intensity	Magnitude

b. Identifiers/Open-Ended Terms
Conflagration
Los Angeles County, California

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
NTIS		62
	20. Security Class (This Page)	22. Price

(See ANSI–Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

CRISIS MANAGEMENT
corporation

1650 South Pacific Coast Highway
Redondo Beach, California 90277 U.S.A.
(213) 316-2257
FAX (213) 316-2389

FIRE IGNITIONS FROM THE WHITTIER NARROWS EARTHQUAKE OF OCTOBER 1, 1987

TABLE OF CONTENTS

TALBE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Con't)

LIST OF TABLES

CRISIS MANAGEMENT corporation
1650 South Pacific Coast Highway
Redondo Beach, California 90277 U.S.A.
(213) 316-2257
FAX (213) 316-2389

EXECUTIVE SUMMARY

On October 1, 1987 at 07:42 hours, an earthquake having a magnitude of 5.9 (local) occurred in the eastern part of Los Angeles County. Damaging intensity levels encompassed 7.2 million people with the highest Modified Mercalli Intensity reading being VIII. Peak acceleration values reached 0.63g and total losses including secondary and higher order losses, such as business interruption, lost wages, extra funds for caring for homeless people, amounted to about $368,000,000.

The principal objective of this study was to examine the fire ignitions that took place as a result of this earthquake. The principal purpose for studying the fire ignitions is not so much as to learn the extent of fire loss as it participates in the overall loss picture, but rather to determine ignition rates as a function of Modified Mercalli Intensity. Using that information and a complex fire modeling algorithm, the potential for conflagration can be developed.

The major fear of the insurance industry as well as emergency planners is that fire following an earthquake could contribute greater losses than the immediate damage from the earthquake itself. For this reason, good ignition rate algorithms are required for modern day construction. Using ignition rates developed in the 1906 San Francisco earthquake and similar older events may not necessarily be applicable to predicting fire conflagration situations in modern constructed cities.

There were a total of 38 ignitions that took place during this earthquake. The ignition rate compared favorably with that detected during the 1971 San Fernando earthquake, however, the ignition rate for similar intensity zones might be lower for the Whittier Narrows event than that for the San Fernando earthquake. This may indicate that either modern construction has reduced the ignition rate or that intensity zones VI and VII for an M = 5.9 magnitude earthquake are not really as severe as those for an M = 6.6 magnitude earthquake.

It was also shown that the ignition rate in MMI VI regions are 0.21 per 100,000 persons; in MMI VII regions 0.83 ignitions per 100,000 persons. In regions with no ground breakage of MMI VIII and greater, the ignition rate is 2.4 per 100,000 persons. If ground breakage is present in the MMI intensity region VIII and greater, the ignition rate can triple.

It was also shown for Los Angeles, that the maximum credible earthquakes should be able to be dealt with marginally by indigenous fire departments. Complicating conditions such as fire station failures, extremely dry and windy conditions could exacerbate the conflagration conditions.

CRISIS MANAGEMENT
corporation

1650 South Pacific Coast Highway
Redondo Beach, California 90277 U.S.A.
(213) 316-2257
FAX (213) 316-2389

FIRE IGNITIONS FROM THE WHITTIER NARROWS EARTHQUAKE OF OCTOBER 1, 1987

1.0 INTRODUCTION

1.1 Background

On October 1, 1987, an earthquake estimated to have a local magnitude of 5.9, struck the Southern California area at 07:42 hours. The epicenter was eventually determined to be in the Whittier Narrows area, approximately 14 miles east of downtown Los Angeles. The hypocentral depth was estimated at 14 kilometers or 8.7 miles. In spite of the earthquake's small size and distance from the City of Los Angeles, it caused moderate structural damage there, plus numerous injuries. It also produced a strain on the City's emergency operations. The largest impact was felt in the City of Whittier, which experienced a Modified Mercalli VIII intensity level. Other proximate areas suffered as well regarding actual strong shaking.

The greater Los Angeles area is laced with faults of varying significance, type and degree of activity. As a result, the greater Los Angeles area has experienced a number of earthquakes, over the years, dating back to 1769 when the first major earthquake was reported by Father Junipero Serra and a team of missionaries. Since that time a number of serious earthquakes have affected this area. Namely:

1857 - Fort Tejon

1872 - Owens Valley

Late 1800's San Jacinto Fault Region

In recent history, the 1933 Long Beach, 1971 San Fernando and now the 1987 Whittier Narrows event testifies to the continued activity in the Los Angeles area (Figure 1).

1.2 Purpose and Objectives

The purpose of this investigation is to report the number of fire ignitions that took place during the Whittier Narrows earthquake in order to add this valuable source of data to that which has

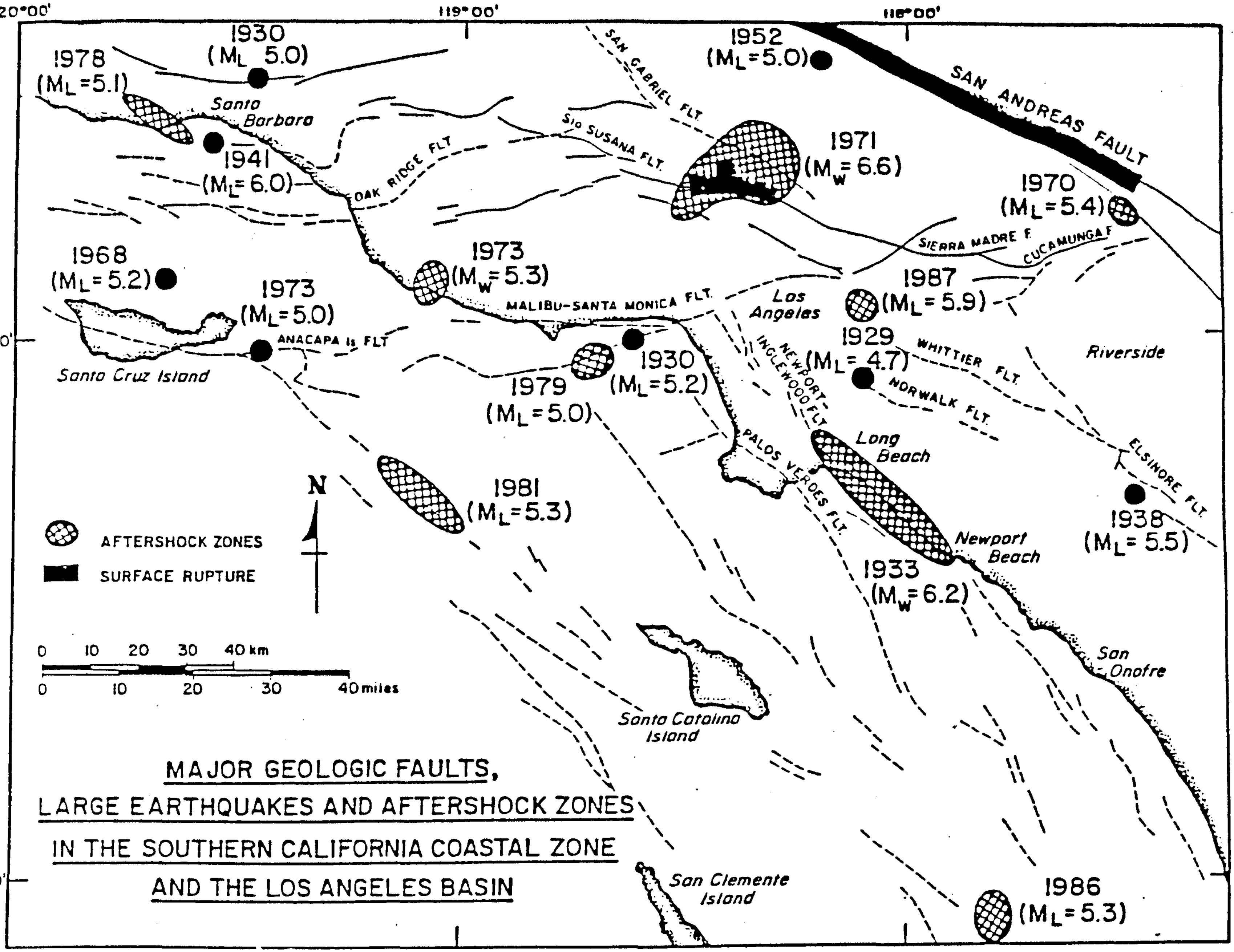


Figure 1. A Map of the Los Angeles Metropolitan Area Showing the Larger Earthquakes to Occur Since 1900. (Reproduced from Jones and Hauksson, 1988)

already been collected for other events. Then, with this recent ignition data, an understanding of the possibility for a major conflagration of populated regions, such as Los Angeles and San Francisco, can be more accurately determined.

The objectives of the study are to count the number of ignitions; describe them as to intensity region and location about the epicenter and; identify the sources of these ignitions, such as electrical, gas or flammable liquid spills.

2.0 THE SETTING AND GENERAL CHARACTERISTICS OF THE FIRE IGNITIONS

The vast majority of emergency activity in the Los Angeles area was caused by numerous minor incidents. There were, however, two noteworthy fire incidents, one involving the California State University at Los Angeles. The first call arrived at 07:50 hours, eight (8) minutes after the earthquake, and the incident required 6 companies, one rescue ambulance, one hazardous materials squad, and a battalion chief. The total incident included a fire on the top floor of the 8 story Physical Sciences building, which had a hazardous material spill in that and another science building. The second was a fatality caused by a concrete slab falling from the side of a parking structure killing a girl. (D.O. Manning, 1987).

One of the major problems that occurred during the earthquake was the saturation of communications on various frequency bands by the fire companies talking back and forth to one another. Thus, in a major event which would significantly affect all of the Southern California area, and not just an area of some 50 square miles of shaking, jammed frequency bands might completely block out the communication potential for fire departments and their emergency response duties.

Furthermore, this event was small compared to a major event on either the Newport-Inglewood Fault or the San Andreas Fault. Steps are being taken to remedy some of the emergency problems counted. In effect, this was a good training exercise for the fire departments of Los Angeles, Los Angeles County and other city fire departments within the county. Since small earthquakes of this type are much more frequent than the large ones forecast for the San Andreas or some major fault within Los Angeles County, significant lessons can be learned by fire departments expected to fight the fires from these large events.

2.1 Overview of Emergency Activity in the City of Los Angeles

On the day of the earthquake, the Los Angeles City fire department responded to 1,185 incidents of all types. Compare this to the Los Angeles Fire Department average of approximately 750 emergency responses including paramedic rescues during a normal day. Of the emergency responses on October 1, 1987, 13.1 percent were of the fire incident category, 63.1 percent were of the emergency services category and 23.8 percent were of the "other" type. (D.O. Manning, 1987).

With regard to the fire group types, the following lists the number of incidents that took place.

DATE	FIRE GROUP
September 30, 1987	122
October 1, 1987	157
October 2, 1987	152
October 3, 1987	183
October 5, 1987	217

As one can note from the above listing, the number of fire incidents in the City of Los Angeles during October 1, 1987, was in the "noise" of the data. No signal about fire ignition starts by the earthquake can be detected. The total listing of fires that occurred immediately after the October 1, 1987 event are listed in Table 1.

Many fire stations received minor damage due to the initial earthquake and later the October 4, 1987 aftershock. The damage consisted primarily of plaster cracks. However, Fire Station #57 in Los Angeles City was closed for two and half days after the aftershock as a precaution due to cracks in the wall. Personnel and apparatus were temporarily relocated to Fire Station 66 while the Department of Building and Safety personnel evaluated the structural integrity of the station and declared it safe for re-occupancy.

All in all, 41 fire stations experienced damage. Total loss to the fire department was $983,100, with Fire Station #57 in the city of Los Angeles experiencing $250,000 worth of damage. Note that there are 100 fire stations in the city of Los Angeles, so that the loss data implies that 41% suffered some minor damage averaging $24,000 per station from this small earthquake.

In the City of Los Angeles during the four day period, from 0742 hours on October 1, 1987 to 2359 hours on October 4, 1987, the Los Angeles City Fire Department responded to 242 reported natural gas leaks. The daily figures are listed below:

TABLE 1

SUMMARY OF IGNITIONS FOR THE WHITTIER NARROWS EARTHQUAKE

LOS ANGELES COUNTY FIRE DEPT.	Acceleration Intensity CMC	Observation Intensity USGS
6208 OXSEE, WHITTIER:	VII	VII

Electrical cause - fire in attic and spread partially to kitchen. Building type: Residential. Loss estimate = $20,000.

16901 VALLEY VIEW AVE., CERRITOS:	VII	VI

Electrical cause - from smoker venting system; causing ignition of vapors inside unit. Building type: Two story industrial plant. Loss estimate = $1,000.

543 VALLOMBROSA, PASADENA:	VII	VII

Electrical cause - overturned light from end-table was turned on by automated timer; damage to living room. Building type: Two story residential. Loss estimate = $28,000.

5505 HARKER, TEMPLE CITY:	VII	VII

Electrical cause - power lines on wood shingle roof. Building type: Residential. Loss estimate = $100.

6920 SLAUSON, CITY OF COMMERCE:	VIII	VII

Gas related cause - ceiling mounted heater came loose and fractured gas line, pilot light ignited gas. Building type: Commercial. Loss estimate = $2,000.

330 McBRIDE AVE., EAST LOS ANGELES:	VIII	VII

Gas related cause - water heater connection, fire confined to washroom. Building type: Single story residential. Loss estimate = $5,000.

4874 GAGE AVE. #147, BELL:	VII	VI

Electrical cause - short occurred in living room after VCR fell. Building type: Mobile home dwelling. Loss estimate = $35,000.

TABLE 1 (CONTINUED)

LOS ANGELES COUNTY FIRE DEPT.(Cont'd.)	CMC	USGS
7041 ELMER ST., WHITTIER:	VII	VII

Electrical and gas cause - gas leak from water heater exploded when either downed power line or pilot light ignited gas. Building type: residential used as bookkeeping service. Loss estimate = $70,000.

5954 MAYWOOD AVE., HUNTINGTON PARK:	VII	VI

Electrical cause - liquor bottles fell from shelf onto electrical box. Building type: Commercial liquor store. Loss estimate = $300.

9102 BERMUDEZ, PICO RIVERA:	VIII	VII

Electrical cause - downed power line, house was energized with electricity. Building type: Residential. Loss estimate = $800.

1917 HOWELL, ROWLAND HEIGHTS:	VI	V

Gas related cause - gas line to water heater failed causing fire ignition in garage. Fire damage to garage, three motor vehicles, downstairs family room, upstairs kitchen and living room. Building type: Residential. Loss estimate = $64,900.

16402 MURIEL AVE., COMPTON:	VII	VI

Gas related cause - gas line to water heater failed. Mutual aid with Compton fire department. Building type: Residential. Loss estimate = $70,000.

There were 8 more events reported by the Los Angeles County Fire Department.

CITY OF LOS ANGELES FIRE DEPT.	CMC	USGS
CALIFORNIA STATE UNIVERSITY LOS ANGELES (EAST LOS ANGELES):	VIII	VII

Electrical and chemical cause - in the chemistry laboratory; Toluene spill ignited by electric oven or potassium metal. Building type: University building. Loss estimate = $24,000.

3937 SOUTH GIBRALTAR AVE. #14:	VII	VI

Electrical cause - combustibles shaken against electrical heater. Building type: UNKNOWN. Loss estimate = $2,600.

TABLE 1 (CONTINUED)

CITY OF LOS ANGELES FIRE DEPT. (Cont'd.)	CMC	USGS
2021 NORTH DRACENA DR.:	VII	VI

Gas related cause - leak in gas line caused explosion and fire in roof-top boiler room. Building type: UNKNOWN. Loss estimate = $6,000.

1007 WEST 69TH ST.:	VII	VI

Gas related cause- malfunction in gas-fueled floor furnace extended fire to structural timbers. Building type: Church. Loss estimate = $8,180.

17835 VENTURA BLVD., ENCINO:	VI	VI

Gas related cause - broken gas line caused fire in air conditioning unit. Building type: UNKNOWN. Loss estimate = $5,200.

13519 RYE ST.:	VI	VI

Electrical cause - lamp knocked over and burned when power was restored. Building type: UNKNOWN. Loss estimate = $250.

PASADENA FIRE DEPT.	CMC	USGS
972 PALO VERDE, PASADENA:	VII	VII

Electrical cause - appliance fell causing a short in living room. Building type: Single story residential. Loss estimate = $6,000.

SAN MARINO FIRE DEPT.	CMC	USGS
1340 VAN DYKE RD., SAN MARINO	VII	VII

Electrical cause - Edison transformer and garage wood shingle roof fully involved. Building type: Residential. Loss estimate = $8,000.

SAN GABRIEL FIRE DEPT.	CMC	USGS
1015 E. VALLEY, SAN GABRIEL:	VII	VII

Minor grass fire in open field.

MONTEBELLO FIRE DEPT.	CMC	USGS
2912 VIA ACOSTA, MONTEBELLO:	VIII	VIII

Electrical cause - power lines burning, Edison notified.

ALHAMBRA FIRE DEPT.	CMC	USGS
	VIII	VII

Gas leak at water heater in an upstairs apartment.

