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A SIMPLIFIED ESTIMATION OF FIRE LOSS FOLLOWING EARTHQUAKES

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ABSTRACT

A new methodology to estimate the potential loss due to fire following earthquakes (FFE) is described in this paper. The methodology is adapted from Hamada's model for FFE losses in Japan, but is calibrated with U.S. data including data from the Loma Prieta earthquake of 1989. The three major phases of a fire are included in the model: Ignition, spread, and suppression with and without wind effects. The burnt area is computed at the zipcode level, from which the residential and commercial real estates affected are inferred and their value estimated based on square footage cost. A computerized system is used to generate probabilistic simulation results on FFE losses for major U.S. cities. Regression techniques are used to quantify the relationship between FFE loss and ground shaking intensity, and to generate a simplified equation which can be universally applied to all points in the U.S. Limited comparison with previous case studies shows good agreement in loss estimates.

KEYWORDS

Fire Following Earthquake, Simulation, Fire Loss

INTRODUCTION

Fires following earthquake can cause extremely severe losses which may sometimes outweigh losses from the direct earthquake damage such as collapse of buildings and disruption of lifelines. For example, in the Kanto earthquake of 1923, Tokyo suffered burnt damage of 34.7 sq. km, and in the 1906 San Francisco earthquake, it is estimated 80% of the damage is from subsequent fires. Though there is much progress in the city planing and fireproofing of modern structures, this problem still exists for the large cities such as Tokyo, San Francisco etc. where there are high earthquake potential , dense urban development and large number of wooden structures. The recent examples are the fires in the Marina District of San Francisco caused by the 1989 Loma Prieta earthquake and the fires in Kobe and Osaka by the 1995 Hanshin earthquake.

It is well known that the estimation of fire loss following earthquakes is a very complicated process and many factors affect it including ignition source, building type, wind conditions, functionality of water systems and fire suppression responsiveness etc. So one way to estimate it is just by using the popular simulation method which will need a lot of input data such as seismic intensity, building area , fire engine number and firebreak width etc. This will become a formidable task for the user, especially when one wants to analyze one large portfolio. So in this paper an efficient methodology is developed for estimating the fire loss following earthquakes on the regional scale. The new method is easy to operate and user friendly.

METHODOLOGY

FFE Simulation Method

The simulation includes two parts. First, the burnt area is estimated based on the probable number of ignition sources and the extent of the spread of the fires in the face of suppression and wind condition. Based on the burnt area in each zipcode, the residential and commercial dwelling areas affected are estimated, and a price tag obtained for the loss. Space limitation permits only a summary of the highlights, and details are referred to [1].

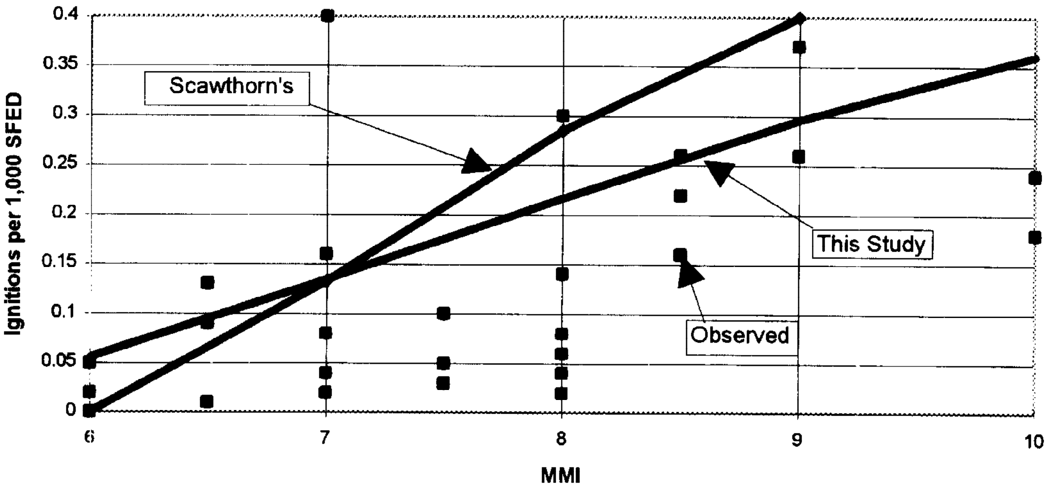

Figure 1. Fire ignitions in United States earthquakes (1906-1989).

