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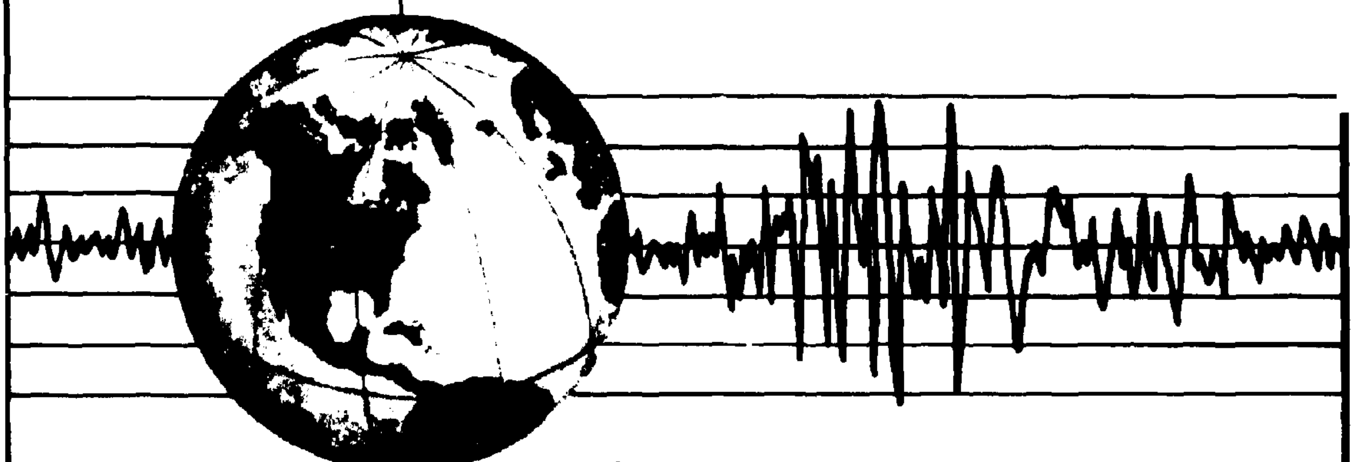
EARTHQUAKE ENGINEERING RESEARCH CENTER

EARTHQUAKE RISK AND INSURANCE

by

DAVID R. BRILLINGER



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EARTHQUAKE RISK AND INSURANCE

by

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This report is based on a Special Lecture
presented at Environmetrics '92
Helsinki, Finland

Report No. UCB/EERC-92/14
Earthquake Engineering Research Center
C ollege of Engineering
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ABSTRACT

Concern is with protection against natural catastrophes through financial insurance. Development of appropriate premium rates requires consideration of a wide variety of variables entering into the occurrence of the disaster and a broad range of scientific and statistical investigations result. Topics discussed include: premium computation, distribution of large earthquakes in time, ground motion at sites, attenuation of energy with distance, damage description and actual practice in various countries. Statistical considerations that arise include: description, stochastic modelling, conditioning, spatial processes, (marked) point processes, uncertainty estimation and robust/resistant procedures. Study of the insurance problem is scientifically enlightening because it requires one to focus on the whole context of the problem; geology, seismology, earthquake engineering, damage.

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1. INTRODUCTION

Statistics has a long involvement with problems of risk and insurance. This occurs because of variabilities, because of uncertainties, because of estimation problems and because of choice of loss functions. Many of the techniques of contemporary statistics appear useful in problems of insurance. In this report there are considerations of: description, stochastic modelling, conditioning, (marked) point processes, spatial processes, robust/resistant procedures and uncertainty estimation. The basic approach is via conceptual modelling and data analysis, in contrast to a "black box" approach.

Preliminary to the problem of determining an earthquake insurance premium is that of seismic risk assessment. Seismic risk assessment may be defined as the process of estimating the probability that certain performance variates at a site of interest exceed relevant critical levels, within a specified time period, as a result of nearby seismic events. The seminal paper on the topic is Cornell (1968). Other basic works are: Vere-Jones (1973), Lomnitz (1974), McGuire (1974), Walley (1976), Blume and Kiremidjian (1979). Addressing the insurance issue forces consideration of more than a risk problem, one needs to consider the whole sweep of geology, seismology, earthquake engineering and damage.

Generally speaking the techniques employed are applicable to other environmental risks, that is to other small probability events with substantial negative consequences.

Much of this report is review of existing material, but some new scientific results are included. In particular an automatic method of constructing isoseismal maps, employing commercially available software, is presented and new expressions relating modified Mercalli intensity to maximum acceleration are derived. It is clear that a variety of interesting statistical and actuarial problems arise.

A general reference for the background seismology is Chapter 17 of Bullen and Bolt (1985). Some elementary expressions for premiums are developed in an Appendix to this report.

2. INSURANCE

Financial insurance is one means our society has devised for alleviation of disasters. There are two distinct formal procedures for setting premiums: first, via specific formulas based on a conceptual model (Richard (1944), Beard et al. (1969), Freifelder (1976), Goovaerts et al. (1984), Sundt (1984), Heilmann (1988), Straub (1988)) and secondly, via the black box (control theory, time series) approach (Bohman (1979), Norberg (1990), Aase (1992)). A concern in the black box approach is that the nonstationarity of the basic quantities may make it difficult to determine parameters of relationships. This report will concentrate on the conceptual approach.

A variety of formulas have been proposed for the determination of premiums, assuming that a random loss may have to be compensated for. Basically a company wants income to approximately equal outgo. The problem is sensibly focussed to two crucial components, Smolka and Berz (1991);

- calculation of a premium commensurate with the risk,
- estimation of the size of the probable maximum loss resulting from a potential catastrophe.

To be specific, consider a time period of one year and suppose that the yearly possible loss is a random amount U. (Interest considerations will be ignored.) The *pure risk premium* for a year's insurance is given by

$$P = E\{U\} = \mu_U \tag{1}$$

Because of expenses, the pure premium will have to be "loaded" and for example the premium taken to be

$$P = (1 + \alpha)\,\mu_U \tag{2}$$

The multiplier $(1 + \alpha)$ has the effect, above handling expenses, of providing some protection against random fluctuations in loss beyond the average $E\{U\}$.

Other premium formulas that have been suggested, and that take note of random fluctuations, are

$$P = \mu_U + \beta\sigma_U \quad \text{and} \quad P = \mu_U + \gamma\sigma_U^2 \tag{3}$$

with $\beta, \gamma > 0$. The latter has the property of being additive for independent risks, see Straub (1988).

A further procedure for determining premiums is to select some acceptable, probability of ruin ε and, supposing that a reserve of R is available, determine the premiums such that

$$Prob\{S_U > R + S_P\} \le \varepsilon \tag{4}$$

where S_U and S_P denote the sums of claims paid out and premiums paid in, respectively, during the year. References to the computation of ruin probabilities are: Beard et al. (1969), Freifelder (1976), Heilmann (1988), Grandell (1991). In the Appendix, the form of (1) - (4) for the case of rare events is considered.

Insurance, for the particular case of earthquakes, is discussed in Straub (1973), Vere-Jones (1973), Lockett (1980), Grases (1986), Porro (1989) and Munich Re (1991).