ORANGE COUNTY FIRE DEPT.	CMC	USGS
	VI	VI

Said there was very minor incident, but wouldn't give any details.

SOUTHERN CALIFORNIA GAS COMPANY	CMC	USGS
1646 SHERBOURNE AVE., LOS ANGELES:	VII	VI

Gas related cause - water heater connector failed. Building type: Residential. Loss estimate = less than $500.

815 N. TAMARIND ST., COMPTON:	VII	VI

Gas related fire - minor appliance fire. Copper pilot tubing compression fitting gave way during the earthquake resulting in a fire confined to the wall furnace burner compartment. Building type: Residential. Loss estimate = less than $500.

13733 E. FRANKLIN ST., WHITTIER:	VII	VII

Gas related cause - gravity furnace connector failed. This single family residence suffered extensive structural damage from earthquake. The building was declared unsafe for occupancy. Fire damage wasn't visible from outside. Loss Estimate = $500

2255 BUENA VISTA, BURBANK:	VI	VI

Gas related cause - water heater connector failed. Building type: Residential. Loss estimate = $500.

2624 GREENWICH ST., FULLERTON:	VII	VI

Gas related cause - water heater connector failed. Building type: Residential. Loss estimate = $500.

TABLE 1 (CONTINUED)

LOS ANGELES DEPT. OF WATER AND POWER	CMC	USGS
560 S. WALL, LOS ANGELES:	VII	VI

On October 6, 1987, a significant fire occurred in one of the three large transformers at receiving station "P" in the downtown area. The fire damage necessitated the shutdown of the station, which caused a major portion of the downtown area to be without service for several hours. The estimated cost to restore this receiving station is $2,000,000. This fire may not have been caused by the earthquake according to Department of Water and Power personnel.

Total accounted for losses due to earthquake generated fire ignitions are $2,359,330.

DATE	NUMBER OF INCIDENTS	NUMBER OF FALSE ALARMS	NUMBER OF SHUT-OFF SERVICE
Oct 1, 1987	112	71	41
Oct 2, 1987	26	24	2
Oct 3, 1987	24	15	9
Oct 4, 1987	80	60	20
TOTALS	242	170	72

(D.O. Manning, 1987)

The figures cited above probably understated the actual number of leaking natural gas incidents for two reasons.

1. A number of the reporters were directed to the front of telephone books which gave instructions on how to shut of the gas so that the reporters themselves could turn off the gas. Others were referred to the Southern California Gas Company.

2. There was underreporting of gas incidents, by the Fire Department.

The Los Angeles County Fire Department responded to 573 calls on October 1, 1987 reporting leaking gas. No breakdown of the detail contained above was given.

By comparison, during the same four day period (1, 2, 3, and 4) in September 1987, which preceded the October events, the Los Angeles City Fire Department responded to a total 27 leaking natural gas incidents. This compares to the 242 reported during the 4 day period including and subsequent to October 1, 1987. Note that the number of shut-off service situations after the earthquake amounted to 72 or about 3 times the normal rate.

The gas leaks were reported in various types of occupancy, for example: residential properties (including single family dwellings, duplexes, apartments and motels) reported 181 incidents out of the 242 incidents making up the total data base. "Other structures" accounted for 18 incidents and "no property use specified" or "occurrences in the street," accounted for the remaining 43 incidents of leaking gas. The number of fires in all Los Angeles County fire jurisdictions caused by leaking natural gas are reported in Table 1.

Following the earthquake, the Southern California Gas Company experienced a significant increase in service requests as well as the fire department. All of these requests could be handled because

because of a detailed plan and an emergency response center setup for dealing with such incidents when the circumstances require mass service. During the period from October 1 to October 3, 1987, they reported the following figures:

Total customer calls received	20,572
Customers who turned off gas unnecessarily......	16,507
Natural Gas leaks found unrelated to earthquake.	2,654
Minor Earthquake-caused natural gas leaks on customer premises................................	1,411
Fires resulting from natural gas leaks (excluding Los Angeles City)...............................	10
Number of Earthquake - caused leaks on Southern California Gas Company underground piping system...........	1

Of the 1,411 earthquake-caused gas leaks, the Gas Company attributed 75% to damaged appliance connectors, and 25% to leakage from customer's gas piping.

The questionable stoppage of gas service by structure occupants was caused to a great degree by customer apprehension, which was enhanced by media instructions to "turn off your gas". Although both the gas company and fire department told citizens that there is no hazard unless a natural gas odor is detected or heard, apparently 16,507 customers decided to play safe. Playing safe however, resulted in a few explosions which were unnecessarily caused by untrained persons attempting to turn the gas and pilot lights back on again.

There were no records available on how many electrical problems required response by the Department of Water and Power (serving the City of Los Angeles, and no unusual electrical fires were reported by the Los Angeles Fire Department or Southern California Edison Company serving the balance of the county. The three incidents that are reported in the data base in Table 1 were all that received attention.

2.2 Continuation of Water Supply after the Earthquake

The water supply in the City of Los Angeles is the responsibility of the Los Angeles Department of Water and Power (DWP). The water operating division has contingency plans for continuing operations during a major disaster. This plan involves the activation of five remote command posts and a water emergency coordination center. A designated emergency operations officer utilizes this command framework to assess damage, direct resources and coordinate with the emergency operations center and other agencies. Coincidentally, the water operating division practiced their emergency management plan in April of 1987 in an exercise called "Earthquake `87." Department of Water and Power officials acknowledged that the training scenario was very similar to the October 1, 1987 earthquake and believed that the efficiency that they exhibited in October was due mainly to the exercise in April.

Although geared up for extensive damage, the water system in their after-action report said "...the magnitude of the earthquake resulted in minimal damage and disruption of service with the water system." They reported total earthquake-related costs of $52,200. Of that amount $35,600 was for damage assessment activities and only $16,600 for damage repair. The major damage was to a 6 inch drain line which had sheared off at the Mulholland tank, which is located above the lower Hollywood reservoir. The resulting leak flowed into the reservoir. The remainder of the damage was confined to three small mains and three service lines.

This example is cited because water supply availability is very important to the possibility of conflagration after ignition and flashover has taken place. It is to be noted that the Whittier Narrows Earthquake was small in size, having a duration of strong shaking of less than 5 seconds and exhibiting no surface ground breakage. All of these factors could have contributed to the good performance of the water supply systems during this earthquake.

2.3 Estimated First Order Losses from the Whittier Narrows Earthquake of October 1, 1987

The following information provides an overview of the results of the Whittier Narrows earthquake of October 1, 1987. The values are still approximate. However, an appreciation for the severity of this event can be gained from the following data:

ITEM OF INTEREST	LOS ANGELES CITY	LOS ANGELES COUNTY	TOTAL
DEATHS	2	5	7
INJURIES	-	-	1,135
PROPERTY DAMAGES	$44,120,000	$169,497,500	$213,617,500
DWELLING UNITS DESTROYED	2,994	1,015	4,009
PERSONS SHELTERED	6,435	3,300	9,735

The above data were variously compiled by the Los Angeles County Department of Health Services, Los Angeles City, the California Office of Emergency Services and the American Red Cross. It does not include secondary and higher order losses such as business interruption, lost wages and extra expense.

The damage was experienced in Modified Mercalli Intensity regions of VI and greater. The total number of persons included within the Modified Mercalli Intensity VI region was approximately 6.9 million as reported by the US Geological Survey Map (Leyendecker et al, 1988) and population counted by Barclay Jones (1988). The isoseismal VI or greater region computed by Crisis Management Corporation (using maximum acceleration readings and related Modified Mercalli Intensity values) would include 7.2 million persons. Thus, the above figures can be ratioed to show that there were approximately: one death per million persons exposed; 162 injuries per million persons exposed; $30 worth of damage per million persons exposed; 572 dwelling units destroyed per one million persons exposed; and 1.4 persons sheltered per million persons exposed.

Of the seven deaths, four were heart attack related, (69 year old male, 72 year old female, 20 year old female, 66 year old female). Two of the other deaths were caused by concrete facia falling on a 23 year old female and a collapse of a dirt shaft upon a 40 year old male. One 32 year old male died from injuries sustained when jumping or falling from a second story window.

3.0 PARAMETERS AFFECTING CONFLAGRATION POTENTIAL DUE TO EARTHQUAKE ACTION

The following discussion is intended to outline the major parametric groups that affect conflagration potential after an earthquake. This listing is mentioned in order to indicate the scope of the study and the influence it might have on estimating conflagration potential in major cities, which may be subjected to earthquake action in the future.

3.1 Earthquake Source

The earthquake magnitude, the length of faulting, the depth of hypocentral activity, all have an effect on the intensity that might be felt. This would then contribute to the ignition potential from the earthquake.

3.2 Attenuation of Modified Mercalli Intensity

The attenuation of intensity from the source of the earthquake to the site of the structure which potentially might generate a fire ignition is important. This is usually related to some base rock or mean soil condition and then adjusted for the soil condition present at the site in question.

3.3 Intensity Amplification Factor

As was alluded to in 3.2, the soil or rock which supports the structure in question may amplify or de-amplify the earthquake intensity at a particular site in relation to what the attenuation relationship used to reduced intensity with distance might estimate, and therefore the ignition potential.

3.4 Fire Ignition Rate

The fire ignition rate as a function of Modified Mercalli Intensity (or some other measure of intensity) can be normalized and expressed in several ways: ignitions per capita; ignitions per number of buildings; ignitions per square feet of a certain kind of building, etc. The ignition size can also be broken down into "minor," "moderate" and "major" ignition sources. For example, an explosion would be a "major" ignition source whereas a pinhole flame at a gas water heater leak might be called a "minor" ignition source.

3.5 Ignition Type

It is important to categorize the different ignition sources by type, such as "gas related," "electrical related," "chemical related," etc., and whether the ignition occurs outside or inside a structure. Those occurring outside a structure may not be as serious for their contribution to conflagration potential as those occurring inside where they could ignite all the fuel in a building.

The above five parameters describe the scope of this study. All influence the ignition potential and therefore conflagration potential. The remaining factors of importance to conflagration but which will not be discussed herein are the following:

3.6 Single Fire Growth Rate

If a fire is hidden, such as in a hot water tank closet, it may grow without being reported, or if people are not present to witness the fire, it may result in a flash-over of a room and possibly the destruction of an entire building.

3.7 Single Fire Discovery Time after Ignition

After an earthquake, there is a certain amount of time for an ignition to be discovered, however, the earthquake itself is usually a good alarm for people to look around the premises and observe a potential ignition situation. This time has an affect on the growth rate of a fire and therefore the growth of the difficultly in suppressing an individual fire.

3.8 Fire Department Contact Time

As was mentioned in an earlier section the time to contact the fire department may be extended if all frequency bands are jammed by other callers. Consequently even though a fire might be discovered and the discoverer is unable to quench the fire above, the contact time for fire department relief can contribute to the further growth rate of the individual fire and therefore the potential for conflagration.

3.9 Single Fire Spread Rate

If no fire suppression takes place during the three variables mentioned above, then the fire can spread from room to room and possibly floor to floor. Thus, making the suppression more difficult and conflagration potential more probable.

3.10 Fire Engine Availability

The number of fire engines available per number of ignitions within the fire engine territory as well as the size of the fire and the type of the fire, would affect the ability of the fire to be suppressed. Further, if fire stations have collapsed on the vehicles, the number available for fire fighting is reduced. Thus, the conflagration potential would be increased by having a low fire engine availability ratio per number of ignitions.

3.11 Fire Engine Arrival Time

The distance from the station to the fire or the distance from another fire that has been suppressed to the fire in question as well as the average speed of the fire engine are important to the time necessary for suppression equipment arrival and extinguishment of the fire. The longer the time, the greater the potential for contributing to the probability of conflagration.

3.12 Water Supply Availability

As has been mentioned earlier, the availability of water supply is important to the ability of the fire engine crew to suppress the fire. The distance to a fire hydrant, the lurching, liquefaction, landslide and fault activities within the area supplying the hydrant, all contribute to the availability of the water supply and thus, the probability of conflagration potential.

3.13 Single Fire Suppression Ability

Given the various types of fires that might be present, the ability to suppress the fire is a function of the number of trucks, the availability of water supply, the size of the fire, the type of the fire, the distance from the building and a host of other parameters, all of which contribute to the probability of conflagration potential.

3.14 Excess Fire Spread Rate

Once a single fire gets going or several multiple fires in a local area are unable to be suppressed, the spread of these fires is a function of the number burning, the moisture conditions in the air, the wind conditions, the number of fire breaks, the width of fire breaks, the serial nature of fire breaks, the number of trucks, etc.. The fire spread rate, of course, will then contribute to the probability of conflagration potential.

3.15 Excess Fire Suppression Time

All the parameters mentioned in 3.14 apply to the time for suppression of the, conflagration.

3.16 Fire Loss Summation Process

It is necessary to mention that there will be some partially destroyed structures within an area that has spreading fire conditions. Thus, the losses must take account of the partial survival situations when summing losses in order to estimate true conflagration totals.

4.0 INTENSITY CONDITIONS IN THE IMMEDIATE VICINITY OF THE WHITTIER NARROWS EARTHQUAKE AND RELATED FIRE IGNITIONS

The first parametric group to determine after an earthquake, in order to understand it, includes the earthquake magnitude, epicenter location and hypocenter depth. These were reported in the introduction. Using the equation,

$$F = e^{1.52\ (M-4.7)} \qquad (1)$$

where, F = fault length and M = local earthquake magnitude, we can compute the effective fault length, F, to be about 6.2 miles. This equation for computing fault length knowing the magnitude of the event was derived from empirical data of fault breaks associated with known magnitude earthquakes developed from data published by Bonilla, (1967).

In a paper by Jones and Hauksson (1988), they report that the earthquake sequence ruptured a small part, 2.5 miles by 3.1 miles, of a previously unidentified, buried thrust fault that strikes east-west and dips 25° down to the north. The epicenter was located at 34°, 3.0' North Latitude, 118° 4.8', West Longitude at a depth of 8.7 miles. The initial shock, occurring at 7.42 A.M. local time, had a local magnitude of 5.9. A large aftershock occurring on October 4, had a local magnitude of 5.3.

The first shock was principally a thrust-fault-like motion, while the second aftershock produced mostly strike slip movement on a steeply dipping northwest plain that bounds the main shock rupture area to the west. Consequently, the "epicentral region" could be considered to be described by an area 1.5 miles in radius surrounding the epicenter. The peak accelerations taken on a number of strong-motion seismic instruments near the epicentral area, are reported in Figure 2. Notice that they generally decay in size with distance from the epicentral region, with one principal exception, that occurring in the region 34.15^{o} North Latitude and 118.5^{o} West Longitude. Note that this acceleration value of 0.62g nearly matches the highest recorded value occurring near the epicenter, 0.63g.

These data were plotted in Figures 3 and 4. Note that the decay of the accelerations with distance drops off nicely in the classical form for Figure 3. However, the reverse occurs in Figure 4 for hypocentral distance.