Number of ignition-The ignition model estimates the number of ignitions from previous earthquakes in the U.S. including the recent Loma Prieta event. The number of FFEs are established by counting the actual FFEs per 1 million sq.ft. of structure inventory, as a function of the ground shaking intensity (MMI) experienced by the zipcode. Figure 1 summarizes the data for U.S. earthquakes from 1906-1989. Note the considerable scatter in the data, which is representative of the state of uncertainty. A second order regression fit to the data is also superimposed in the figure for reference purpose; correlation between the fit and data is quite low, confirming that MMI is by itself not a perfect indicator of fire ignitions. The model used by Scawthorn in [2] is also included for comparison.

Spread-The fire spread model is based on Hamada's work for urban Japan (Hamada,1975) , and its essence is given by the following equation:

$$N_{tV} = \frac{1.5\delta}{a^2} * K_s * (K_d + K_u) \qquad (1)$$

where $N_{t\,V}$ is number of structures fully burned, t is time in minutes after initial ignition, V is wind velocity in meters per second, δ is "built-upness" factor, dimensionless, a is average structure plan dimension in meters, K_s is half the width of fire from flank to flank in meters, K_d is length of fire in downwind direction from the initial ignition location in meters and K_u is length of fire in upwind (rear) direction from the initial ignition location(K_s, K_d and K_u are as defined in Figure 2).

It is well known that the Hamada model gives different fire spreading rates in the downwind, sidewind, and upwind directions even for zero wind speed. To correct this defect, a linear interpolation function is introduced to force the fire spreading rates to be equal in all directions as the wind speed approaches zero.

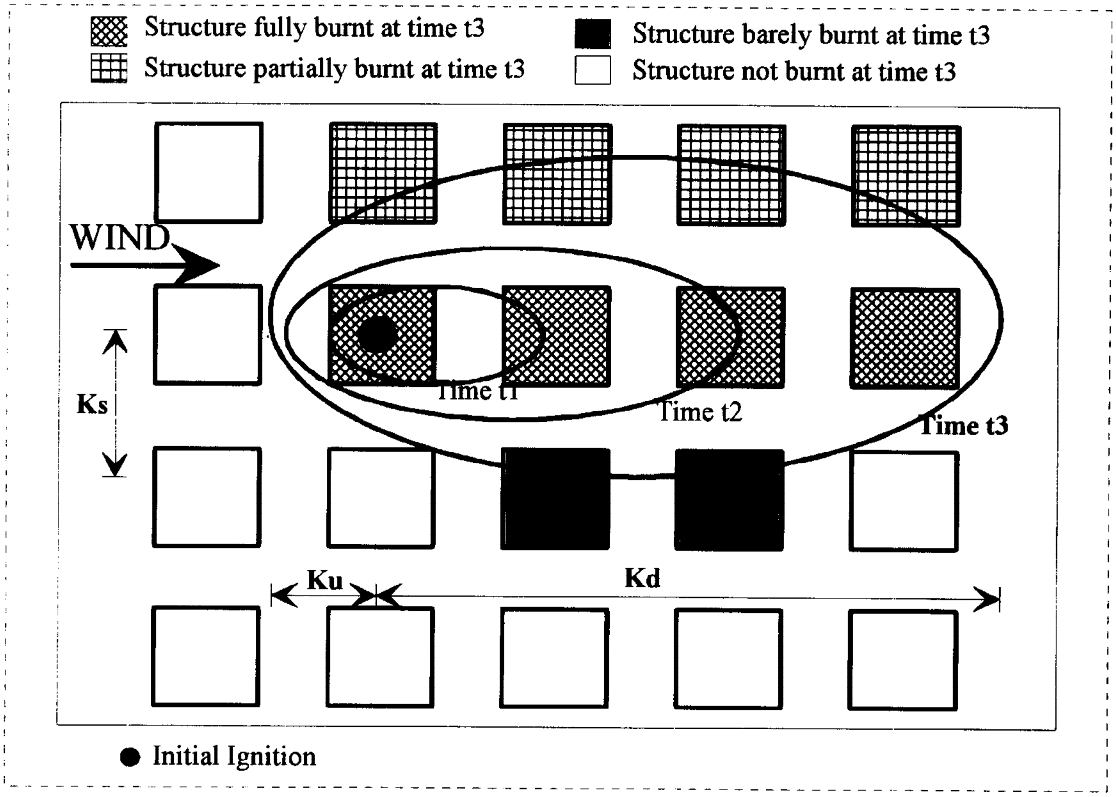

Figure 2. The fire spreading process.