3. STRATEGY

The usual approach to seismic risk assessment, defined in Section 1, is to break the problem down into basic components that may be investigated individually. This multistage analysis requires critical investigation of four pieces: (a) sources of events, (b) intermediate transmission of energy from the sources, (c) the locai site and (d) the particular facility of concem. The earthquakes may be thought of as originating at points, on lines or within zones (the geometry). They will have different sizes and occurrence times. The intermediate transmission of the seismic signal involves attenuation of energy with distance and depends on the media traversed. Aspects of the local site include geology and ground type. In some studies the dynamic response and resistivity of the structure of interest are modelled. The fields of geology, geophysics, seismology and engineering are ali involved.

In a naive assessment one might postulate: (i) that there is a single source with the point process of events Poisson of rate μ and with earthquake magnitudes distributed exponentially, $(Prob\{magnitude > M\} = \exp\{-\beta M\})$, (ii) that intensity of motion falls off with magnitude and distance in accordance with

$$I = \beta_0 + \beta_1 M + \beta_2 \log d + noise \tag{5}$$

d being the source to site distance and *noise* being a normal variate with mean 0 and variance σ^2, and (iii) that the behavior of the structure is effectively described by I. The risk may be evaluated explicitly in this case as

$$Prob\{intensity\ i\ exceeded\ within\ time\ period\ of\ u\}$$

where

$$G(i) = \exp\{-(i-\beta_0-\beta_2 \log d)\beta/\beta_1 + \frac{1}{2}\sigma^2\beta^2/\beta_1^2\}$$

It needs to be mentioned that each of these assumptions is debatable and that variants have been investigated.

In the insurance case one needs to continue and to model the loss that could be experienced. This may be done through the percent of damage likely to be experienced for a given building type, see discussion in Section 7.

There is a need for models, for parameter estimates and for the recognition of statistical regularities in the work.

4. TEMPORAL ASPECT

As indicated in the previous section, some means of describing the temporal rates of occurrence of damaging earthquakes is required. The basic series of times involved is often modelled by a stochastic point process. A variety of specific point process models has been suggested, see Vere-Jones (1970). When for example total damages are associated with the earthquake times, one has a marked point process.

The following is an explicit example of the development and fitting of a point process model. Pallett Creek is an area in Southern California lying by the San Andreas Fault. In Brillinger (1982) and Sieh et al. (1989) the times between large seismic events there are modelled as independent Weibull variates. A Weibull variate may be defined as follows: if x denotes the time elapsed since the preceding event, then the hazard function

$$h(x) = Prob\,\{event\ in\ (x, x+\Delta) | last\ at\ time\ 0\} / \Delta$$

for small Δ, has the form

$$\frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta-1}$$

For example, if $\beta = 1$ it is constant and if $\beta > 1$ it increases steadily with u. The reasonableness of this assumption may be assessed by a cumulative hazard plot, see Nelson (1972). Figure 1 provides such a plot based on the Pallett Creek data. One graphs the times between events and checks to see if they fall near a straight line. The Weibull assumption does not appear invalidated in this case.

A difficulty that arose for the Pallett Creek data was that in one case, it could be inferred that an earthquake had taken place between two others. The dates of the bounding two could be estimated directly, but the date of the event in between could not. This led to one observation that was the sum of two Weibulls. Also in forming the likelihood, the censorship involved in the open interval starting at 1857 and measurement error had to be taken account of. Details are provided in Sieh et al. (1989). The maximum likelihood estimates determined were

$$\hat{\alpha} = 166.1 \pm 44.5 \qquad \hat{\beta} = 1.50 \pm 0.80$$

The following risk estimate was then determined

$$Prob\{event\ in\ next\ year \mid last\ in\ 1857\}$$

with a corresponding approximate 95% confidence interval of (0.004,0.026).

5. SPATIAL ASPECT

After a sizeable earthquake many measurements of consequences are made in the surrounding regions. For example, strong motion seismometers will be examined to see if they were triggered. In the case that they were, the maximum acceleration recorded will be noted. In addition reports are received from selected observers on a verbally described scale, the scale of modified Mercalli (MM) intensities. This scale provides 12 discrete levels of increasing severity. For example the description of MM_{VIII} reads

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

There are certainly basic difficulties with the MM scale. An important one is that there are not susceptible structures at every location so that possible damage there could not be recorded. Various aspects of the MM scale are discussed in Reiter (1990) and critical remarks may be found in Steinbrugge and Algermissen (1990). Most workers seem to agree however that for damage studies it is the best thing generally available. An improved scale is suggested in Brazee (1979).

When such acceleration or intensity data are examined, there is found to be a general fall-off in severity of effect, with distance from the earthquake source, however substantial variability and irregularity are invariably present. This may be seen in Figure 4 below.

In the case of intensity data, isoseismal maps are prepared. The purpose of such maps is to show the pattern of ground-shaking and associated damage. The isoseismals are meant to be contours of equal intensity, to bound areas within which the predominant intensity is the same. The drawer seeks, for example, to draw a curve encircling all the MM VIII values, but scattered VIII's will be ignored. The drawing of the contours is highly personal, eg. Reiter (1990), p. 37 states "... drawing isoseismals can be a subjective process that may lead to different outcomes for different analysts." Bruce Bolt has emphasized to this writer a critical aspect of existing isoseismal maps, namely they are conservative in two senses. First the indicated intensity level at a location is the highest one noted. Second the isoseismals themselves are drawn as far out from the source as reasonable to include all locations with given intensity.

One intention of this paper is to indicate that it is in fact possible to employ formal algorithms to generate isoseismals. Figure 2 presents some preliminary results for the Loma Prieta, California, event of 17 October 1989. This, "World Series", disaster took place near Santa Cruz, California. It had magnitude 6.9, duration 10 seconds, and led to 63 deaths, 1300 buildings destroyed and 5.9 billion dollars damage. The largest MM intensity was IX. (Further details of the event may be found in the October 1991 number of Bull. Seismol. Soc. America.) In Figure 2 the small triangles indicate the positions of the measurements. The source of the earthquake is marked by a hexagon.

The MM intensity data analyzed are those employed in Stover et al. (1990). There were 921 observations. The isoseismals appearing in Figure 2a were prepared via the procedure "loess", described in Cleveland and Devlin (1988), or Chapter 8 of Chambers and Hastie (1992). This is a local regression procedure that smooths the data in a robust/resistant fashion. In simplest form, the "smoothed value" at the position with latitude and longitude (x,y) is $\hat{g}(x,y) = g((x,y)|\hat{\theta}_{x,y})$ where $\hat{\theta}_{x,y}$ is the value mininimizing

$$\sum_i w_i(x,y)\,[I_i - g((x_i,y_i)|\theta)]^2 \tag{6}$$

and for example $g(x,y)$ is a function assumed linear in θ and x, y. The data are intensity I_i recorded at location (x_i,y_i), for $i=1,\ldots,n$. In the loess procedure

$$w_i(x,y) = W(d_i(x,y)/d_{(q)}(x,y))$$

where

$$W(u) = (1-u^3)^3 \quad \text{for} \quad |u| < 1 \quad \text{and} \quad = 0 \quad \textit{otherwise}$$

with $d_i(x,y)$ the distance from (x,y) to (x_i,y_i) and $d_{(q)}(x,y)$ the q-th smallest of these distances. One includes in (6) a prespecified fraction q/n of the points, here 0.1. There is also a robust/resistant variant that downweights outliers. (Details may be found in Chambers and Hastie (1992)). The smoothed values, at points on a grid, are then contoured for plotting. The resultant Figure 2a is notably similar to the United States Geological Survey's officially produced map, Stover et al. (1990). The spread of the MM intensities about the smoothed values has $\hat{\sigma} = 1.09$. (The values are very scattered.) One can also obtain standard errors for the smoothed function values.