When the accelerations were related to a linear fit of the data (Figure 5 & Figure 6) it can be seen that the logarithm of peak ground acceleration decreases with hypocentral distance to the -1.25 power. The general relationships are:

$$\text{Log } A = -2.95 + 0.3 \text{ (MMI)} \quad (2)$$

$$\text{MMI} = 2.67 \text{ Log (DAF)} + 0.94 + 1.5 M_l - 3.74 \log R \quad (3)$$

where A = peak acceleration, g

DAF = site dynamic amplification factor, dimensionless

M_l = local earthquake magnitude

R = hypocentral distance, mi.

for California earthquakes. Equation (2) was determined by the Applied Technology Council (1985) and Equation (3) by Culver et al (1975). Equation (2) was developed from:

(see ATC (1985) for these references)

Trifunac and Brady (1975)	log A = -2.98 + 0.30 MMI
Ambraseys (1974)	log A = -3.15 + 0.36 MMI
Murphy and O'Brien (1977)	log A = -2.74 + 0.25 MMI
Culver (1975)	log A = -2.94 + 0.29 MMI
AVERAGE	log A = -2.95 + 0.30 MMI

Multiplying the coefficient of MMI in Equation (2) by the coefficient of Log R in Equation (3), we compute that acceleration should on the average drop off with distance to the -1.122. This compares favorably to the -1.25 power noted in Figure 6. An average dynamic amplification factor (DAF) for California should be about 5.0 as determined by

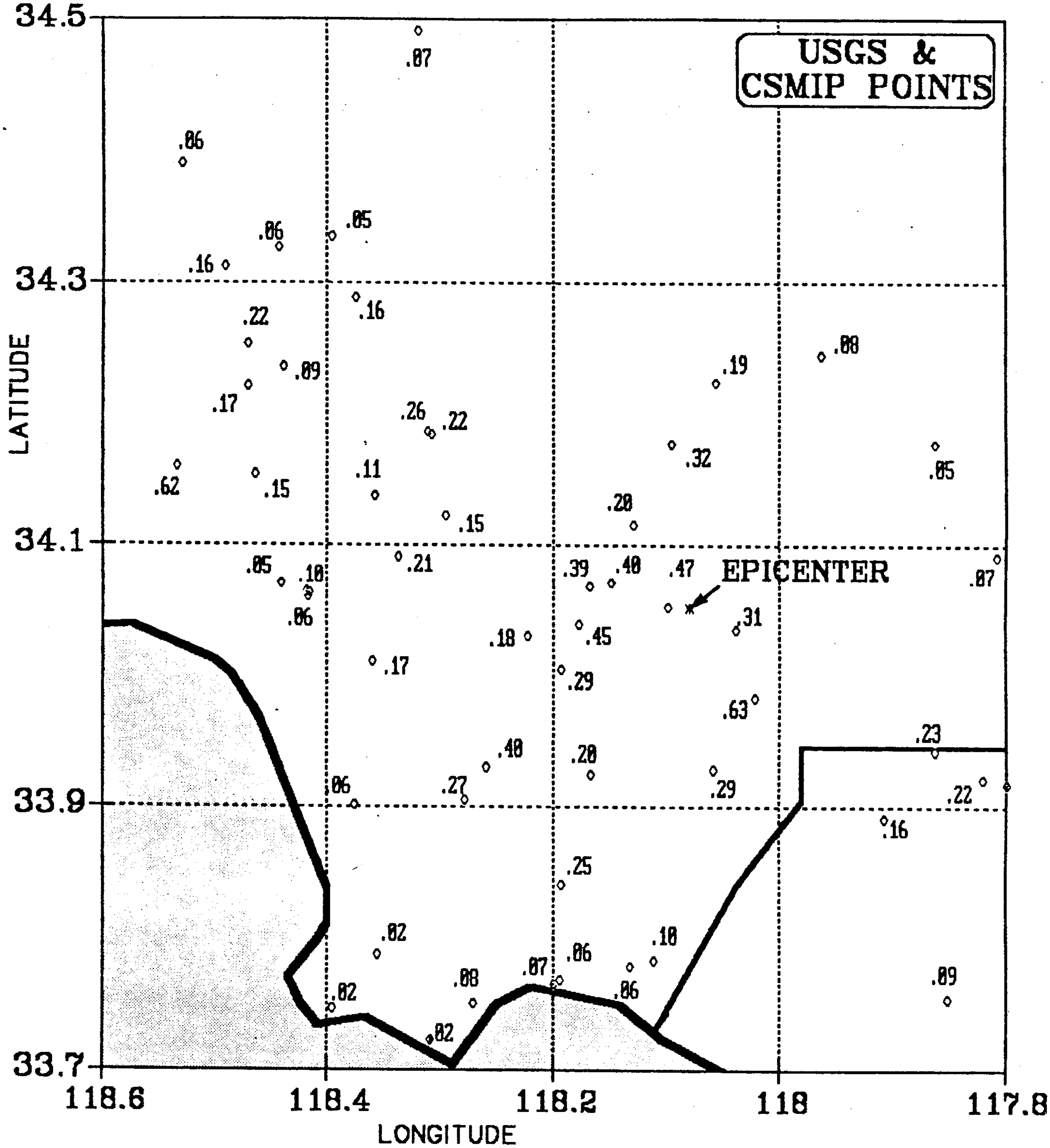


Figure 2. Peak Ground Accelerations (g) for the Whittier Narrows Earthquake.

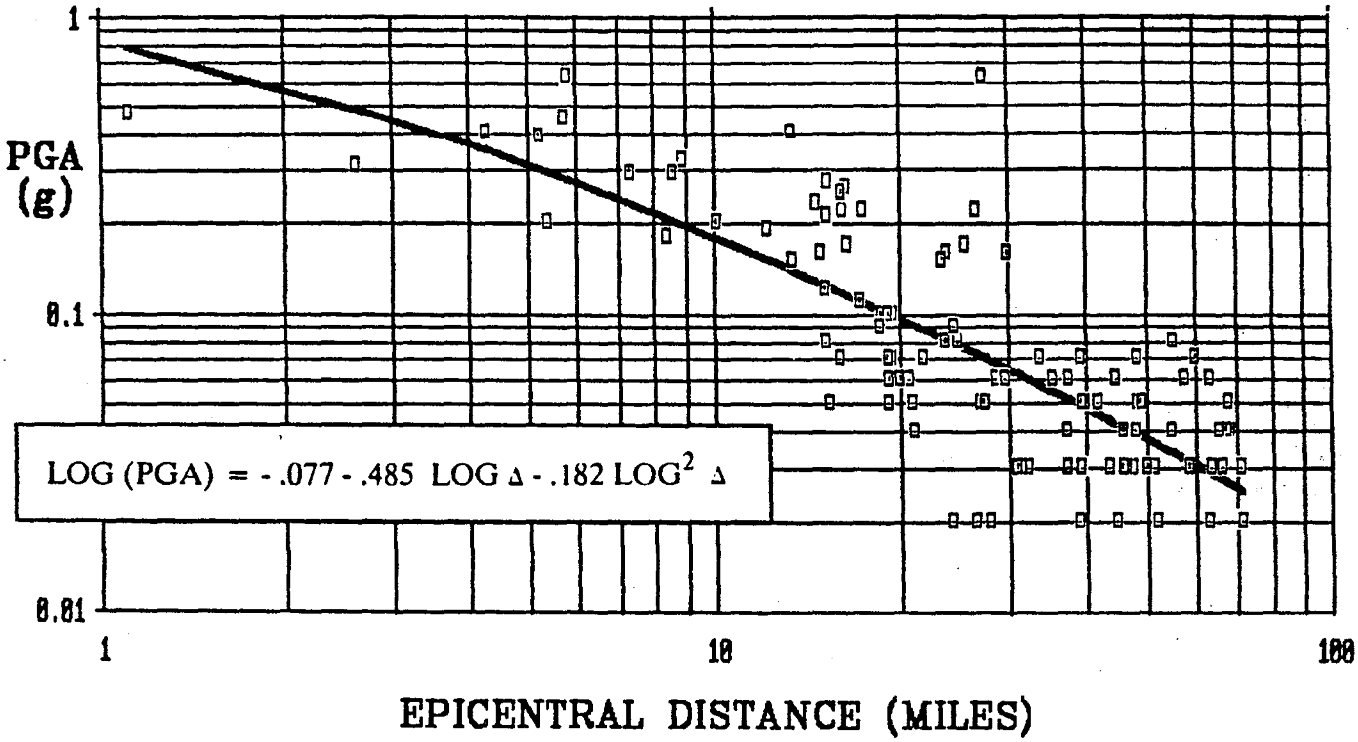


Figure 3. Log Plot for PGA vs. Epicentral Distance Using Non-Linear Fit.

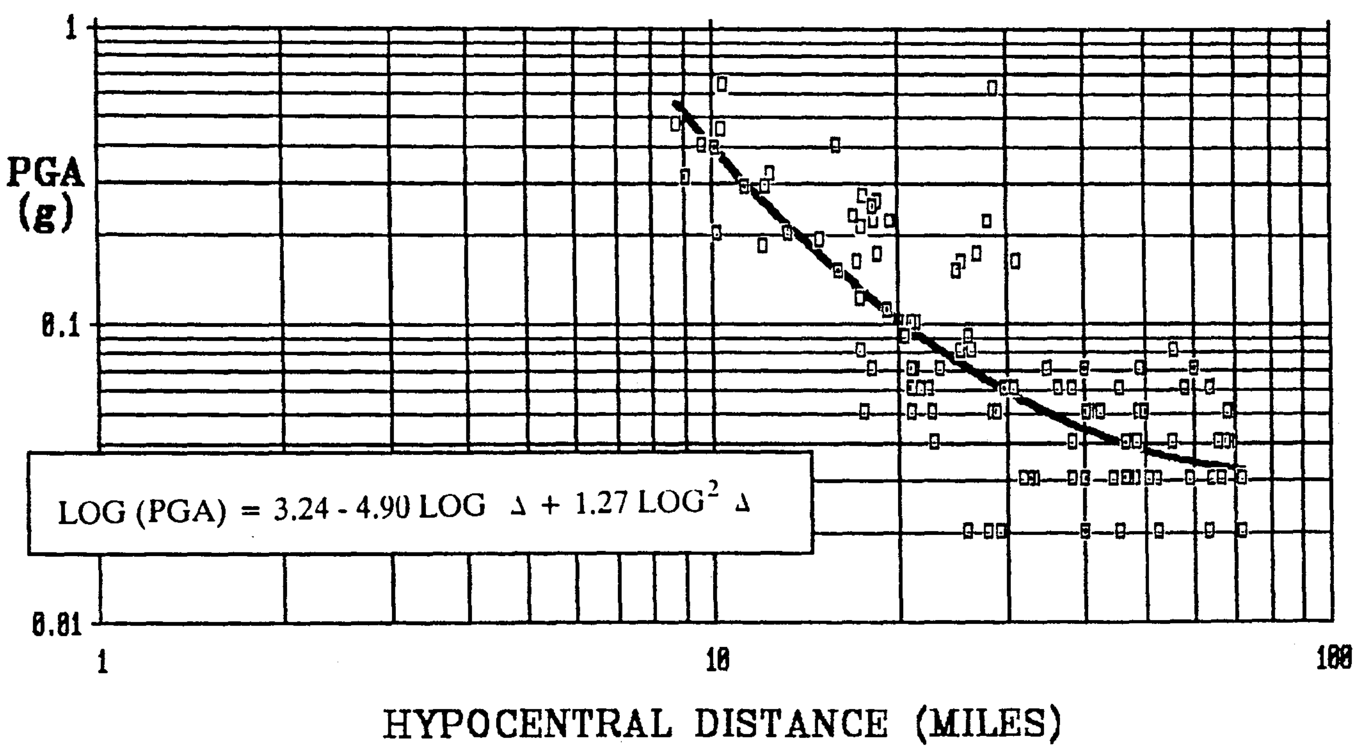


Figure 4. Log Plot for PGA vs. Hypocentral Distance Using Non-Linear Fit.

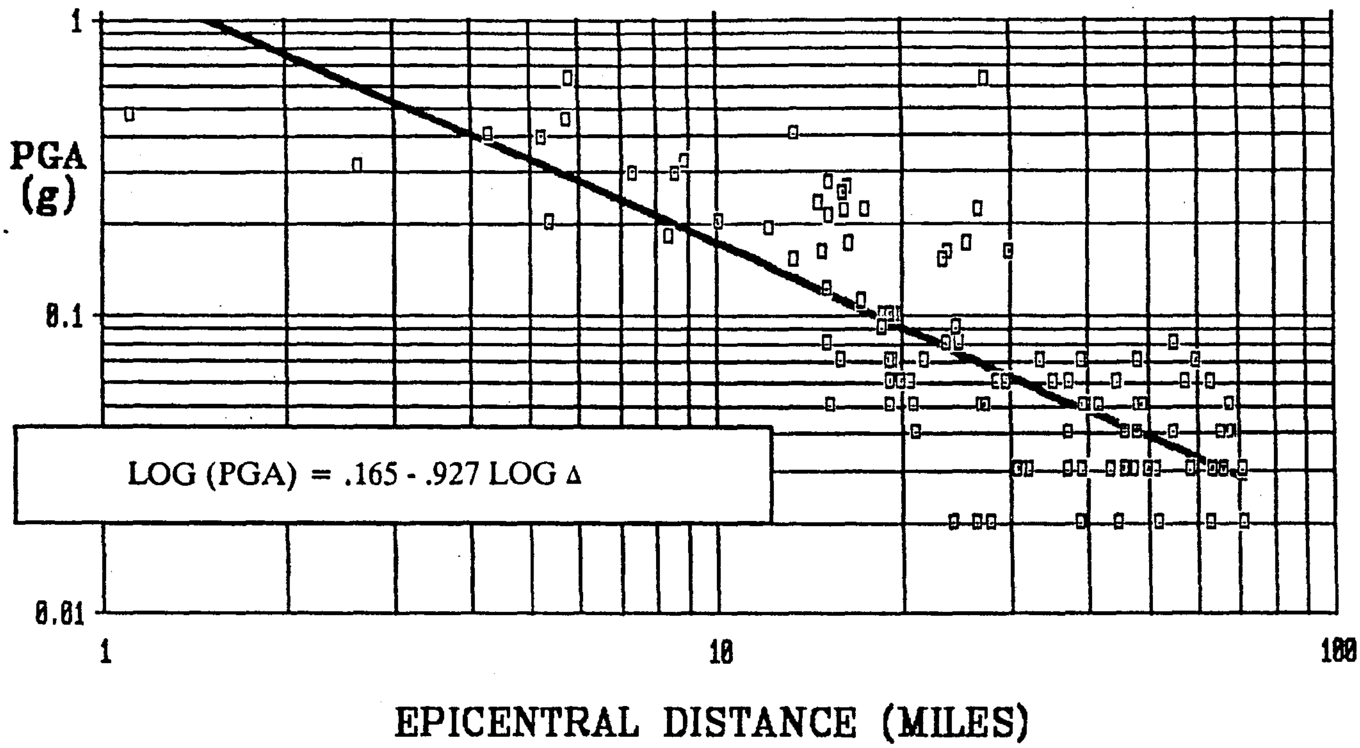


Figure 5. Log Plot for PGA vs. Epicentral Distance Using Linear Fit.

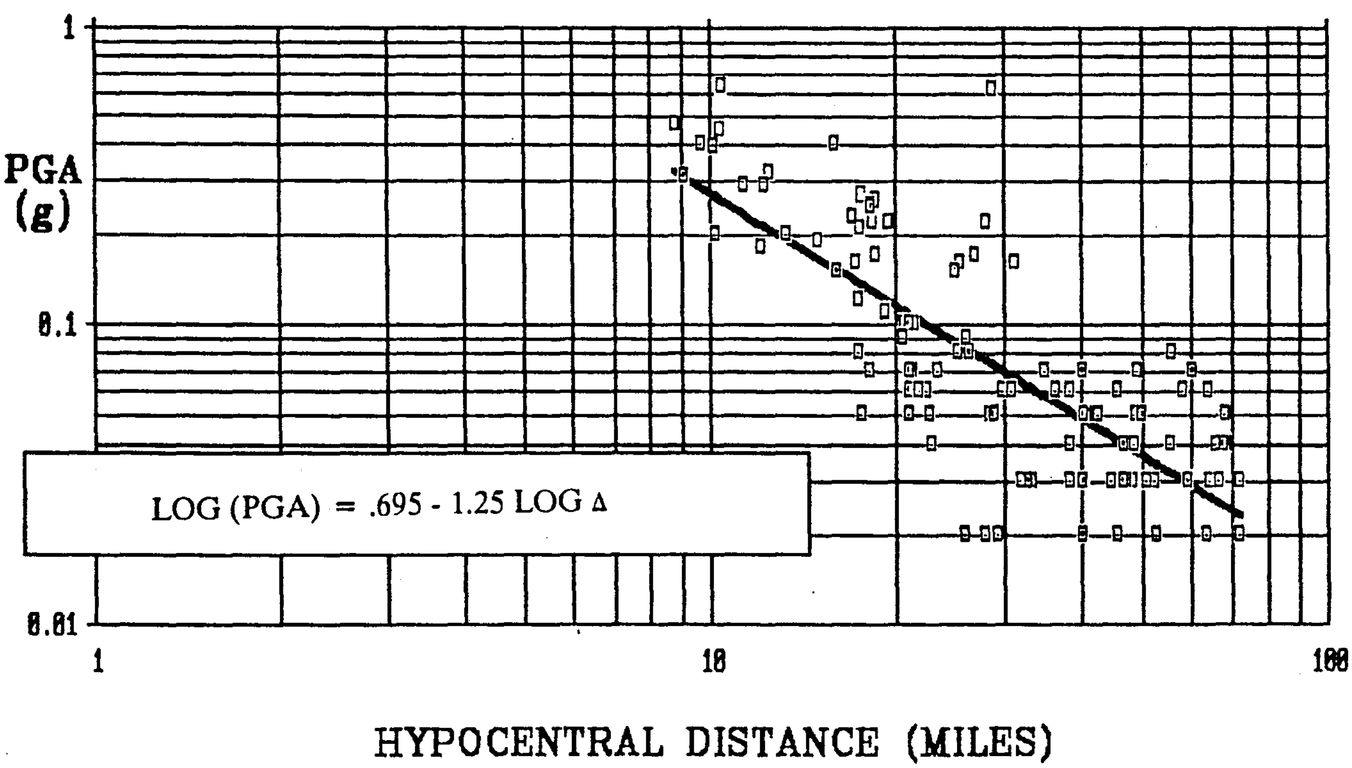


Figure 6. Log Plot for PGA vs. Hypocentral Distance Using Linear Fit.

Wiggins (1961). It may be computed that the peak ground acceleration noted in Figure 6 will correspond exactly to Equation (3) relating DAF, local magnitude and hypocentral distance with Modified Mercalli Intensity for a DAF = 5.28 @ 10 miles, DAF = 4.74 @ 20 miles and DAF = 4.44 @ 30 miles.

In other words, from a linear averaging point of view, this earthquake was similar to other earthquakes that have taken place in California during recorded earthquake history regarding estimated intensity, given local magnitude and hypocentral depth.