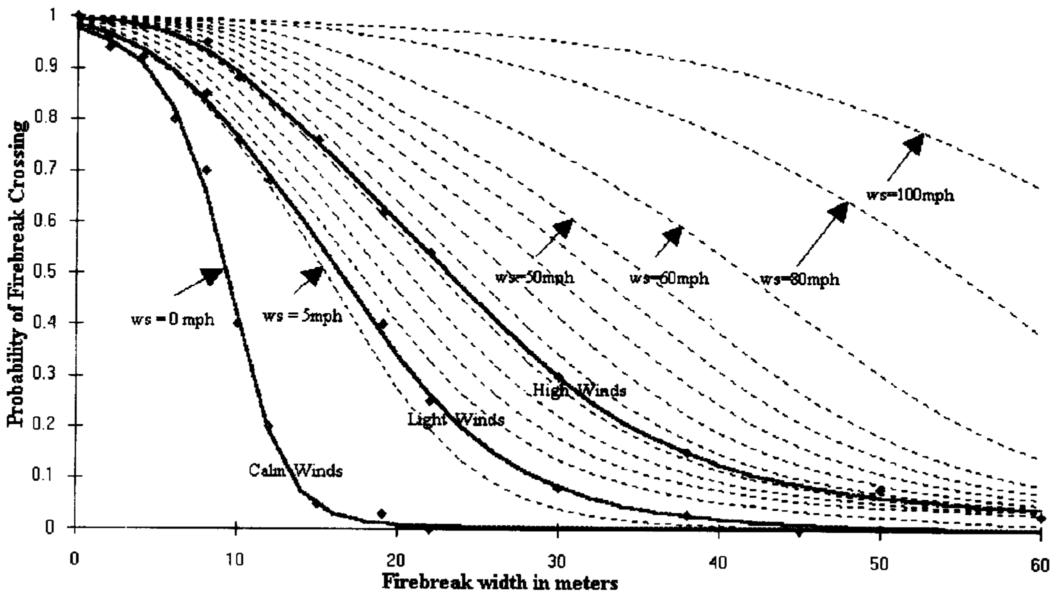

Figure 3. Neural network representation of the crossing probability with suppression

Suppression - Suppression refers to all efforts to extinguish a fire, beginning with its discovery. Its major components are: discovery, report, arrival and control. Furthermore, control time depends on the class of fire and whether the required fire-fighting resources are available. Suppression is incorporated into the fire spread model to give the spread rate, which is the key variable in the FFE model. The effect of fire-breaks is also considered. The probability of a fire jumping a fire break increases with wind velocity, decreases with the width of the break, and decreases with active fire suppression as shown in Fig.3.

Built-in Database

The major FFE related databases include wind conditions, population, building inventory and real estate values . Wind conditions are used in fire spread estimates, and building inventory/value are used in computing losses. Population data are used to determine building density as well as number of fire engines when such information for a locale is not available. We describe the wind database for illustration.

The wind database is provided by EarthInfo [4]. The entire U.S. is divided into 12 regions, and we have selected 20 major cities from these regions as the baseline. The baseline data cover the period from 1948-1992 and contain records at 375 stations throughout the U.S. We sorted and compiled these data to generate the probability of exceedance of wind speed for selected wind speeds for use in the simulation. Figure 4 shows the wind profile generated for one major city , and is representative of the results obtained.