Figure 2b presents the results of the same computations for the maximum accelerations. In this case the data are taken from Boore et al. (1989). There are 266 observations. The general fall-off of strength of motion with distance from the source of the earthquake is again apparent.

The similarity of Figures 2a and 2b is noteworthy for seismologists and seismic engineers. These professionals have been concerned with relating Mercalli intensity and maximum acceleration. One reason is that intensity estimates are available for historical earthquakes for important regions, while maximum accelerations have only been recorded routinely in the last thirty years. Contemporary seismic risk analyses are often based on acceleration values. When acceleration data are unavailable, there is impetus to include estimates for old events based on MM intensities. A serious difficulty in constructing a conversion relationship however is that, even when recorded for the same event, the intensities and accelerations are usually measured at different places. The solution employed here is to obtain smoothed values of both quantities at common grid locations and then fit a relationship. The smoothing has the effect of reducing "measurement error".

Figure 3 is a scatter diagram of the smoothed acceleration values of the grid of Figure 2b against the corresponding smoothed MM values of Figure 2a. There is a suggestion of approximate linearity with considerable scatter. Robust/resistant prediction lines of each variate on the other have been added. The prediction relations determined are:

$$\ln \hat{A} = -8.44 + 1.04\, I_{MM} \qquad IV \le I_{MM} \le VIII \tag{7}$$

$$\hat{I}_{MM} = 7.71 + 0.79 \ln A \qquad 0.02 \le A \le 0.50 \tag{8}$$

Here acceleration is measured in units of $g = 980 cm/sec^2$. There follows a table of predictor and corresponding predicted values,

Table 1

I_{MM}	$\hat{A}$, g		A, g	$\hat{I}_{MM}$
8	0.89		1.0	7.7
7	0.31		0.5	7.2
6	0.11		0.25	6.6
5	0.04		0.125	6.1
4	0.01		0.063	5.5

No standard errors have been provided for these fits because in their computation, note would be taken that the values at the different grid points are statistically dependent. (Standard errors will be developed in later work.) For comparative purposes one can note that Trifunac and Brady (1975) determined the following relationship, for horizontal accelerations,

$$\ln \hat{A} = -6.558 + 0.691\, I_{MM} \quad \text{for} \quad IV \le I_{MM} \le X$$

while Bolt (1978) found

$$\ln \hat{A} = -7.671 + 0.721\, I_{MM}$$

and Dowrick (1989) determined, for New Zealand,

$$\ln \hat{A} = -7.772 + 0.721\, I_{MM} \quad \text{for } I_{MM} \le IX$$

Standard errors are needed to assess whether these various relationships are essentially different. It is important to have the two relationships, (7) and (8), because on some occasions one wishes to replace A and on some occasions I_{MM}.

An interesting question is how to indicate the uncertainty of maps like those of Figure 2. Musmeci (1984) proposes the use of a bootstrap procedure. Bootstrap procedures are discussed in Diaconis and Efron (1983), for example.

De Rubeis et al. (1992) have also proposed an objective procedure for constructing isoseismal maps and discuss the importance of having such. Their procedure involves least squares fitting of polynomials within circles. It does not handle outliers, downweight points smoothly with distance, nor provide standard errors however.

6. ATTENUATION

For assessing seismic risk and determining insurance premiums at a particular site, an attenuation law like (5) above is needed.

Figure 4 is a graph of the accelerations and MM intensities of the Loma Prieta event plotted versus distance from the source. (In the case of the intensities, distances are taken from Boore et al. (1989)). A substantial amount of scatter is present, and there is a falloff of severity with distance. The smooth curves on the figures correspond to robust/resistant smoothing of the data. The cluster of high values at a distance of about 100km corresponds to the extreme motions recorded in the San Francisco / Oakland region, perhaps due to local geology, Lomax and Bolt (1992).

It is convenient to have a particular functional form for the attenuation. One such that has been proposed by Joyner and Boore (1981), for the maximum acceleration at distance d for an event of moment magnitude M, is

$$A = \frac{1}{d} e^{\beta M} e^{-\gamma d}$$

involving parameters β and γ. In Brillinger (1989) a variant of this is fit to data (d_{ij}, M_i, A_{ij}) for $I = 23$ western U.S. events, the i-th having J_i data values, i.e. $j = 1,\ldots,J_i$ and $i = 1,\ldots,I$. The model fitted is

$$\log A_{ij} = \alpha_i + \beta_i M_i - \log\sqrt{d_{ij}^2+\delta_i^2} - \gamma_i \sqrt{d_{ij}^2+\delta_i^2} + \varepsilon_{ij} \qquad (9)$$

where the α_i, β_i, γ_i, δ_i are independent random effects for the ith earthquake with normal distributions and the ε_{ij} are independent normal noise values. The relationship (9) could be converted to one for I_{MM} via the prediction formula (8).

Figure 5 provides the result of fitting model (9) to the Loma Prieta acceleration data in the manner of Brillinger (1989). The curve provides an estimate of the acceleration, for the Loma Prieta event, at a given distance from the source.

In the analysis local site effects have been ignored since the emphasis is on damage and on the relationship of A and I_{MM}.

7. DAMAGE

By damage is here meant economic loss caused by an earthquake. It relates to the performance of structures. Most of the discussion to follow has in mind damage to insured properties. Damage is commonly described by a loss ratio that varies with the strength of shaking and type of structure. For a given strength of motion a variety of damage levels are seen to occur, necessitating the use of distributions. Dowrick and Rhoades (1990) for example found the distribution of damage ratios in an intensity zone to be approximately lognormal. One needs something like a motion-damage relationship or damage-probability matrix, see Panel on Earthquake Loss Estimation Methodology (1989) in order to proceed. The following is an example of loss ratios for buildings, by risk category in percent,

Table 2

Risk type vs MMI	VI	VII	VIII	IX	X
residential	0.4%	1.7%	6%	17%	42%
commercial	0.8%	3.5%	11%	27%	60%
industrial	0.1%	0.7%	3%	11%	30%

These values are taken from Figure 42 in Munich Re (1991).

Specific formulas have been proposed on occasion. Following California studies, Steinbrugge and Algermissen (1990) suggest, in the case of pre-1940 dwellings

$$Y = (0.114M + 0.259)(8.534Fe^{-0.05389X})$$

where Y is loss over the deductible in percent, X is deductible in percent, M is the event's magnitude and F is an uncertainty factor, for example 1.50. There are similar formulas for other ages and types of structures. McGuire (1986) suggests

$$D = 24.7 + 17.8 \log_{10}(A) \quad \text{for } A > 0.041$$

where D is damage as a percentage of value and A is in units of g. This could be rewritten in terms of I_{MM} using the relationship (7).

There is an extensive discussion of this topic in Panel on Earthquake Loss Estimation Methodology (1989). A difficulty in carrying out damage studies is that the data are often proprietary.

8. PARTICULAR PRACTICE

The practice and laws of earthquake insurance vary with country and even within country. A brief description of some follows.