Fitting the data with Equation (2) relating acceleration to intensity, an isoseismal map denoted as that prepared by Crisis Management Corporation is presented in Figure 7. This map was prepared by averaging all of the peak ground acceleration values for 0.2^{o} x 0.2^{o} Longitude and Latitude areas. Note in Figure 8, however, that higher MMI values in some locations would have been predicted using Equation (2) had not the averaging been exercised. Also, please note that the highest isoseismal zone (MMI = VIII) lies to the west of the epicenter.

Figure 9 plots the location of ignitions in relationship to the Crisis Management isointensity contours. Note the number of ignition points within MMI = VIII region. Figure 10 shows the same ignition locations, but it compares those with the U.S. Geological Survey isointensity contour lines. Only a very small area in Whittier, California was assigned an MMI = VIII, in which no ignitions took place. The MMI VII region was also extremely small compared to that derived by the Crisis Management technique relating acceleration to MMI. Further, one ignition located at 34^{o} North Latitude 117.87^{o} West Longitude, lies in the USGS Map intensity region V, whereas all of the ignitions fall within MMI VI regions or higher as mapped by Crisis Management Corporation.

These differences can result from several possibilities,

1. The Modified Mercalli Intensity scale in the regions VI and higher depend principally on damage observations. Since construction over the last 30 years has, in general, been improved with regard to earthquake vulnerability, the intensity values higher than VI should encompass smaller areas, due to lower amounts of damage.

2. The assignment of intensity values was purposely underestimated since damage was the <u>only</u> criterion used for rating Modified Mercalli Intensity. The report by Leyendecker et al. (1988) indicates that both possibilities may have been correct.

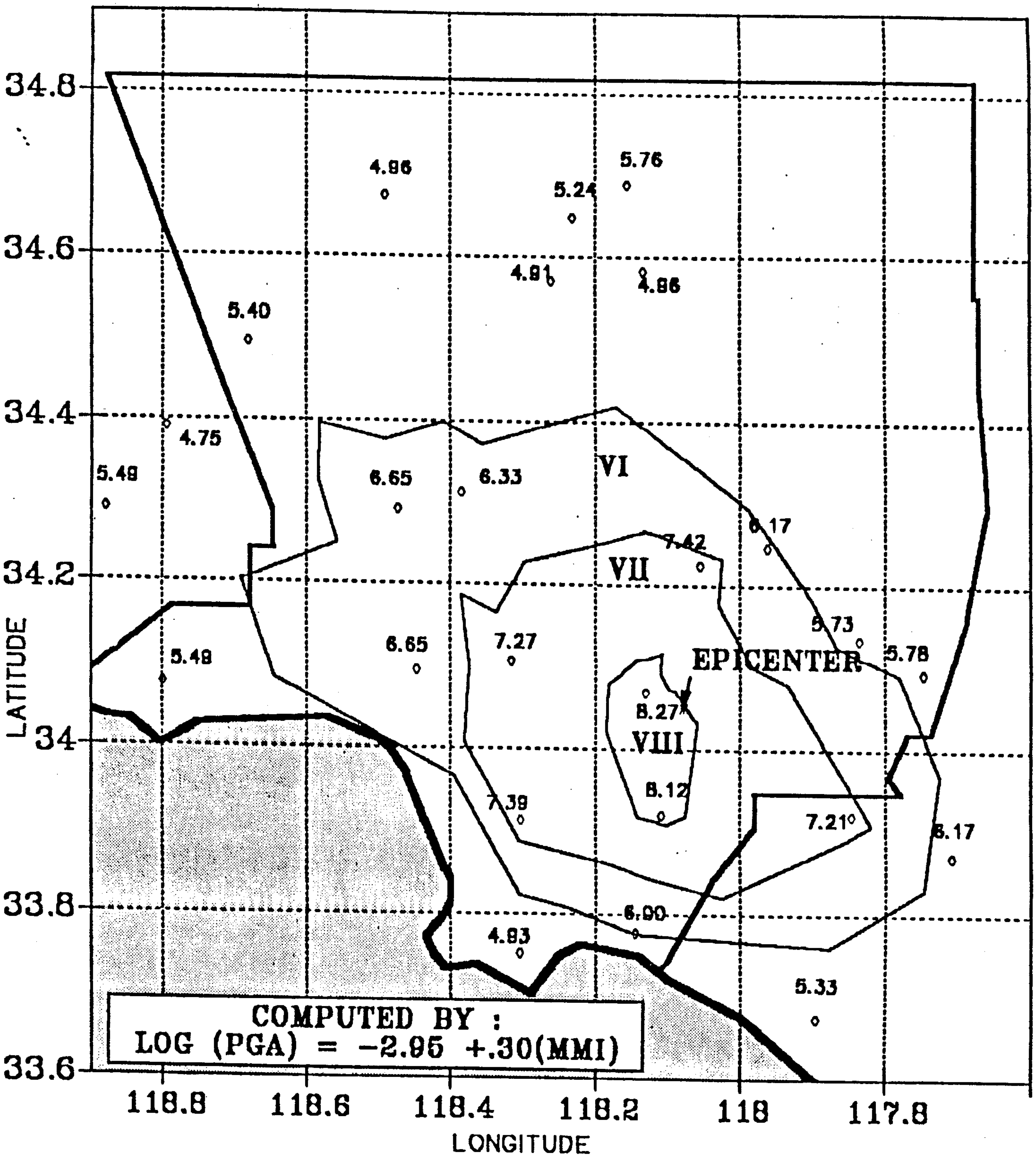


Figure 7. MMI Intensity Points with Crisis Management Mapped Isoseismal Zones for the Whittier Narrows Earthquake Across Los Angeles County.

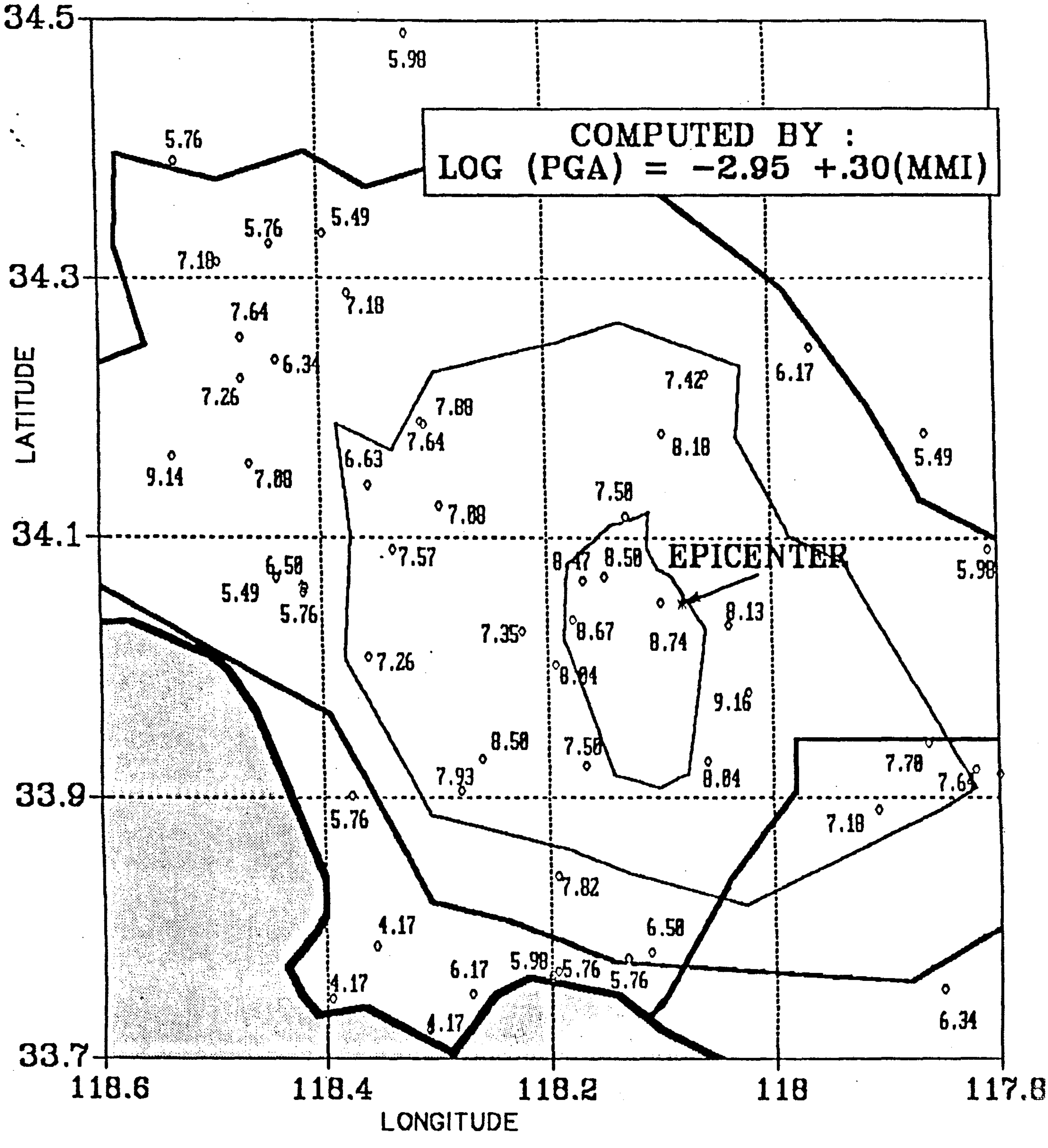


Figure 8. MMI Intensity Points for the Whittier Narrows Earthquake with Crisis Management Mapped Isoseismal Zones Across Los Angeles Basin.

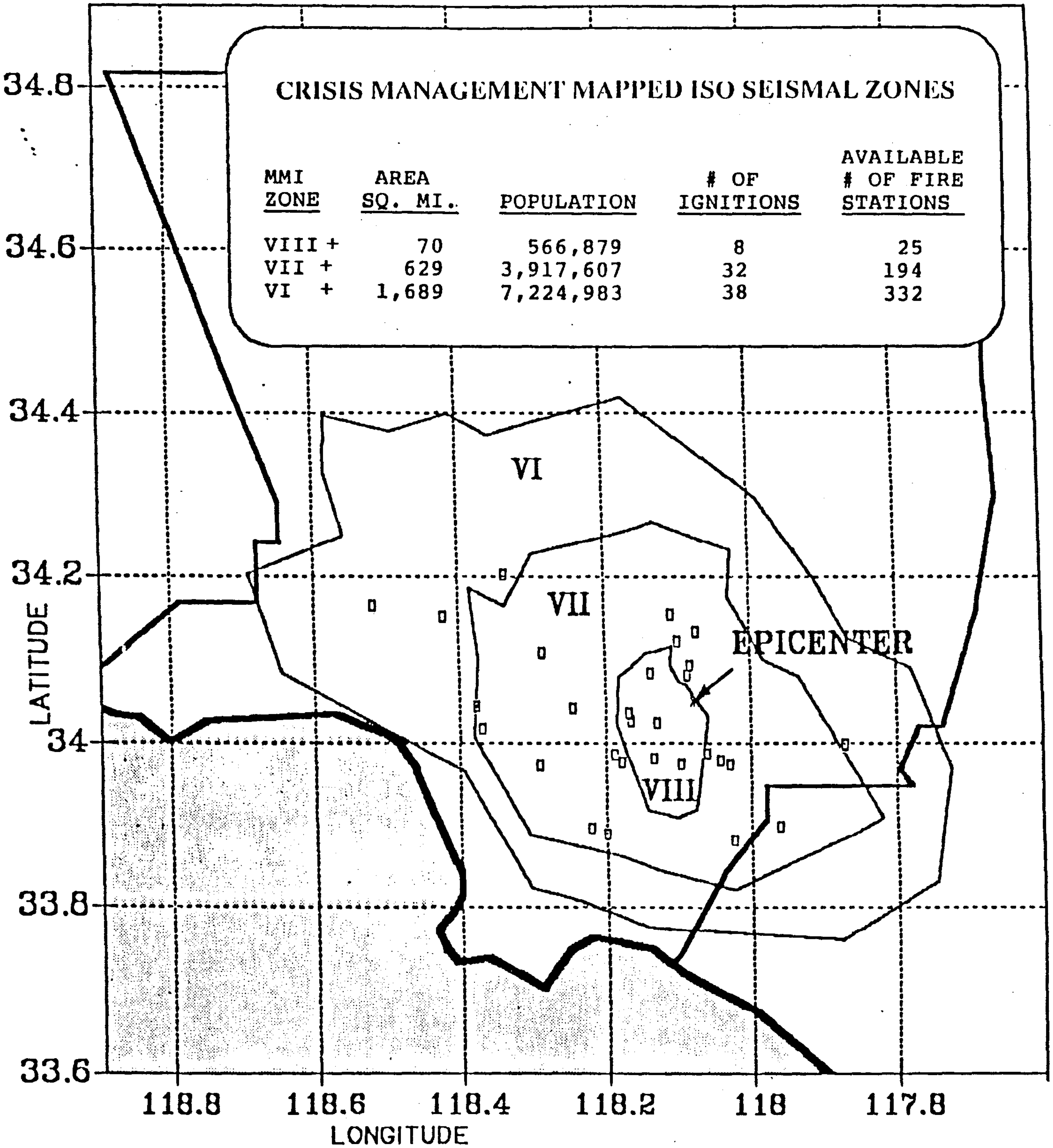


Figure 9. The 30 Documented Fire Ignition Locations for the Whittier Narrows Earthquake Plotted vs. Crisis Management Isointensity Contours. Data Cited in the Box Increases the 30 Ignitions by the Ratio 38/30, Since 38 Ignitions are Known to have Occurred, 8 of which have No Location Identification.

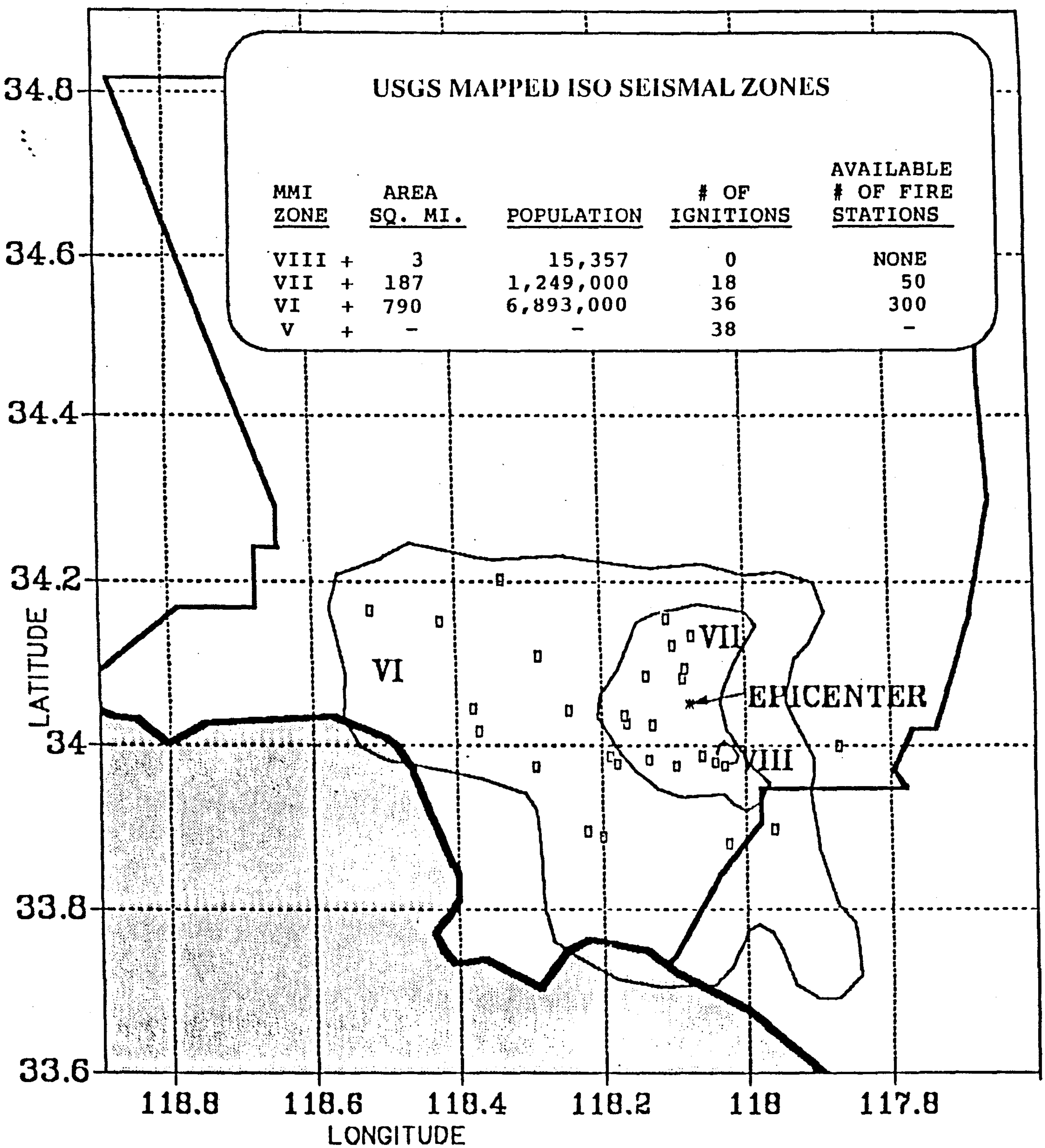


Figure 10. Fire Ignition Locations for the Whittier Narrows Earthquake Plotted vs. USGS Isointensity Contours. Note Figure 9 for Data Explanation.