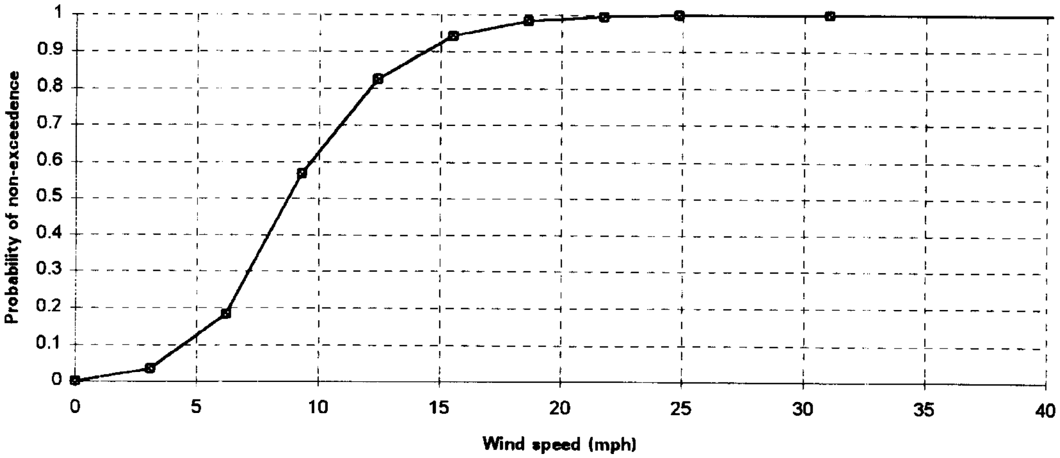

Figure 4. Sample probability of exceedance curve for wind speed of one major city

Estimation of Fire Loss

The FFE kernel is used to generate probabilistic simulation results on FFE losses for major U.S. cities. From these results, regression techniques are used to quantify the relationship between FFE loss and ground shaking intensity,and to generate a simplified equation which is then universally applied to all points in the U.S. This strategy is necessary because for a large country such as the U.S., using the FFE kernel to estimate losses for each county (or even city) will consume an enormous amount of effort but, more importantly, such a direct method is not justified in view of the approximate nature of the kernel algorithm and the scarcity of information. For most locales, the information required by the kernel is incomplete or simply unavailable.

Accordingly, for each of the major cities three seismic maps are generated to define its (FFE) loss sensitivity to seismic intensity. One seismic map is generated using the maximum credible event for the region. The second and third maps are generated based on the first, with the intensity in each zipcode reduced by 0.5 and 1 unit, respectively. If these three levels of intensity do not bracket the reference intensity 9 (MMI IX), the intensities of the maps are raised proportionally until the highest intensity reaches 9.5. The need for doing so will be apparent shortly.

For each intensity map, the fire loss for each block in the city is simulated using the kernel for selected wind speeds of 0, 5, 7.5, 10, 12.5, 15, 20 and 25 mph. For each wind speed, six seed numbers are used to simulate the randomness of fire ignition, the difference in fire suppression effectiveness, etc. A sample simulation output from the kernel is shown in Fig.5. From these results, the average fire loss for given wind speed and that for all wind speed are obtained.