California. In California some companies use three "territories". For example in Territory 1 (mainly Imperial County) for a frame house with a deductible of 10% the cost of insurance is 6.50 dollars per 1000 coverage. There has been a State run plan, the California Residential Earthquake Recovery Program, providing coverage for houses of 15,000 dollars, with a deductible of 1000 dollars for a cost of 60 dollars/year.

Israel. The Israeli case is detailed in Kahane (1988). The insurance is part of the homeowners policy. The country pays reinsurance premiums on order of 15,000,000 dollars and is said to be "one of the largest customers of earthquake insurance in the world market" ibid.

Japan. The insurance for homes is an endorsement to fire coverage. Premiums are based on a statistical analysis, see Matsushima (1989). Historical records provided evidence of 349 damaging earthquakes during the 485 years between 1494 and 1978. Their magnitudes and hypocentres were estimated. The probable amount of damage that these would cause if they occurred in the present year was estimated. The pure premium was this amount divided by 485. Finally loadings were included. In the analysis the country was divided into five zones. For example the rates, per thousand yen insured, for wooden buildings were 4.80 for Zone 5 (Tokyo, Kanagawa and Shizuoka.) Reinsurance is provided by the government.

New Zealand. The New Zealand approach changed recently. It is part of fire insurance. For homes there is a limit of 100,000 dollars coverage at a cost of 0.50 per 1000. The country has a billion dollars of reinsurance cover for 1992 for 31,698,000 dollars for claims above 1.25 billion, see EQC (1992). The New Zealand reinsurance program is thought to be the largest catastrophe coverage in the world, Steven (1992).

The following quotes indicate some of the flavor of earthquake insurance practice.

"The rate of premium has never been actuarially based." Hellberg (1984)

"We are a California company so cannot offer earthquake insurance because of the risk." California Casualty (1989)

"earthquake loss estimation is presently more an art than a science" Rojahn and Sharpe (1985)

"There are surprises after every earthquake" Steinbrugge (1989)

"The calculation and enforcement of 'correct' premium rates is, of course, important in the long term. Nevertheless, there are further economic and social factors that also influence the rates charged eventually." Smolka and Berz (1991)

Some of the practice of reinsurance companies in determining rates is described in Porro (1989) and Munich Re (1991). The latter may be described as follows: one has Table 2 of damage percents. For the site of interest one determines a table of annual probabilities such as

Table 3

I_{MM}	VI	VII	VIII	IX	X
Prob.	0.04	0.014	0.005	0.003	0.001

For residential properties this leads to a net premium of

$$0.4\times0.04 + 1.7\times0.014 + 6\times0.005 + 17\times0.003 + 42\times0.001 = 0.1628\%$$

or 1.63 per 1000 dollars coverage. Loadings would be added to this figure.

9. OTHER ASPECTS

This report has so far focussed on only part of the loss estimation story. Attention has been directed to the problems of event timings, attenuation of energy and damage laws. However in a study for a given region the particular locations of faults are needed. As an example for the case of California see Wesnousky (1986). Magnitudes or intensities are also needed for each fault. There are functional forms based on the lengths of faults. Attenuation laws, like (5) and (9), are next applied followed in turn by damage laws.

Nonscientific issues arise too. Regulatory agencies are concerned with the solvency of insurance companies. In California the concept of probable maximum loss (PML) is employed in assessing this, see California Department of Insurance (1990). The PML is defined as the average probable maximum monetary loss which will be experienced by 9 out of 10 buildings in a given earthquake building class in the specified earthquake PML zone. There are 8 such zones for California. An event of Richter magnitude 8.25 is assumed. A yardstick sometimes employed to assess solvency is that the potential loss on one risk should not exceed 10% of the surplus, ibid.

Insurers protect themselves by reinsurance. This is the sharing of insurance risks with other insurers. It is used extensively for earthquakes and catastrophes. As an example of just how extensive note that for California Zone B (Los Angeles and Orange Counties), only 26 % of the PML is retained by the insurer of record, California Department of Insurance (1990). However wanting reinsurance is one thing, getting it is another as Japan and New Zealand have found on occasion.

10. DISCUSSION

General needs of the insurance industry are discussed in Holden and Real (1990) and Workshop Report (1990) and the practice is evolving. Both New Zealand, New Zealand Government (1988), and the United States are involved with major changes and controversies. In the United States case the insurance industry sponsored the Earthquake Project, a proposal to the Federal government for a joint program in the event of a major earthquake. The Federal Emergency Management Agency (FEMA) was not impressed and recommended against the program. In California too the government program was viewed negatively and the California Earthquake Recovery Program ended.

Another aspect of earthquake insurance is how it is treated under tax laws. One point of dispute relates to the taxation of reserves. Kahane (1988) remarks on the "need for tax rules allowing for larger reserves for unexpired risks".

The focus of this report has been on earthquake insurance, but the basic principles apply to other catastrophes as well. We may mention: floods, hail, firestorms, landslides, tsunamis, volcanic eruptions, windstorms.

It is clear that many technically interesting problems remain for geologists, seismologists, engineers, statisticians and actuaries.

REFERENCES

Aase, K. K. (1992). Dynamic equilibrium and the structure of premiums in a reinsurance market. Geneva Papers on Risk and Insurance Theory, to appear.

Benjamin, S. (1986). Loadings for insurance premiums. Geneva Papers on Risk and Insurance 11, 110-125.

Beard, R. E., Pentikainen, T. and Pesonen, E. (1969). Risk Theory. Chapman and Hall, London.

Blume, J. A. and Kiremidjian, A. S. (1979). Probabilistic procedures for peak ground motion. J. Struct. Div. Amer. Soc. Civil. Eng. 11, 2293-2311.

Bohman, H. (1979). Insurance protection for large risks with a low claim frequency. Proc. 42nd Session Internat. Statist. Inst. 48, 125-135.

Bohman, H. (1986). Reinsurance, profitability and insurability. Geneva Papers on Risk and Insurance 11, 126-129.

Bolt, B. A. (1978). Fallacies in current ground motion prediction. Proc. Second Int. Conf. Microzonation, Vol. II, 617-633.

Boore, D. M., Seekins, L. and Joyner, W. B. (1989). Peak accelerations from the 17 October 1989 Loma Prieta earthquake. Seismological Research Letters 60, 151-166.

Brazee, R. J. (1979). Reevaluation of modified Mercalli intensity scale for earthquakes using distance as a determinant. Bull. Seism. Soc. Amer. 69, 911-924.

Brillinger, D. R. (1982). Seismic risk assessment: some statistical aspects. Earthquake. Prediction Res. 1, 183-195.

Brillinger, D. R. (1989). Some examples of the statistical analysis of seismological data. Pp. 266-278 in Observatory Seismology (Ed. J. J. Litehiser). University of California Press, Berkeley.

Bullen, K. E. and Bolt, B. A. (1985). An Introduction to the Theory of Seismology. Cambridge University Press, Cambridge.

California Casualty (1989). Personal communication.

California Department of Insurance (1990). California Earthquake Zoning and Probable Maximum Loss Evaluation Program. California Dept. of Insurance, Los Angeles.

Chambers, J. M. and Hastie, T. J. (1992). Statistical Models in S. Wadsworth, Pacific Grove.