5.0 COMPARISON OF WHITTIER NARROWS EARTHQUAKE FIRE IGNITIONS WITH THOSE FROM THE 1971 SAN FERNANDO EARTHQUAKE

The San Fernando earthquake of February 9, 1971 occurred at 0601 in the morning. It was similar to the Whittier Narrows earthquake in almost all respects with the exception of the following:

1. The magnitude was 6.6 instead of 5.9 (or 11 x more energy).
2. The fault broke the surface of the ground in 1971, whereas no surface breaks occurred in the 1987 event.
3. The population exposed was somewhat smaller in 1971 than in 1987.

With the exception of the aforementioned differences, there were many similarities between the Whittier Narrows event and the 1971 San Fernando event:

1. Both were thrust faults.
2. Both occurred at the fringe area of the most populated regions.
3. The same cities were by and large affected.

With regard to a summary of fire ignitions for the Whittier Narrows earthquake please note Table 2. In that event there were a total 38 ignitions that affected 19 cities plus Los Angeles County remaining areas. (see Table 3). Table 3 shows all of these ignitions as a function of Crisis Management as well as USGS Mapped Modified Mercalli Intensity regions.

In contrast, the San Fernando earthquake had 109 ignitions, 82 of which are displayed in Figure 11. A blowup of the highly shaken area MMI IX - X is shown in Figure 12. In both these figures, 82 ignition locations are shown out of the total of 109 ignitions reported.

Of the 82 ignitions shown the breakdown by intensity region is as follows:

MMI	NUMBER OF IGNITIONS	G	E	D	S	F
IX - X	23	14	7	-	2	-
VIII	21	10	9	1	1	-
VII	26	4	15	3	2	2
VI	12	4	7	4	_	1
TOTAL	82	32	38	4	5	3

TABLE 2 SUMMARY OF IGNITIONS FOR THE WHITTIER NARROWS EARTHQUAKE

LOS ANGELES COUNTY FIRE DEPARTMENT

LOCATION	BLDG TYPE	ENG. COMP	FIRE LOCATION	IGNITION CAUSE	TOTAL LOSS	MMI ZONE CMC	MMI ZONE USGS	COMMENTS
7041 ELMER, WHITTIER	RESID.	1	OUTSIDE WALL	NATURAL GAS	$70,000	VII	VII	LEAKING GAS EXPLODED.
16402 MURIEL, COMPTON	RESID.	2	WATER HEATER	NATURAL GAS	$70,000	VII	VI	MUTUAL AID W/ COMPTON FIRE
1917 HOWELL, ROWLAND HTS.	RESID.	1	GARAGE	NATURAL GAS	$64,900	VI	V	THREE VEHICALS DESTROYED.
4874 GAGE #147, BELL	MOBILE	1	LIVING RM.	ELECTRICAL	$35,000	VII	VI	VCR FELL AND SHORT CIRCUITED.
543 VALLOMBROSA, PASADENA	RESID.	1	LIVING RM.	ELECTRICAL	$28,000	VII	VII	OVERTURNED LAMP FROM ENDTABLE.
6208 OXSEE, WHITTIER	RESID.	1	ATTIC	ELECTRICAL	$20,000	VII	VII	
330 McBRIDE, EAST LOS ANGELES	RESID.	1	WASHROOM	NATURAL GAS	$5,000	VIII	VII	WATER HEATER.
6920 SLAUSON, COMMERCE	COMMER.	1	CEILING	NATURAL GAS	$2,000	VIII	VII	CEILING MOUNTED HEATER CAME LOOSE.
16901 VALLEY VIEW, CERRITOS	INDUST.	1	SMOKER VENT	ELECTRICAL	$1,000	VII	VI	
9102 BERMUDEZ, PICO RIVERA	RESID.	1	ROOF	ELECTRICAL	$800	VIII	VII	FIREMAN HOSPITALIZED.
5954 MAYWOOD, HUNTINGTON PRK.	COMMER.	1	LIQUOR STORE	ELECTRICAL	$300	VII	VI	BOTTLES FELL ON ELECTRICAL BOX.
5505 HARKER, TEMPLE	RESID.	1	ROOF	ELECTRICAL	$100	VII	VII	POWER LINE FELL.
COUNT = 12 INCIDENTS					$297,100			
MISSING 8 INCIDENTS					$128,700			FROM COUNTY SUMMARY TO SUPERVISORS
L.A. COUNTY TOTAL FIRE LOSS					$425,800			

CITY OF LOS ANGELES FIRE DEPARTMENT

LOCATION	BLDG TYPE	ENG. COMP	FIRE LOCATION	IGNITION CAUSE	TOTAL LOSS	MMI ZONE CMC	MMI ZONE USGS	COMMENTS
CAL. STATE UNIV. LOS ANGELES	UNIV.	1 TO 2	CHEM. LAB.	CHEM SPILL	$24,000	VIII	VII	TOLUENE SPILL.
1007 W. 69TH, HYDE PARK	CHURCH	2	FLOOR FURNICE	NATURAL GAS	$8,180	VII	VI	
2021 N. DRACENA, LOS FELIZ	-	2	LAUNDRY ROOM	NATURAL GAS	$6,000	VII	VI	WATER HEATER.
17835 VENTURA, ENCINO	COMMER.	1	ROOF	NATURAL GAS	$5,200	VI	VI	HEATER/AIR COND. CONNECTOR FAILED.
3937 GIBRALTER, BALDWIN HILLS	-	1 TO 2	INDOORS	ELECTRICAL	$2,600	VII	VI	COMBUSTIBLES AGAINST HEATER.
13519 RYE ST., SHERMAN OAKS	-	1 TO 2	INDOORS	ELECTRICAL	$250	VI	VI	LAMP KNOCKED OVER.
CITY OF LOS ANGELES TOTAL FIRE LOSS					$46,230			

DEPARTMENT OF WATER OF POWER -- (OCCURRED ON OCT. 6, 1987)

LOCATION	BLDG TYPE	ENG. COMP	FIRE LOCATION	IGNITION CAUSE	TOTAL LOSS	MMI ZONE CMC	MMI ZONE USGS	COMMENTS
560 S. WALL, LOS ANGELES	COMMER.	?	RECEIVING STATION "P"	TRANSFORMER LEAK	$2,000,000	VII	VI	DOWNTOWN AREA WITHOUT SERVICE FOR SEVERAL HOURS.

TABLE 2 SUMMARY OF IGNITIONS FOR THE WHITTIER NARROWS EARTHQUAKE (CONTINUED)

LOCATION	BLDG TYPE	ENG. COMP	FIRE LOCATION	IGNITION CAUSE	TOTAL LOSS	MMI ZONE CMC	MMI ZONE USGS	COMMENTS
PASADENA FIRE DEPARTMENT 972 PALO VERDE, PASADENA	RESID.	2	LIVING RM.	ELECTRICAL	$6,000	VII	VII	APPLIANCE FELL CAUSING SHORT.
SAN MARINO FIRE DEPARTMENT 1340 VAN DYKE, SAN MARINO	RESID.	4	GARAGE ROOF	ELECTRICAL	$8,000	VII	VII	POWER LINE FELL
SAN GABRIEL FIRE DEPARTMENT 1015 E. VALLEY, SAN GABRIEL			OPEN FIELD	BRUSH FIRE	$0	VII	VII	-
ALHAMBRA FIRE DEPARTMENT UNKNOWN	APT.		INDOORS	NATURAL GAS	-	VIII	VII	DEPT. DID NOT PROVIDE INFORMATION
MONTEBELLO FIRE DEPARTMENT 2912 VIA ACOSTA, MONTEBELLO		1	OUTDOORS	ELECTRICAL	-	VIII	VII	EDISON POWR LINES BURNING -- MINOR
ORANGE COUNTY FIRE DEPARTMENT STATED THAT THERE WAS ONE MINOR EVENT, BUT DIDN'T GIVE DETAILS					-	VI	V	-

SO. CALIF. GAS COMPANY RECORDS

LOCATION	BLDG TYPE	ENG. COMP	FIRE LOCATION	IGNITION CAUSE	TOTAL LOSS	MMI ZONE CMC	MMI ZONE USGS	COMMENTS
1646 SHERBOURNE, LOS ANGELES	RESID.	0	INDOOR	NATURAL GAS	$500	VII	VI	EXTINGUISHED BY HOMEOWNER
815 N. TAMARIND, COMPTON	RESID.	0	WALL FURNICE	NATURAL GAS	$500	VII	VI	EXTINGUISHED BY HOMEOWNER
13733 FRANKLIN, WHITTIER	RESID.	0	FURNICE	NATURAL GAS	$500	VII	VII	EXTINGUISHED BY HOMEOWNER
2255 BUENA VISTA, BURBANK	MOTEL	0	WATER HEATER	NATURAL GAS	$500	VI	VI	EXTINGUISHED BY MANAGER
2624 GREENWICH, FULLERTON	RESID.	0	WATER HEATER	NATURAL GAS	$500	VII	VI	EXTINGUISHED BY HOMEOWNER
TOTAL GAS RECORDS LOSS					$2,500			

TOTAL FIRE LOSSES FOR OCTOBER 1,1987	$488,530
TOTAL FIRE LOSSES FOR OCTOBER 6,1987	$2,000,000
TOTAL FIRE LOSSES FOR WHITTIER EARTHQUAKE	$2,488,530

TABLE 3

WHITTIER NARROWS EARTHQUAKE
IGNITION FACT SHEET AND SUMMARY

AFFECTED CITY	NO. OF IGNITIONS	MMI CMC	MMI USGS	CITY AREA (SQ MILE)	DAMAGE LOSSES
WHITTIER	3	VII	VII	12.13	$90,500
COMPTON	2	VII	VI	10.50	70,500
ROWLAND HEIGHTS	1	VI	V	5.92	64,900
BELL	1	VII	VI	2.83	35,000
PASADENA	2	VII	VII	23.00	34,000
EAST LOS ANGELES	2	VIII	VII	5.91	29,000
SAN MARINO	1	VII	VII	3.75	8,000
COMMERCE	1	VIII	VII	6.60	2,000
CERRITOS	1	VII	VI	8.81	1,000
PICO RIVERA	1	VIII	VII	8.23	800
BURBANK	1	VI	VI	17.13	500
FULLERTON	1	VII	VI	22.10	500
HUNTINGTON PARK	1	VII	VI	2.98	300
TEMPLE CITY	1	VII	VII	3.78	100
OTHER L.A. COUNTY	8 *	2 @ VIII, 5 @ VII, 1 @ VI			128,700
ALHAMBRA	1	VIII	VII	7.69	MINOR
MONTEBELLO	1	VIII	VII	8.20	MINOR
ORANGE COUNTY	1	VI	V	524.87	MINOR
SAN GABRIEL	1	VII	VII	5.10	MINOR
CITY OF LOS ANGELES				463.70	
CENTRAL : D.W.P.	1	VII	VI		2,000,000
HYDE PARK	1	VII	VI		8,180
LOS FELIZ	1	VII	VI		6,000
ENCINO	1	VI	VI		5,200
BALDWIN HILLS	1	VII	VI		2,600
CHEVIOT HILLS	1	VII	VI		500
SHERMAN OAKS	1	VI	VI		250
TOTALS :	38			1143.23	$2,488,530

* APPORTIONED BY RATIOING OTHER KNOWN SOURCE LOCATIONS.

AFFECTED AREA	NO. OF IGNITIONS	MMI CMC	MMI USGS	POPULATION	DAMAGE LOSSES
CRISIS MGMT. CORP. MAPPED ISO INTENSITY ZONES :					
MMI VIII	8	VIII		566,879	$31,800
MMI VII	24	VII		3,350,728	$2,257,180
MMI VI	6	VI		3,307,376	$70,850
USGS MAPPED ISO INTENSITY ZONES :					
MMI VIII	0		VIII	15,357	$0
MMI VII	18		VII	1,233,653	$164,400
MMI VI	18		VI	5,644,000	$2,130,530
MMI V	2		V		$64,900

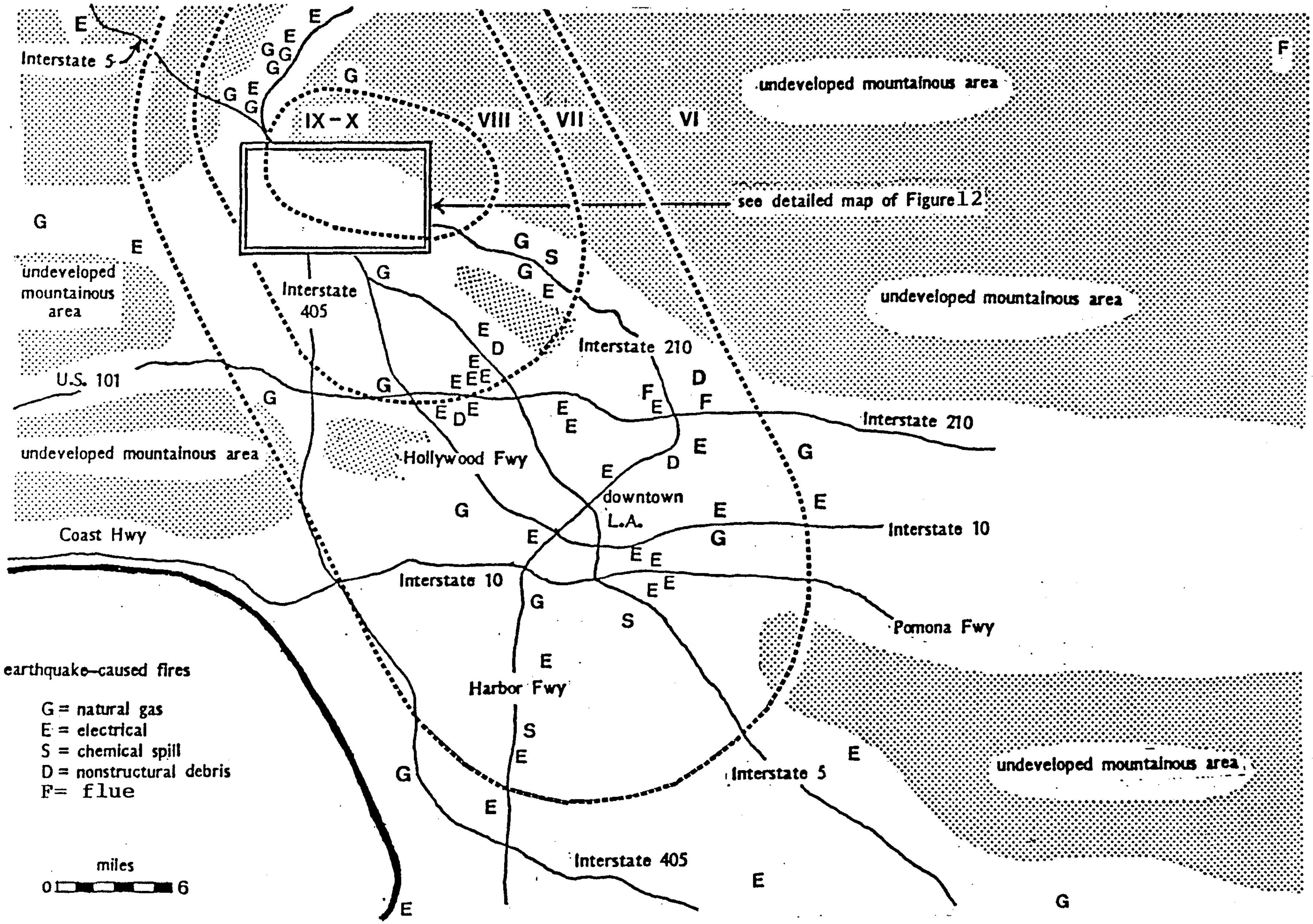
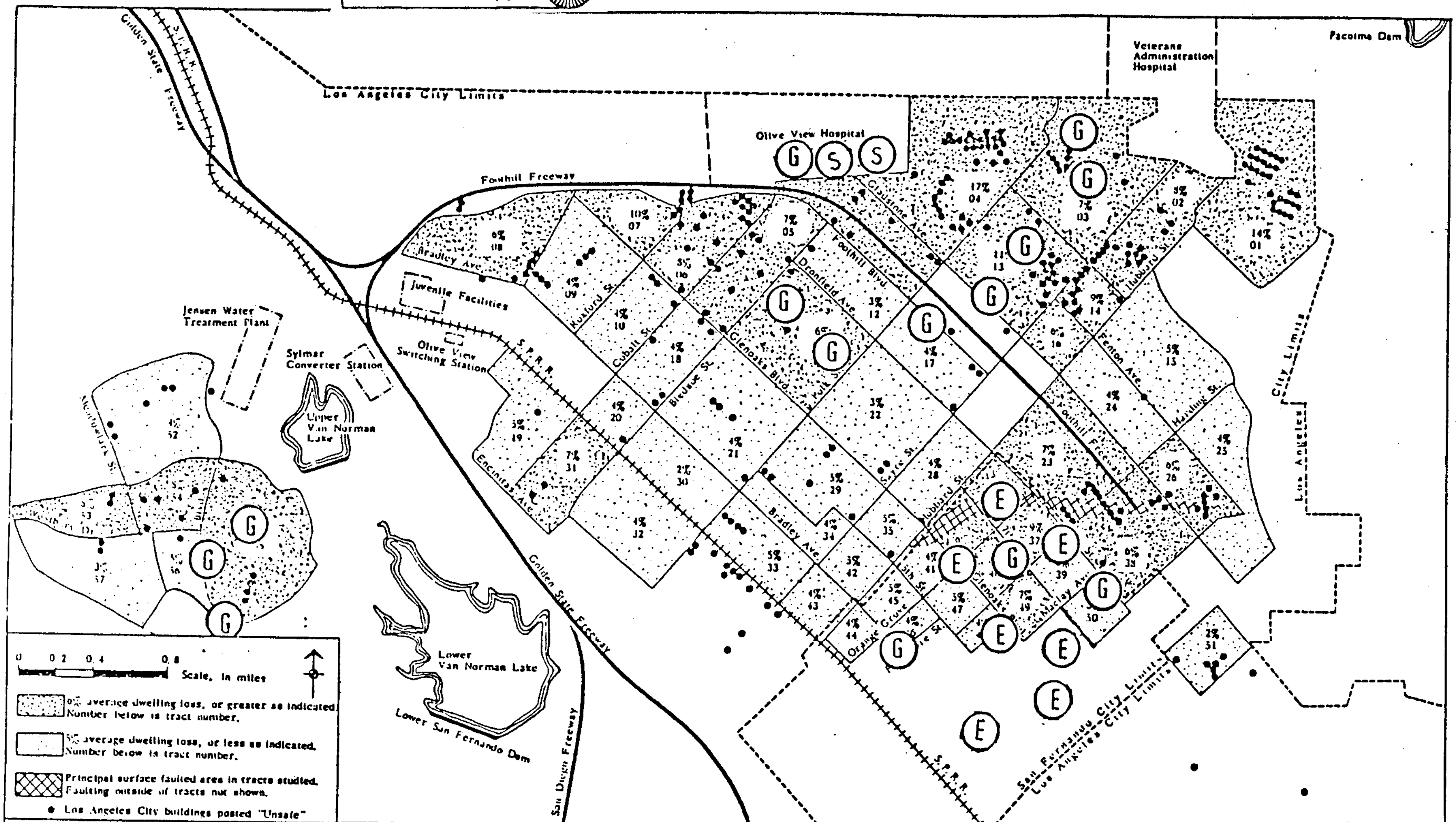


Figure 11. Fires Caused by the 1971 San Fernando Earthquake.