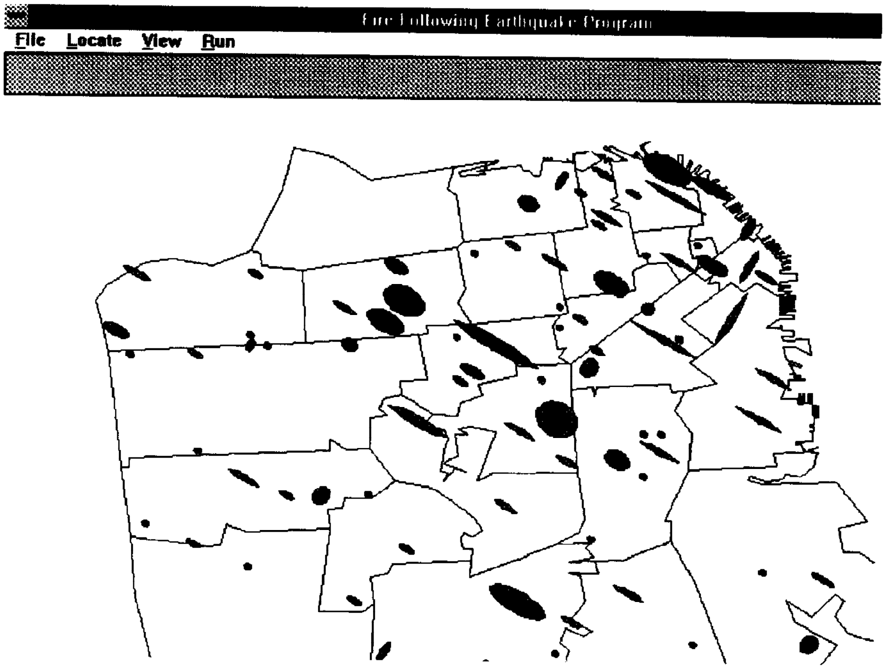

Figure 5. Sample simulation results of burnt area (San Francisco shown).

Losses for zipcodes in the city with the same intensity are weighted by the building area of the zipcode, summed and averaged to arrive at the weighted average fire loss ratio (called simply, the fire ratio) in a region. This ratio gives the percentage of a unit building area that is burnt, and is found from simulation results to vary almost linearly with intensity for all major cities. It is based on this finding that a simple equation for fire loss is formulated:

$$FLI = \begin{cases} 0 & \text{if } MMI \le 6.5 \\ FLI\dfrac{(MMI - 6.5)}{2.5} & \text{otherwise} \end{cases} \qquad (2)$$

where FLI is the fire loss at reference intensity IX referred to previously; it is the normalization parameter for the equation, and, hence, will be called the fire loss index. Note that FL may stand for the loss ratio at a given wind speed, or the loss ratio averaged over all wind speeds corresponding to what FLI represents.

Fire loss computed by Eq.2 is further modified for the effects of wind in two ways. If the wind speed is known, a wind-speed modification factor based on averaged simulation results for the major U.S. cities is used to quantify its effect. On the other hand, if the prevalent wind speed is not known, simulation results for the canonical wind speeds of 5 mph, 10 mph, etc. are combined with the probability distribution of wind speed (such as shown in Fig.4) to compute the expected fire loss and its variance.

To extend Eq.2 to parts of the country other than the major cities, the corresponding FLI must be determined in the absence of the necessary databases that are available for major cities. This difficulty is circumvented by basing FLI on other parameters that are more commonly available or more uniform across the country. Building density BD and engine number ED are selected for this purpose. Accordingly, the fire loss indices for the major cities obtained previously are processed using the following regression equation:

$$FLI = a + b \cdot BD + c \cdot ED + d \cdot BD \cdot ED \tag{3}$$

Once the regression coefficients a, b, c and d are determined, Eq.3 can be applied to any locale where BD and ED are known.

COMPARISON WITH CURRENT RESULTS

Loss estimates for the scenarios and regions studied by Scawthorn (1987 [2], 1992 [5]) are generated, and the results compared in Tables 1 and 2, respectively. Estimates using our methodology compare well with previous studies; they are higher for the cases considered in [5]. One reason for the discrepancy is the higher fire ignition rate in our model mentioned previously.

Table 1. Loss Ratio for Property Value at Risk (see Ref.2).

	Loss Ratio (%)	
	This Study	Reference [2]
San Andreas (8.3)	2.33	2.60
Newport-Inglewood (6.5, Three Counties)	1.15	1.90

Table 2. Loss Ratio for Property Value at Risk (Five Counties, see Ref.5)

	Loss Ratio (%)	
	This Study	Reference [5]
San Andreas (7.8)	2.13	1.1
Hayward (7.1)	1.72	0.60
Newport-Inglewood (6.8)	1.27	0.40

CONCLUSIONS

In this paer, the fire loss is firstly estimated for 20 major cities in U.S.A. by using the simulation method. Then based on these results, the relationship between the fire loss and the major parameters affecting the fire loss following earthquake is obtained by regression, which can be universally used all over U.S.A.. This methodology is efficient and doesn't require the user of the detailed information related to the fire hazard such as local building area, local fire departments and types and availability of water systems etc. as they are already considered in the fire loss index. Then based on the fire loss index, the fire loss for any kind of complicated porfolios can be obtained by using the simplified equation.

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