Cleveland, W. S. and Devlin, S. J. (1988). Locally weighted regression: an approach to regression analysis by local fitting. J. Amer. Statist. Assoc. 83, 596-610.

Cornell, C. A. (1968). Engineering seismic risk analysis. Bull. Seismol. Soc. Amer. 58, 1583-1606.

De Rubeis, V., Gasparini, C., Maramai, A. and Tertulliani, A. (1992). The uncertainty and ambiguity of isoseismal maps. Earthquake Eng. and Structural Dynamics 21, 509-523.

Diaconis, P. and Efron, B. (1983). Computer-intensive methods in statistics. Scientific American 116-179.

Dowrick, D. J. (1989). The nature and attenuation of strong ground motion in the 1987 Edgecumbe earthquake, New Zealand. New Zealand J. Geology and Geophysics 32, 167-173.

Dowrick, D. J. and Rhoades, D. A. (1990). Damage ratios for domestic buildings in the 1987 Edgecumbe earthquake. Bull. New Zealand Nat. Soc. Earthquake Engineering 23, 137-149.

EQC (1992). Report of the Earthquake and War Damage Commission. Lower Hutt, New Zealand.

Freifelder, L. R. (1976). A Decision Theoretic Approach to Insurance Ratemaking. Huebner Foundation, Philadelphia.

Goovaerts, M. J., De Vylder, F. and Haezendonck, J. (1984). Insurance Premiums. North-Holland, Amsterdam.

Grandell, J. (1991). Aspects of Risk Theory. Springer-Verlag, New York.

Grases, J. (1986). Perdidas com Consecuencia de Terremotos. Seguros Caracas, Caracas.

Heilmann, W-R. (1988). Fundamentals of Risk Theory. Verlag Versicherungswirtschaft, Karlsruhe.

Hellberg, M. (1984). Insurance and natural hazards: the response of New Zealand Governments. Pp. 446-465 in Natural Hazards in New Zealand. UNESCO, Wellington.

Holden, R. and Real, C. R. (1990). Seismic Hazard Information Needs of the Insurance Industry, Local Government, and Property Owners in California. California Department of Conservation, Sacramento.

Joyner, W. B. and Boore, D. M. (1981). Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California earthquake. Bull. Seismol. Soc. America 71, 2011-2038.

Kahane, Y. (1988). Earthquake risk and insurance - policy considerations: the Israeli case. Geneva Papers on Risk and Insurance 13, 137-164.

Lockett, J. E. (1980). Catastrophes and catastrophe insurances. J. Inst. Actuaries Students Soc. 24, 91-134.

Lomax, A. J. and Bolt, B. A. (1992). Broadband waveform modelling of anomalous strong ground motion in the 1989 Loma Prieta earthquake using three-dimensional geologic structures. Seismographic Stations, Berkeley. Preprint.

Lomnitz, C. (1974). Global Tectonics and Earthquake Risk. Elsevier, Amsterdam.

Matsushima, M. (1989). An overview of earthquake insurance in Japan. Bull. New Zealand Nat. Soc. Earthquake Engineering 22, 244-250.

McGuire, R. K. (1974). Seismic structural response risk analysis, incorporating peak response regressions on earthquake magnitude and distance. M.I.T. Dept. Civil Eng. Report, R-74-51.

McGuire, R. K. (1986). Modelling earthquake insurance and losses. Risk Engineering, Golden, Colorado.

Munich Re (1991). Insurance and Reinsurance of the Earthquake Risk. Munich Re, Munich.

Musmeci, F. (1984). A method for drawing confidence bounds on seismic contour maps. ENEA, Rome.

Nelson, W. (1972). Theory and applications of hazard plotting for censored failure data. Technometrics 14, 945-966.

New Zealand Government (1988). A Review of Earthquake Insurance. New Zealand Government, Wellington.

Norberg, R. (1990). Risk theory and its statistics environment. Statistics 21, 273-299.

Panel on Earthquake Loss Estimation Methodology (1989). Estimating Losses from Future Earthquakes. National Research Council, Washington.

Pinedo, M. and Shpilberg, D. (1981). Stochastic models with memory for seismic risk evaluation. J. Risk and Insurance 6, 46-58.

Porro, B. (1989). The role of reinsurance in earthquake risk assessment. Bull. New Zealand Nat. Soc. Earthquake Engineering 22, 219-226.

Reiter, L. (1990). Earthquake Hazard Analysis. Columbia Univ. Press, New York.

Richard, P. J. (1944). Théorié et Pratique des Opérations d'Assurance. Doin, Paris.

Rojahn, C. and Sharpe, R. L. (1985). Earthquake Damage Evaluation Report for California. Report 13, Applied Technology Council, Redwood City.

Sieh, K., Stuiver, M. and Brillinger, D. R. (1989). A more precise chronology of earthquakes produced by the San Andreas fault in Southern California. J. Geophysical Research 94 (B1), 603-623.

Smolka, A. and Berz, G. (1989). The Mexico earthquake of September 19, 1985- an analysis of the insured loss and implications for risk assessment. Earthquake Spectra 5, 223-248.

Smolka, A. and Berz, G. (1991). Seismic zoning in earthquake insurance: past and future. Proc. Fourth International Conference on Seismic Zonation IV, 245-252.

Steinbrugge, K. V. (1989). Loss estimation for insurance purposes: United States practices. Bull. New Zealand Nat. Soc. Earthquake Engineering 22, 193-198.

Steinbrugge, K. V. and Algermissen, S. T. (1990). Earthquake Losses to Single-Family Dwellings: California Experience. U. S. Geological Survey Bulletin 1939-A U. S. Gov. Printing Office, Washington.

Steven, L. (1992). The Earthquake & War Damage Commission - a look forward (and a look back). Bull. New Zealand Nat. Soc. Earthquake Engineering 25, 52-55.

Straub, E. (1973). Earthquakes and statistics from the insurance point of view. Bull. Inter. Statist. Inst. 45 (Book 3) 462-466.

Straub, E. (1988). Non-Life Insurance Mathematics. Springer-Verlag, Berlin.

Stover, C. W., Reagor, B. G., Baldwin, F. and Brewer, L. R. (1990). Preliminary isoseismal map for the Santa Cruz (Loma Prieta), California, earthquake of October 18, 1989 UTC. Open-File Report 90-18, National Earthquake Information Center, Denver.

Sundt, B. (1984). An Introduction to Non-Life Insurance Mathematics. Verlag Versicherungswirtschaft, Karlsruhe.

Trifunac, M. D. and Brady, A. G. (1975). On the correlation of seismic intensity scales with the peaks of recorded strong ground motion. Bull. Seismol. Soc. Amer. 65, 139-162.

Vere-Jones, D. (1970). Stochastic models for earthquake occurrence. J. Roy. Statist. Soc. B 32, 1-62

Vere-Jones, D. (1973). The statistical estimation of earthquake risk. New Zealand Statistician 8, 7-16.

Walley, P. (1976). The estimation of earthquake risk in New Zealand. Tech. Report 49, Applied Math. Division, DSIR, Wellington.

Wesnousky, S. G. (1986). Earthquakes, quaternary faults, and seismic hazard in California. J. Geophysical Research 91, 12587-12631.

Workshop Report (1990). Information needs of the earthquake insurance industry in New Zealand. Bull. New Zealand Nat. Soc. Earthquake Engineering 23, 284-287.