(G) natural gas

(E) electrical

(S) chemical spill

The base map and all non-fire information is from Steinbrugge et al, (1982).

Figure 12. Detailed Map of Inset Area in Figure 11. Fires Caused by San Fernando Earthquake.

Of the total identified fire sources in the San Fernando and Whittier earthquakes, Table 4 describes the major ignition source types and compares the results of the San Fernando event with those of the Whittier event. Recall that the San Fernando earthquake was larger and broke ground. Thus, more fire incidents were associated with "natural gas" outdoors as well as "chemical debris" and "broken flue" sources. The greater intensity (up to X in the San Fernando event), plus the broken gas lines in the fault area contributed to this overage. Nevertheless, it can also be seen that the "natural gas" indoor, and "electrical" indoor ratios compare quite favorably for both events, namely, 28 ignitions resulted from "natural gas" indoor compared with 27 ignitions from "electrical" indoor for the San Fernando event. For the Whittier Narrows event, the corresponding number of ignitions were 12 for each category.

Neither of these events occurred in or about Wilmington or Long Beach, where a number of chemical plants and refineries are located. Had the major intensities occurred in these areas, the ignition rate as well as the number of "chemical indoor" and other sources may have been larger.

6.0 IGNITION SOURCES FROM PAST EARTHQUAKES

A number of earthquakes have occurred, which have caused ignitions during current times. The term "current" is taken advisedly in that data from the 1906 San Francisco earthquake ranging up to the 1933 Long Beach earthquake cannot be used since the fire ignition possibilities now are so much different than they were during the period of time when those events took place. In commercial buildings the open stairwells are now closed; fire departments have better equipment; engine companies have radio communications; training procedures and emergency response procedures have been considerably updated. There are no live coals in fire places, as they were in the houses during the 1906 event. Water supply and water supply sources, as well as emergency services for maintaining water supply are better planned and built.

As a result of the foregoing observations, we have selected for analysis earthquakes that have taken place since 1940 to represent current fire ignition conditions. The events selected for analysis are detailed in Table 5. Very little data were listed in the literature dealing with events prior to 1971. However, the information that the literature revealed is shown in the table.

When the Whittier event is added to the 11 other earthquake data sets ignition rates per person for various Modified Mercalli Intensity zones can be established (Tables 6 and 7). Ignition rates for the various events by Modified Mercalli Intensity region are shown in Figure 13. Note that the data is highly scattered when plotted by event alone.

TABLE 4

IDENTIFIED IGNITION SOURCE COMPARISON FOR WHITTIER NARROWS AND SAN FERNANDO EARTHQUAKES

	SAN FERNANDO		WHITTIER NARROWS	
IGNITION SOURCE	# OF IGNITIONS	PERCENT	# OF IGNITIONS	PERCENT
Natural Gas - Indoor	28	34.1%	14	37.8%
Natural Gas - Outdoor	4	4.9%	1	2.7%
Electrical - Indoor	27	32.9%	14	37.8%
Electrical - Outdoor	9	11.0%	5	13.6%
Chemical - Indoor	6	7.3%	1	2.7%
Debris - Indoor	5	6.1%	0	0%
Broken Flue - Indoor	3	3.7%	0	0%
Transformer Leak (Receiving Station)	0	0%	1	2.7%
Brush Fire	0	0%	1	2.7%
TOTAL FOR IDENTIFIED IGNITION SOURCES	82	100%	37	100%
UNIDENTIFIED IGNITION SOURCES	27		1	
TOTAL IGNITIONS	109		38	

TABLE 5

SUMMARY OF IDENTIFIED IGNITION SOURCES FOLLOWING PAST EARTHQUAKES

IGNITION DATA — IGNITION SOURCE IDENTIFICATION

EARTHQUAKE	YEAR	MAG	IGNITION LOCATION	MMI	INDOOR OUTDOOR	NATUR GAS	ELECTR	CHEM SPILL	DEBRIS	BRUSH FIRES	OTHER	COMMENTS
KERN COUNTY	1952	7.7	SO. BAKERSFIELD	VIII	OUT						1	REFINERY EXPLOSION- BUTANE LEAK
DALY CITY/S.F.	1957	5.3	WESTLAKE APT.	VII	IN	1						WATER HEATER
COALINGA	1983	6.5	COALINGA	VIII	IN				1			FLASHOVER CAUSED BY LIQUOR BOTTLE
				VIII	IN				3			MINOR KITCHEN FIRES
				VII	OUT					15		
MORGAN HILL	1984	6.2	MORGAN HILL	VII	IN	1						31 CHESTNUT ST., WATER HEATER
			MORGAN HILL	VII	OUT		1					17455 MONTEREY RD., FLOODLAMP
			MORGAN HILL	VII	OUT					2		
			SAN JOSE	VI	IN		1					ATTIC FIRE IN A LAUNDRY
			SAN JOSE	VI	OUT		1					POWER LINE ON MOBILE HOME ROOF
			SAN JOSE	VI	IN	1						WATER HEATER VENT DISLODGED
			SAN JOSE	VI	IN	1						FLASHOVER AT SHOPPING COMPLEX
			SAN JOSE	VI	OUT					1		
SANTA ROSA	1969	5.7	SANTA ROSA	VII	IN			1				MEMORIAL HOSPITAL LABORATORY FIRE
			SANTA ROSA	VII	IN	1						WATER HEATER
IMPERIAL COUNTY	1979	6.4	EL CENTRO	VII	IN	1						BROKEN GAS LINE ON TRAILER
			EL CENTRO	VII	?						1	UNKNOWN
PALM SPRINGS	1986	5.9	CATHEDRAL CITY	VII	IN		1					GLASS COMP. FIRE CAUSED BY SHORT
			IDYLLWILD	VI	IN						1	PROPANE WATER HEATER CONNECTOR
			CABAZON PEAK	VII	OUT					2		
MAMMOTH LAKES	1980	6.3	CONVICT LAKE	VII	IN	1						GAS HEATER AT RESEARCH LABORATORY
IMPERIAL COUNTY	1940	7.1	CALEXICO	VIII	?						4	INCLUDES HOTEL FIRE IN MEXICO
ALASKA	1964	8.4	ANCHORAGE	VIII	?						4	MINOR FIRES
	TOTAL IGNITIONS :					7	4	1	4	20	11	47

IDENTIFIED IGNITION SOURCES BY MMI ZONE		NATUR GAS	ELECTR	CHEM SPILL	DEBRIS	BRUSH FIRES	OTHER	TOTALS PER MMI ZONE
MMI ZONE 8	VIII				4		9	13
MMI ZONE 7	VII	5	2	1		19	1	28
MMI ZONE 6	VI	2	2			1	1	6
TOTAL IGNITIONS :		7	4	1	4	20	11	47

TABLE 6

IGNITIONS FOR PAST EARTHQUAKES APPORTIONED TO MMI
INCLUDING THE WHITTIER EVENT AS REPORTED BY USGS AND THIS STUDY

EARTHQUAKE	YEAR	MAG	MAX MMI	GROUND BREAKAGE POPULATED AREA	STRUCTURE FIRES	WITH FLASHOVERS	BRUSH FIRES	POPULATION VI & GREATER	POPULATION VII & GREATER	POPULATION VII & GREATER
Mammoth	1980	6.3	VIII	No	1	0	0	31,430	6,817	-
Alaska	1964	8.4	X	Yes	4	0	0	-	-	95,667
Daly City (SF)	1957	5.3	VII	No	1	0	0	1,955,122	923,379	-
Imperial County	1940	7.1	X	No	4	0	0	68,876	54,760	33,224
Palm Springs	1986	5.9	VIII	No	2	0	2	348,022	77,581	-
Imperial County	1979	6.4	VIII	No	2	0	0	89,682	74,032	-
Morgan Hill	1984	6.2	VII	No	6	1	3	1,064,116	648,079	-
Kern County	1952	7.7	X	No	1	1	0	5,890,554	2,031,427	56,077
San Fernando	1971	6.4	X	Yes	109	0	0	9,281,581	3,903,858	834,345
Coalinga	1983	6.5	IX	No	4	1	15	78,863	17,383	7,855
Santa Rosa	1969	5.7	VIII	No	2	0	0	106,441	61,244	-
Whittier Narrows *(USGS Mapped ISO Intensity)*	1987	5.9	VIII	No	37	6*	1	6,893,000	1,249,000	15,357
Whittier Narrows *(Crisis Management Mapped ISO Intensity)*	1987	5.9	VIII	No	37	6*	1	7,224,983	3,917,607	566,879
				TOTAL	173	9	21	>26,235,337	>11,811,334	1,594,047
				TOTAL IGNITIONS:				194	164	79

[box] Subject of this study.

* Flashover defined as structure damage greater than $10,000

TABLE 7.

IGNITION RATE DATA PER 100,000 PERSONS FOR VARIOUS INTENSITY CONDITIONS RANKED BY POPULATION AFFECTED.

RANK BY POP. AFFECTED	EVENT; MAGNITUDE; GROUND FAILURE;	TOTAL POPULATION ≥ VI	RATE ≥VI	ONLY VI	≥VII	ONLY VII	≥VIII
1.	San Fernando (71); M=6.4; YES	9,281,581	1.2	0.30	2.4	1.1	7.0
2.	Whittier Narrows (87); M=5.9; NO	6,893,000* 7,224,983	0.59* 0.53	0.32* 0.18	1.4* 0.82	1.5* 0.72	0* 1.4
3.	Kern County (52); M=7.7; NO	5,890,554	0.017	0.0	0.049	0.0	1.8
4.	Daly City (57); M=5.3; NO	1,955,122	0.051	0.05	0.11	0.11	-
5.	Morgan Hill (84); M=6.2; NO	1,064,116	0.85	1.2	0.62	0.62	-
6.	Palm Springs (86); M=5.9; NO	348,022	1.1	0.37	3.9	3.9	-
7.	Santa Rosa (69); M=5.7; NO	106,441	1.9	0.0	3.3	3.3	-
8.	Alaska (64); M=8.4; YES	>VIII 95,667	-	0.0	-	0.0	4.2
9.	Imperial County (79); M=6.4; NO	89,682	2.2	0.0	2.7	0.0	-
10.	Coalinga (83); M=6.5; NO	78,863	24	0.0	109	157	51
11.	Imperial County (40); M=7.1; NO	>VIII 68,876	5.8	0.0	7.3	0.0	12

TABLE 7. (CONTINUED)

RANK BY POP. AFFECTED	EVENT; MAGNITUDE; GROUND FAILURE;	TOTAL POPULATION ≥ VI	≥VI	ONLY VI	≥VII	ONLY VII	≥VIII
12.	Mammoth (80); M=6.3; NO	31,430	3.2	0.0	15	15	-
	Average		3.7	0.18	13	15	13
	All Ignitions/ All Population		0.74	0.21	1.4	0.83	5.0
	Scawthorn (1987, pg.20)		-	1.51	-	4.9	10.6
	Scawthorn Results/ This Study		-	x7.2	-	x5.9	x2.1

*USGS Isoseismal map used in conjunction with ignition data.

[ ] Subject of this study

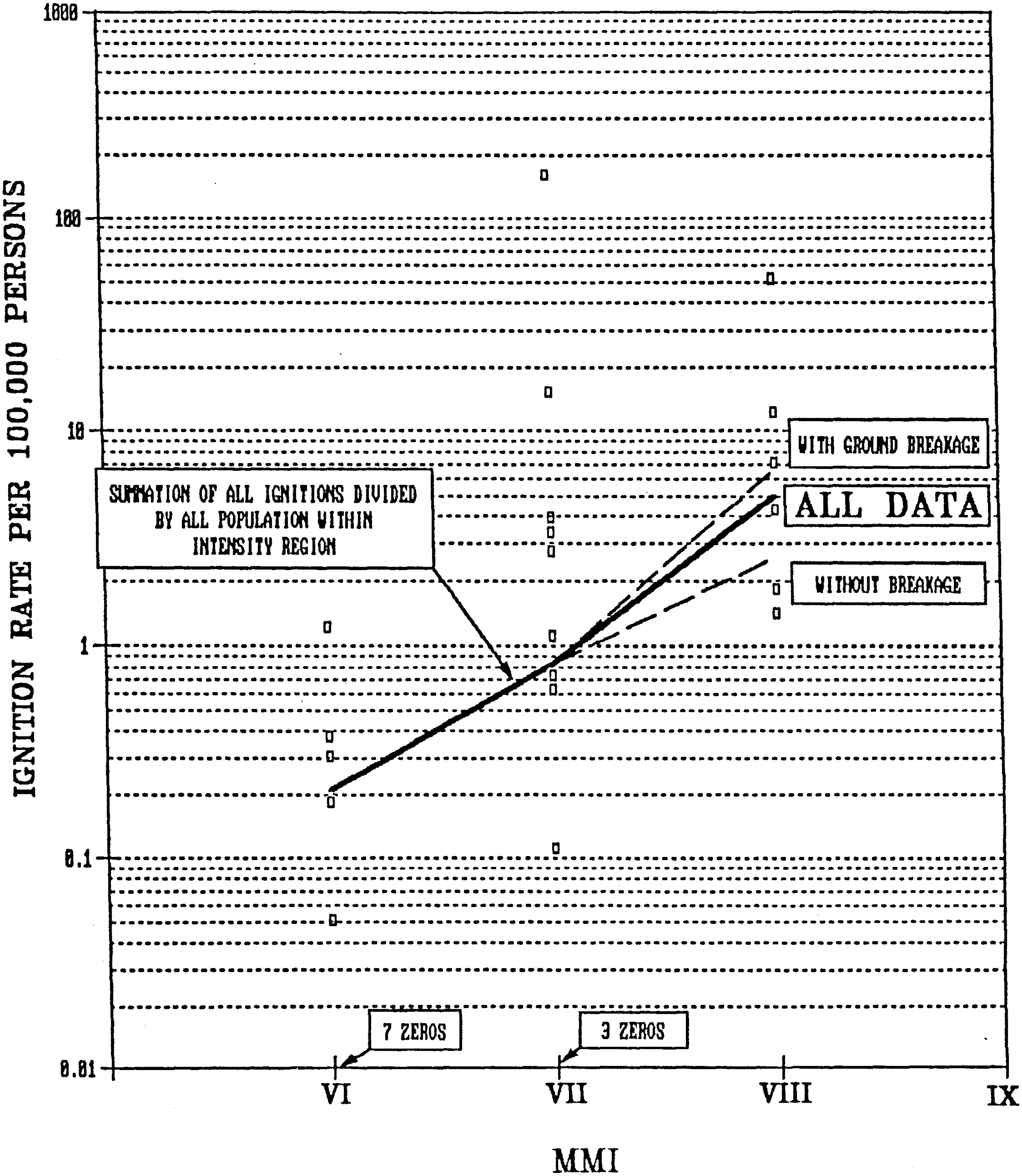


Figure 13. Plot of Ignition Rates for Individual Earthquakes Compared with Ignition Rate Cummulated Over Population for all Events.