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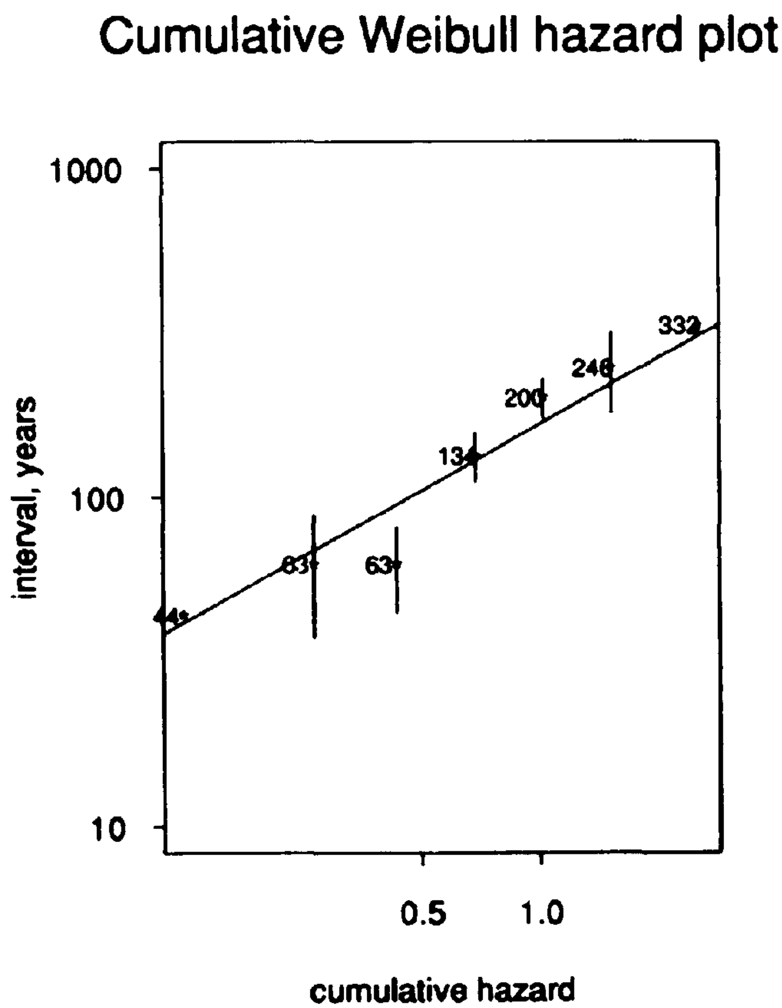

Figure 1. A hazard probability plot to assess the reasonableness of the Weibull distribution for the intervals between earthquakes at Pallett Creek. The points plotted correspond to estimates of the intervals between events. The vertical bars indicate plus and minus twice their standard errors. If the distribution is reasonable the points should fall near a straight line. For reference a fitted line has been added.

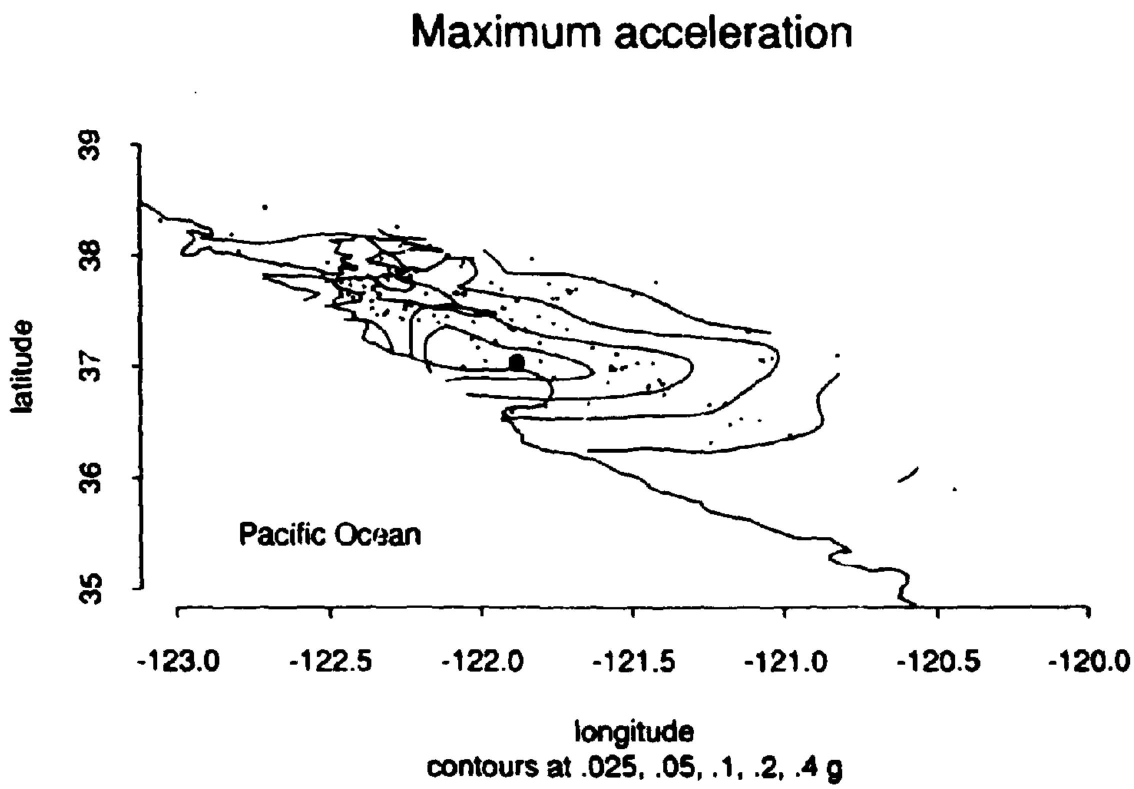

Figure 2a. Smoothed values of the maximum acceleration at logarithmically spaced levels for the Loma Prieta event. The triangles give the locations of the measurements.

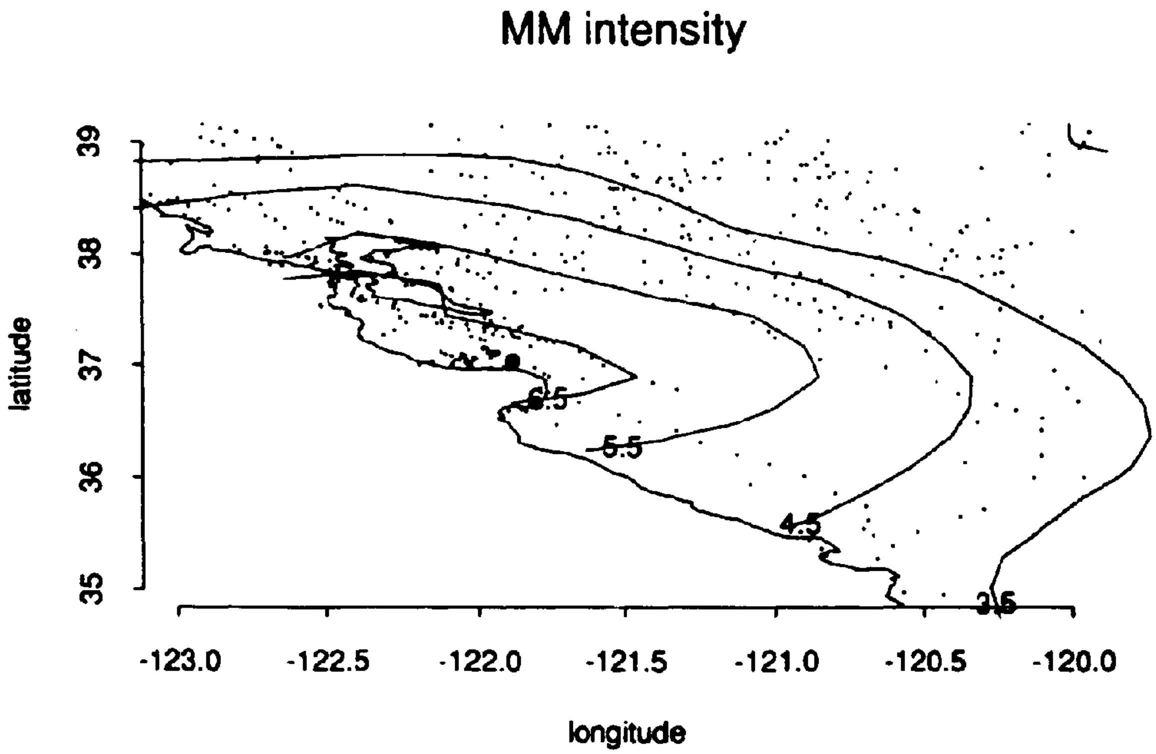

Figure 2b. Isoseismals obtained by employing the procedure loess of Chambers and Hastie (1992). For example the region between the contours 4.5 and 5.5 is meant to correspond to an MM intensity of V. The triangles give the locations of measurements.

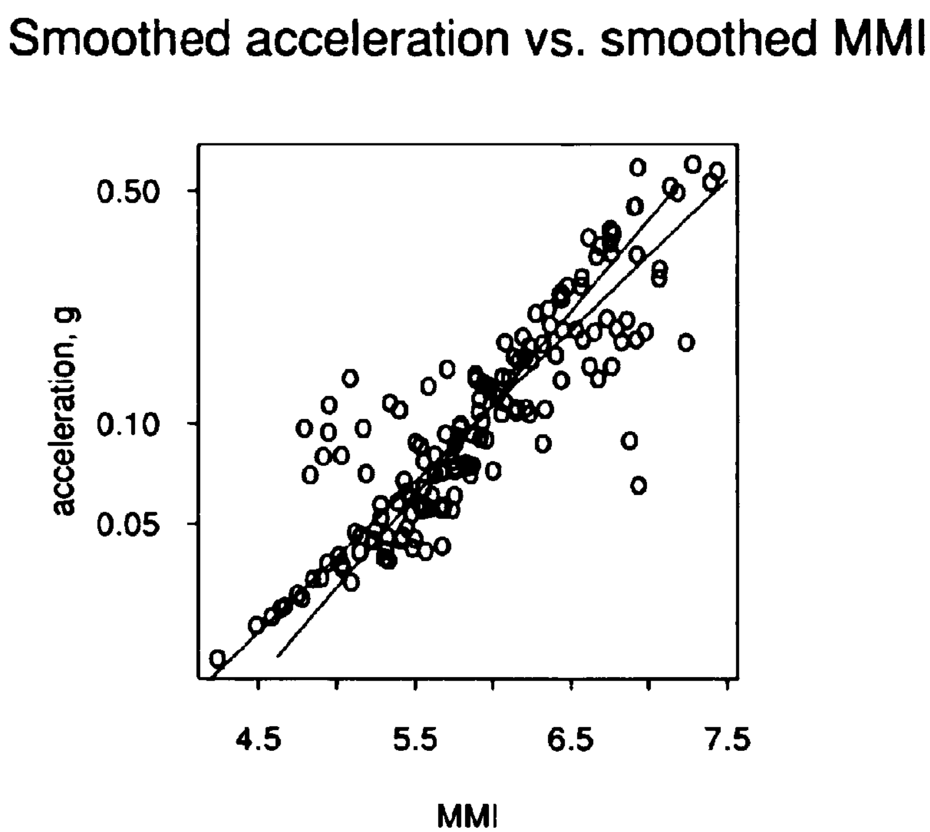

Figure 3. Corresponding smoothed values of accelerations and MM intensity on which Figures 2a and 2b were based are plotted against each other. The lines are robust/resistant regression lines of A on I_{MM} and vice versa.

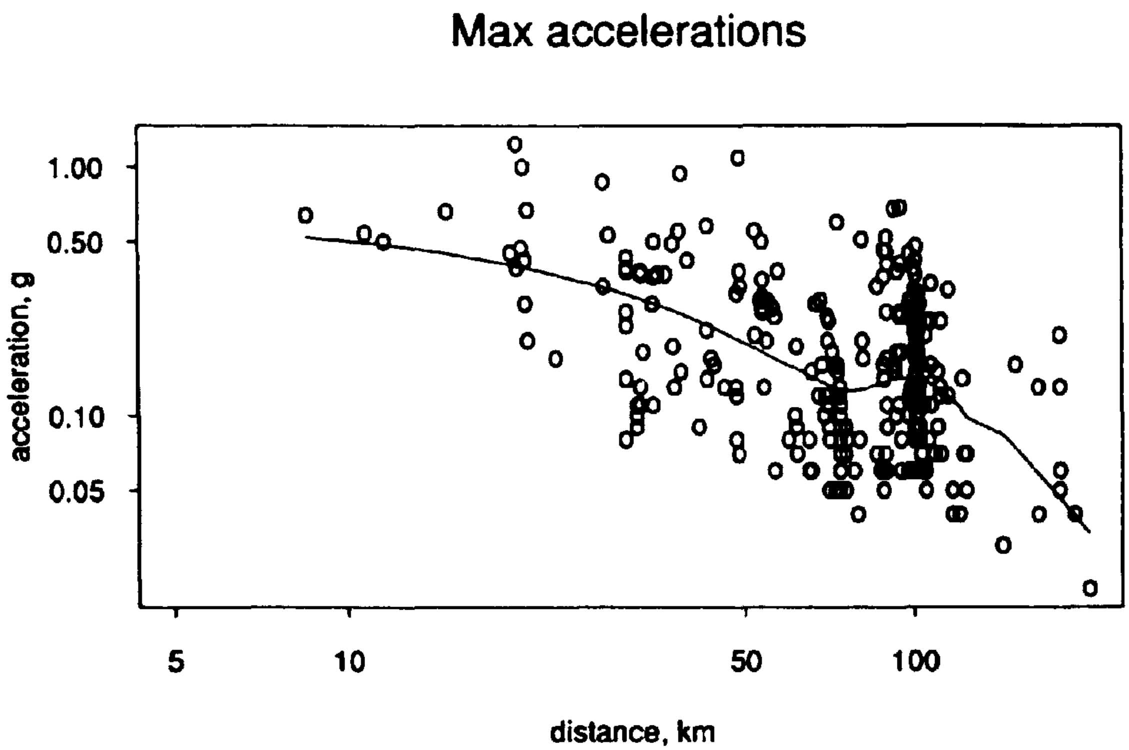

Figure 4a. A scatter diagram of observed maximum acceleration values versus distance for the Loma Prieta event. The curve added is robust/resistant smoothed. The data are taken from Boore et al. (1989).