Scawthorn (1987) developed an ignition curve per 1,500,000 square feet of construction exposed. Results implied by this curve is reproduced in Table 7 assuming 554 square feet per person. His curve used data from the earthquake events:

Alaska (64)	1 data point
San Francisco (06)	5 data points
San Francisco (71)	5 data points
Coalinga (83)	1 data point
Long Beach (33)	1 data point
Morgan Hill (84)	2 data points
Santa Barbara (25)	1 data point
Santa Rosa (69)	1 data point
San Francisco (57)	1 data point
Total	19 data points

Our curve is reproduced by 30 data points from 12 earthquake events with data from San Francisco (06) Santa Barbara (25) and Long Beach (33) eliminated.

When all population in each Modified Mercalli zone is added and ratioed with all ignitions in the same intensity region a more uniform line is developed. Naturally, the Whittier Narrows event and the San Fernando event dominate the construction of this line since the greatest number of ignitions and the greatest population is contained within the regions affected by these two events. However, this technique appears to be the most logical way of normalizing the data.

The question of how much influence ground breakage might have on ignition rate when it affects populated areas is answered in Table 8. It denotes the ignition rate for all 12 events including the two events (San Fernando 1971 and Anchorage, Alaska 1964) which included significant ground breakage. When only the two earthquakes that experienced ground breakage in populated areas were analyzed, the rates are higher in the Modified Mercalli Intensity regions VIII and greater by a factor of 3. It stands to reason that ground breakage during an event would contribute additional ignitions, however the ratio of 3 to 1 developed by only two data points does not necessarily established a proper or accurate ratio. However, it is all we have to use at this time.

Table 8

Summation of All Earthquake Ignition Data with and without Events Having Significant Ground Breakage within Populated Areas

IGNITION RATE	VI	VII	>VIII
Including all data having significant ground breakage	0.21	0.83	5.0
Without any data with significant ground breakage	-	-	2.6
Data Summed for Alaska (64) and San Fernando (71) events only	-	-	ZONES WITH GROUND BREAKAGE 6.7

The ignition rates during the San Fernando earthquake for the MMI = VI and VII regions were higher than those for the Whittier Narrows earthquake (Table 7). In both intensity regions in which no ground breakage took place the San Fernando earthquake rates were about 60 percent higher than those for the Whittier Narrows earthquake when compared to the CMC map. They are virtually the same when compared to the U.S.G.S. isointensity map. Could it be that the average construction and the associated ignition propensity has decreased by 30-40 percent in the last 16 years?

7.0 BACKGROUND INFORMATION ON FIRES IN GENERAL THAT OCCUR IN THE LOS ANGELES AREA

Figure 14 shows the number of fire stations within Los Angeles County that are available to serve in case of a next great event. Table 9 shows that there are 367 fire stations and a total of 385 engine companies within the area.

Los Angeles County encompasses some 4,070 square miles of area including approximately 1,058 square miles occupied by the Angeles National Forest. The Los Angeles County Fire Department serves more than one-half of the total area within Los Angeles County.

There are a total 834,316 housing units within Los Angeles County served by the county fire department. These housing units shelter some 2,592,808 residents for a ratio of about 3.1 persons per housing unit. In 1986 the Los Angeles County Fire Department attended 12,090 fires broken down by type:

Structures	2,702
Vehicles	4,068
Rubbish	3,029
Brush/Grass	1,917
Outside Storage	33
Miscellaneous	341
TOTAL	12,090

Other incidents attended by the Los Angeles County Fire Department excluding paramedic rescues include 19,621 events for a total 2,643 events attended in every month for an average of 87 per day for 142 engine companies. This would imply that the 385 engine companies scattered throughout the county, as a routine, service 236 calls per day on average of which 90 are fires and 20 are structural fires.

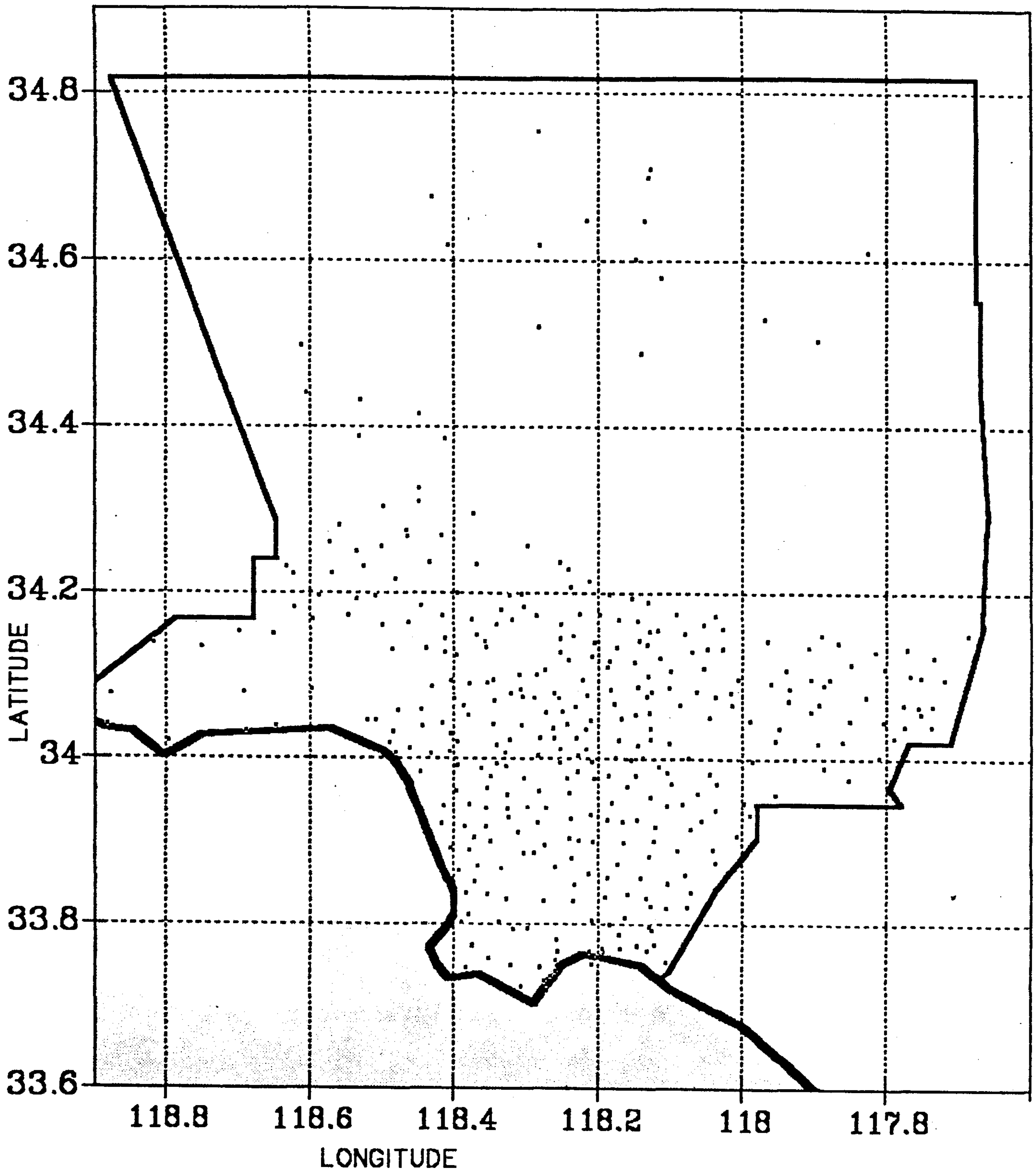


Figure 14. Fire Station Locations Across Los Angeles County.

TABLE 9
FIRE PROTECTION STATISTICS

FIRE DEPT.	NO. OF STATIONS	ENGINE COMPANY*	SQUARE AREA	POPULATION
L.A. CITY	100	100**	463.70	3,210,600
L.A. COUNTY (WITH 46 CITIES)	128	142	2165.00***	2,591,808
ALHAMBRA	4	4	7.69	71,100
ARCADIA	3	3	11.25	48,600
BEVERLY HILLS	3	4	5.69	33,300
BURBANK	6	6	17.13	3,400
COMPTON	4	4	10.50	90,100
COVINA/WEST COVINA	8	8	21.00	133,100
CULVER CITY	3	3	4.89	39,200
DOWNEY	4	4	12.80	85,400
EL MONTE	4	4	10.00	92,500
EL SEGUNDO	2	2	5.47	13,752
GARDENA	2	2	5.16	49,000
GLENDALE	9	9	30.42	152,000
HAWTHORNE	3	3	5.58	59,400
HERMOSA BEACH	1	1	1.36	18,700
INGLEWOOD	4	4	9.10	101,300
LA HABRA HEIGHTS	1	1	6.30	4,786
LA VERNE	2	2	7.29	23,508
LONG BEACH	22	24	49.66	389,400
LYNWOOD	2	2	5.00	54,200
MANHATTAN BEACH	2	2	3.86	33,900
MONROVIA	1	1	13.80	32,800
MONTEBELLO	3	3	8.20	57,800
MONTEREY PARK	3	3	7.32	59,900
PASADENA	8	8	23.00	129,100
POMONA	8	8	22.85	109,700
REDONDO BEACH	2	2	6.02	62,700
SAN GABRIEL	2	2	5.10	32,200
SAN MARINO	2	2	3.75	13,307
SANTA FE SPRINGS	4	4	8.76	15,300
SANTA MONICA	4	5	8.30	94,300
SIERRA MADRE	2	2	16.60	10,837
SOUTH PASADENA	1	1	3.44	23,900
TORRANCE	6	6	20.50	137,600
VERNON	4	4	5.06	90
TOTAL	367	385	3011.55	8,078,588

* Does not include truck companies or resuce squads.

** Has 53 single engine companies and 47 task forces, - task force is composed of 2 engines (pumpers) and one truck (aerial ladder or platform tower).

*** Los Angeles County total area is 4070 Sq. Miles with the Angeles National Forest occupying approximate 25% of the total.

CRISIS MANAGEMENT corporation

Property losses other than vehicles, as a result of fire, amounted to $51,283,000 in 1986 for a total of over $140,000 per day. This averages to about $436,000 per day for all fire departments in the county. In comparison, the total earthquake losses experienced from fires on October 1, 1987, was $488,530 (not counting the Los Angeles Water & Power fire). This is comparable to the average daily losses experienced by all fire departments in the county.

Therefore, it can be seen that neither the Los Angeles City nor the Los Angeles County or any other city fire department was extended by actual fire ignitions, on the date of the earthquake. That is not to say that a large number of calls were not received. They were. There were a number of false reports; there were a number of gas leaks that had to be turned off; as well as a number other non-life threatening or property threatening events which were attended to. However, Figure 15 illustrates that October of 1987 for the Los Angeles County Fire Department was no different than any other month. This mirrors the experience of the Los Angeles City Fire Department mentioned earlier on page 4.

In the discussion about the various parameters affecting conflagration, response time was called out. We quizzed the Los Angeles County Fire Department at length regarding the average response time for battalions scattered throughout the county. With the exception of Battalion 6 and Battalion 11, which are scattered in lowly populated regions, the average response time, based on 25 miles per hour average speed, was three and one half minutes. This is considered to be conservative, since they believed that 35 miles per hour was a better average speed to be used, as can be shown in Figure 16.

Based on the number of fire stations, number of engine companies, the average 3 1/2 minute response time to fires and given uncluttered communications and streets, we believe that the conflagration potential, for the City of Los Angeles in the next major event is low.

For example, if an M = 8 or greater earthquake occurs on the San Andreas fault, thirty-seven miles from downtown Los Angeles, (the Federal Emergency Management Agency (1980) estimates the annual likelihood = 3%) the intensity of VIII or greater for all of Los Angeles County might be used as an approximate average level of shaking. For no ground breakage (since the fault is 37 miles away) the average ignition rate is 2.6 per 100,000 persons. When multiplying this by 8,000,000 people, a total of 208 ignitions is computed. These 208 ignitions would be serviced by 367 fire stations or 385 engine companies (please note that there are more than one engine per engine company in many instances, as well).

These data would indicate that there are about two engine companies to service one average ignition due to quake caused fires alone. Add to this the 90 fires per day attended to by all fire departments within the county, there is still more than one engine company available per ignition. If during the emergency vehicle fires were not attended then there would be 268 fires for 385 engine companies for a ratio of 1.43 engine companies per fire.

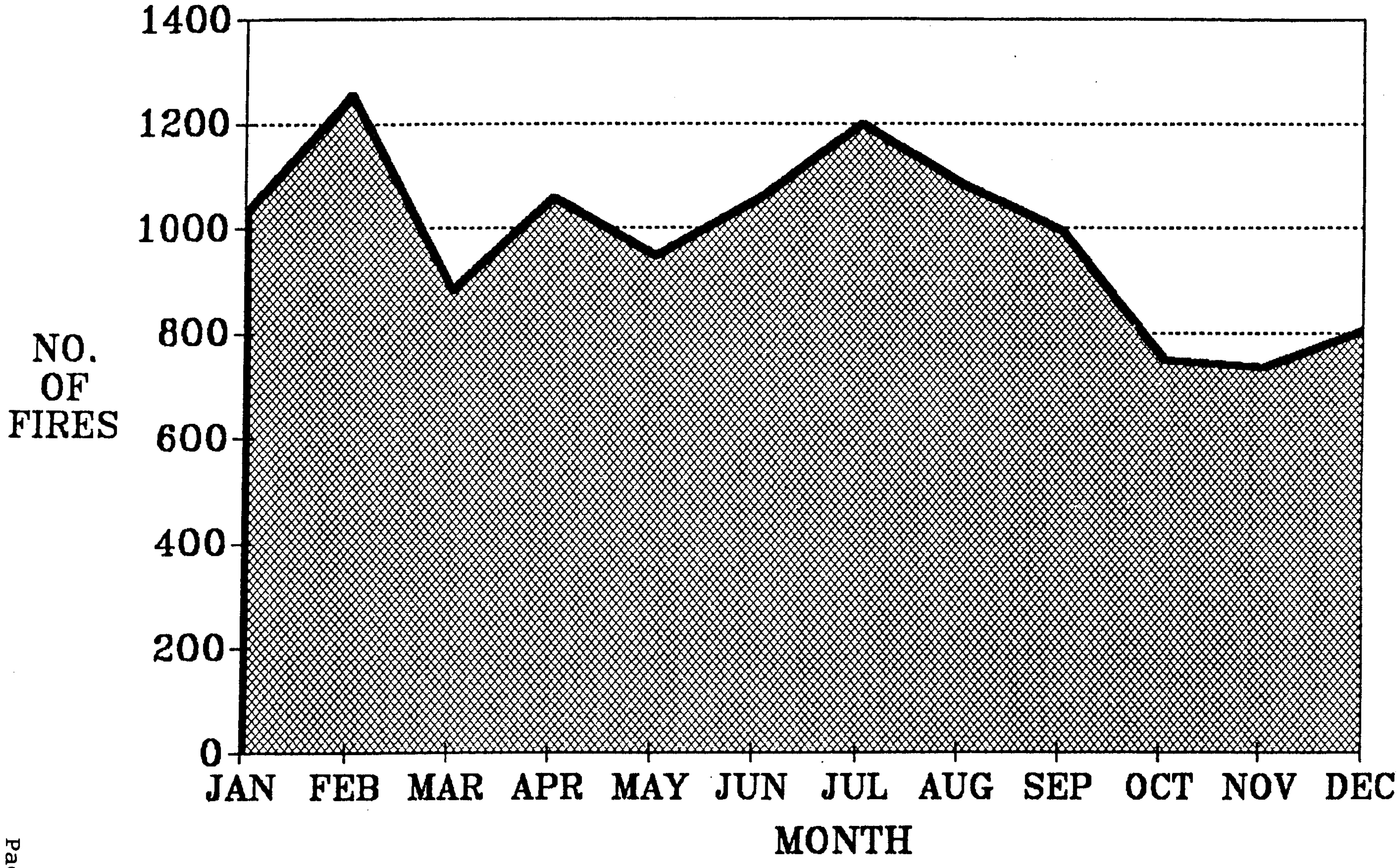


Figure 15. Total Monthly Fires for Los Angeles County Fire Department Domain.

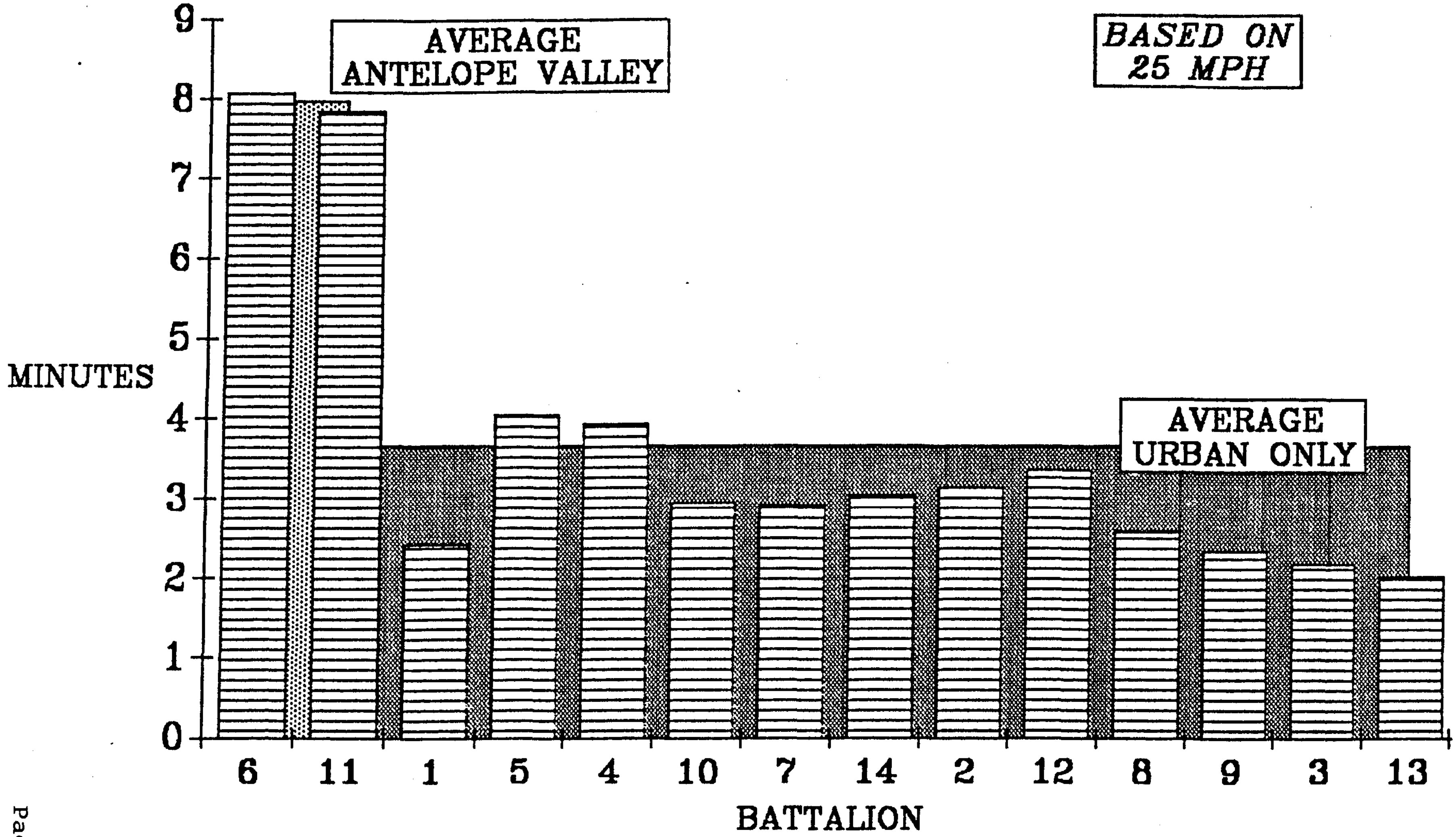


Figure 16. Average Response Time for the Los Angeles County Fire Department for Each Battalion.

Should personnel be depleted for search and rescue purposes the effective number of engine companies might be reduced and the ratio made smaller yet. Add the possibility of fire station failures, as well as dry and windy conditions and conflagration could be a highly unlikely but real condition.

Local earthquakes are expected to occur somewhere in or about Los Angeles County in accordance with the following listing:

Local Magnitude	Annual Probability of Occurance %
≥ 5.0	30
≥ 6.0	4
≥ 7.0	0.5
7.5	0.2

These probabilities were computed from past earthquakes reported in the county over the last 87 years.

A worst case scenario might occur for a local earthquake (M=7.5) occurring on the Newport-Inglewood fault or the center of major population. (Scawthorn (1987) assumed an earthquake of M=6.5.) The Federal Emergency Management Agency (1980) estimates the annual likelihood of this to be (0.1%). Although this is considered highly improbable and maybe impossible, considerable ground breakage could be expected with the accompanying increase in fire ignition rate. Assuming that 500,000 persons would experience intensities of VIII or greaterincluding ground breakage, and the remaining 7.5 million persons would experience intensities VIII and greater without ground breakage and using the two ignition rates with and without ground breakage for VIII and greater, 229 ignitions are computed.* Adding these to the 90 fires that would occur ordinarily, a total number of fires in the one earthquake day would be 319. Obviously, this event is pushing the conflagration potential even further than the San Andreas event.

With proper planning, limiting the use of communications channels, having one company attend more than one fire, as well as all fire departments for the various cities and county working together, it is believed that even in this extreme scenario all ignitions could be handled. Further, if the citizenry is alerted to the need for them to have proper fire extinguishment equipment and materials on premises, the number of these

---

* Scawthorn (1987) computed an ignition total in Los Angeles County of 423 for an M = 6.5 earthquake on the Newport-Inglewood fault. The corresponding rate is 6.2/100,000 persons, and the average intensity is VII. Remember that the San Fernando earthquake caused 109 ignitions and was of similar size. It occurred, however, in a slightly more favorable geographic position.

ignitions can be dealt with by people on the spot. During the Whittier event several fires were knocked down by persons using garden hoses.

Nevertheless, a severe event on the Newport-Inglewood fault would severely test the fire fighting abilities of all city and county fire departments. We have been assuming that all fire houses are left intact. This may not be the case. There may not be 385 available engine companies. Further, if the weather were hot and dry and the wind strong, a complicating situation would be presented.

8.0 CONCLUSIONS

1. There were a total of 38 ignitions during the Whittier Narrows earthquake of October 1, 1987. 7,200,000 persons were included within the MMI $\geq$ VI area in which fire ignitions are most likely to take place.

2. Figure 17 illustrates the fire ignition versus Modified Mercalli Intensity situation for two estimates of MMI during the Whittier Narrows Earthquake.

3. Approximately half of the ignitions were gas or gas equipment related, whereas the other half were electrical related. This compares favorably with the 1971 San Fernando event.

4. With the exception of the area that was broken by the fault in the 1971 San Fernando event, the fire ignition rates for the Whittier Narrows and the San Fernando events compare favorably. The Whittier Narrows rates are lower, if they are computed using the CMC isointensity map. The ignition rate propensity may have decreased in the last 16 years.

5. The fire ignition data from the Whittier Narrows event compares with the scatter range for fire ignitions from 11 other, post 1939 earthquakes.

6. The fire ignition rate for Modified Mercalli Intensity zone VI is expected to be about 0.21 per 100,000 persons; in Intensity Zone VII, about 0.83 ignitions per 100,000 persons.

7. Without significant ground breakage, the number of ignitions per 100,000 persons in intensity zone VIII and greater is expected to be about 2.6 per 100,000 persons; in areas of intensity equal to or greater than VIII within which ground breakage has taken place, the number of ignitions can triple.

8. The number of ignitions expected from maximum credible events in the Los Angeles basin may exceed the number of engine companies available.

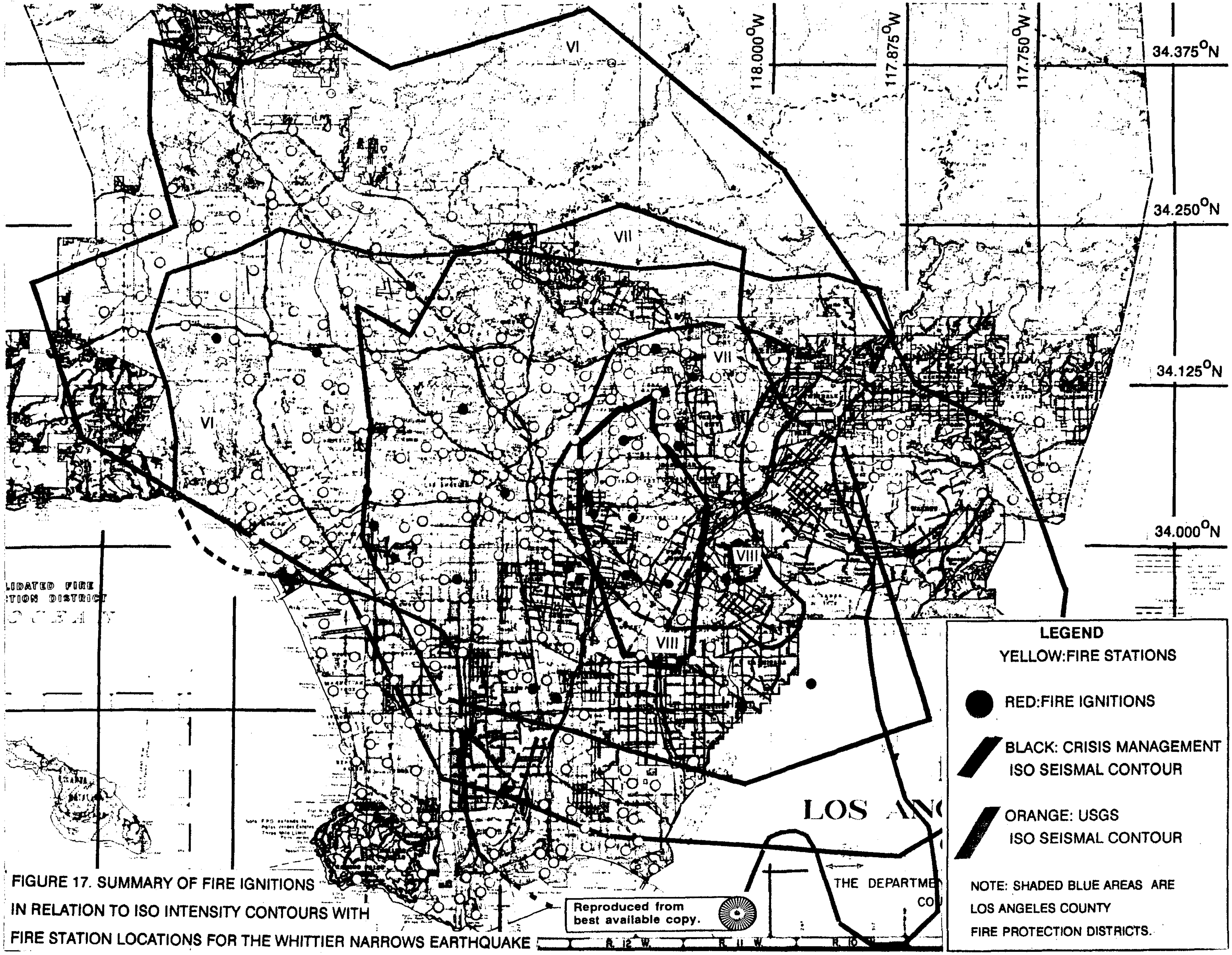


FIGURE 17. SUMMARY OF FIRE IGNITIONS IN RELATION TO ISO INTENSITY CONTOURS WITH FIRE STATION LOCATIONS FOR THE WHITTIER NARROWS EARTHQUAKE

9.0 RECOMMENDATIONS

1. Fire departments need to develop means for clearing their radio communications frequencies during major emergencies so that the more important information can be transmitted. This information should also be dealt with by a prioritization plan developed before the event.

2. The less important fires during a maximum credible earthquake as well as the calls other than structural or grass fires need to be screened so that the most important problems can be attended to first.

3. A better indicator of ignition rate than the "per 100,000 persons" indicator used in this study should be developed. Since gas and electrical sources are the principle types of causes, some unitizing which is a function of gas hookups, electrical connections, etc. should be devised.

4. People should be encouraged to have fire fighting equipment on premises which can be used by laymen. Some fire suppression training materials should be made generally available so that individual fires can be dealt with rapidly by on-the-spot personnel.

PF\NS202001.doc

CRISIS MANAGEMENT corporation

1650 South Pacific Coast Highway
Redondo Beach, California 90277 U.S.A.
(213) 316-2257
FAX (213) 316-2389

REFERENCES

Applied Technology Council, Earthquake Damage Evaluation Data for California, Prepared for the Federal Emergency Management Agency under Contract Number.EMW-C-0912 (1985).

Bennett, John H. and Roger W. Sherburne, Editors, The 1984 Morgan Hill, California Earthquake, Special Publication 68 California Department of Conservation, Division of Mines and Geology (1984).

Bonilla, M.G., Historic Surface Faulting, Intercontinental United States and Adjacent Parts of Mexico, U.S. Geological Survey, (1967).

Culver, Charles, et. al, Natural Hazard Evaluation of Existing Buildings, National Bureau of Standards, BSS#61 (1975).

Federal Emergency Management Agency, An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken, FEMA, Washington D.C., (November, 1980).

Hafen, Douglas and Frederick C. Kintzer, Correlations Between Ground Motion and Building Damage, Engineering Intensity Scale Applied to the San Fernando Earthquake of February 1971, Report Number URS/John A. Blume and Associates Engineers, Prepared Under Contract EY-76-C-08-0099 (November, 1977).

Huang, M. J., et al., CSMIP Strong-Motion Records from the Palm Springs, California Earthquake of 8 July, 1986, California Division of Mines and Geology, Report Number OSMS86-05 (1986).

Huang, M. J., et al., CSMIP Strong-Motion Records from the Superstition Hills, Imperial County, California Earthquakes of 23 & 24 November, 1987, Report Number OSMS87-06, California Department of Conservation, Division of Mines and Geology (24 December 1987).

Huang, M. J., et al., CSMIP Strong-Motion Records from the Palm Springs, California Earthquake of 8 July 1986, Report Number OSMS86-05, California Department of Conservation, Division of Mines and Geology (6 August, 1986).

Jennings, Paul C., Editor, Engineering Features of the San Fernando Earthquake of February 9, 1971, Report Number EERL71-02, California Institute of Technology Earthquake Engineering Research Laboratory (June 1971).

Jones, Barclay G. and Nicolaides, Costakis N., "Buildings at Risk in the Whittier Narrows, California, Earthquake, October 1, 1987," Earthquake Spectra Vol. 4, #1 (February, 1988).

Jones, L.N. and E. Hauksson, "The Whittier-Narrows California Earthquake of October 1, 1987 Seismology," Earthquake Spectra Vol. 4, #1 (Feb. 1988).

Joyner, William B., et al., Peak Horizontal Acceleration and Velocity from Strong-Motion Records Including Records from the 1979 Imperial Valley, California, Earthquake, U.S. Geological Survey Open-File Report 81-365 (March 1981).

Leyendecker, E.V., et al., "The Whittier-Narrows, California Earthquake of October 1, 1987, Early Results of Isoseismal Studies and Damage Surveys," Earthquake Spectra Vol. 4 # 1 (February 1988).

Manning, Donald O., A Report by the Los Angeles City Fire Department on the Whittier Narrows Earthquake of October 1, 1987, Los Angeles Fire Department (Released April, 1988).

Rand McNally, 1987 Commercial Atlas and Marketing Guide, 118th Edition," Published by Rand McNally Corporation, Chicago, New York, San Francisco (1987).

Reitherman, Robert, "Fire Departments and Earthquakes," Manuscript Unpublished (1986).

Scawthorn, Charles, Fire Following Earthquake, Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles, and San Francisco, All-Industry Research Advisory Council, Oak Brook, Illinois 60521 (March, 1987).

Scholl, Roger E. and James L. Stratta, Editors, Coalinga, California, Earthquake of May 2, 1983, Reconnaissance Report Published by the Earthquake Engineering Research Institute (January 1984).

Shakal, A. F., et al., Process Data from Strong-Motion Records of the Morgan Hill Earthquake of 24 April 1984, Part I Ground-Response Records, Report Number OSMS85-04, California Department of Conservation, Division of Mines and Geology (May 1986).

Shakal, A. F., et al., CSMIP Strong-Motion Records from the Whittier, California Earthquake of 1 October 1987, Report Number OSMS87-05, California Division of Conservation, Division of Mines and Geology (October 31, 1987).

Steinbrugge, Karl V., et al., San Fernando Earthquake, February 9, 1971," Pacific Fire Rating Bureau (August 10, 1971).

Strand, Carl L., Summary Catalog of Post-Earthquake Structural Damage Caused by Gas Leaks and Related Incidents, Copyright 1988, by Carl L. Strand (April 18, 1988).

U.S. Geological Survey Professional Paper 733, The San Fernando, California, Earthquake of February 9, 1971, Published by the U.S. Geological Survey (1971).

U.S. Geological Survey Professional Paper 1254, The Imperial Valley, California Earthquake of October 15, 1979, Published by the U.S. Geological Survey (1982).

U.S. Bureau of the Census, Population Statistics for Years Varying from 1940 Through 1987.

Wiggins, John H., Evaluation of the All-Industry Research Advisory Council Report Entitled: Fire Following Earthquake: Estimates of the Conflagration to Insured Property in Greater Los Angeles and San Francisco, By: Dr. Charles Scawthorn, Dames and Moore, March 1987, Prepared for Industrial Indemnity, San Francisco, California (October 29, 1987).

Wiggins, John H., Effect of Soft Surfical Layering on Earthquake Intensity, Civil Engineering Studies, University of Illinois, Structural Research Series #216 (May 1961).