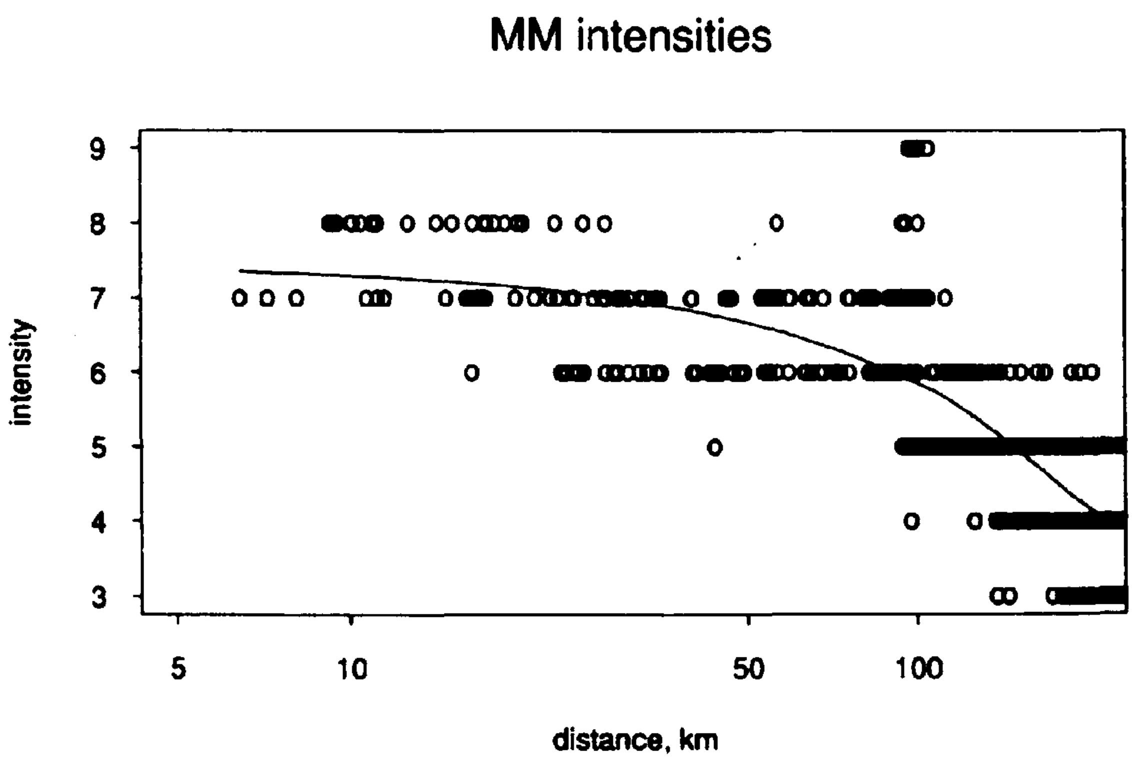

Figure 4b. A scatter diagram of observed MM intensities versus distance for the Loma Prieta event.

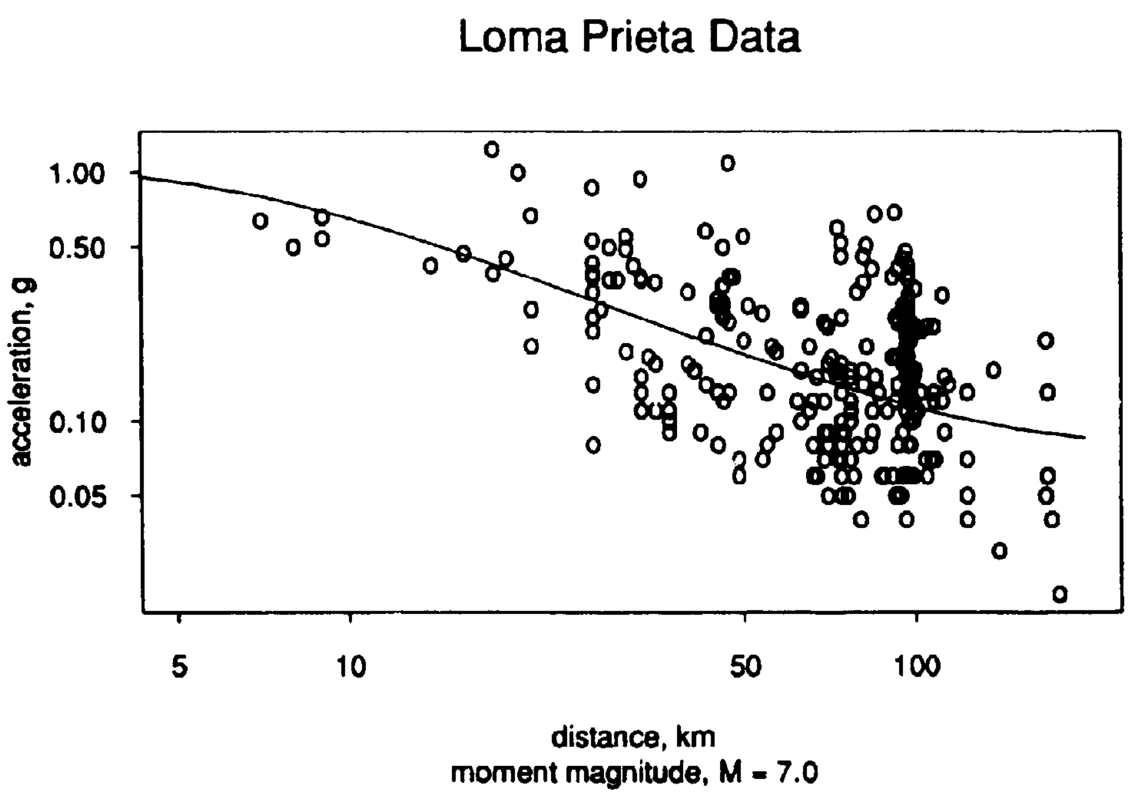

Figure 5. The data of Figure 4a with a fitted line derived under the model (9) added.

APPENDIX

Attention will focus on a single year and a damaging event that can happen at most once in that year. Let π denote the probability of the event's occurrence, $Prob\{U = 0\}$, and if the event does occur, suppose the random loss is L.

Define an indicator variable I that equals 1 if the event occurs and 0 if it does not. Then the loss, U, of Section 2 may be written as $U = IL$. >From this one sees that

$$\mu_U = \pi\mu_L$$

and

$$\sigma_U^2 = \pi(1-\pi)\mu_L^2 + \pi\sigma_L^2 \simeq \pi E\{L^2\}$$

respectively, with the last relationship assuming that π is small.

In the case that many units are involved, L will be the sum of many individual losses and the distribution may be approximated by a normal. If $\Phi(.)$ denotes the normal cumulative, then the probability of (4) is given by

$$Prob\{IL > R + P\}\pi\,[1 - \Phi((R+P-\mu_L)/\sigma_L)]$$

For the premium rule (1), $P = \pi\mu_L$, this becomes

$$\pi[1 - \Phi((R - (1-\pi)\mu_L)/\sigma_L)]$$

which may be used to compute the probability of ruin given the reserve, R and the values of μ_L and σ_L. Alternately, for given ε one can solve for the premium as follows

$$P = \mu_L + \sigma_L\ \Phi^{-1}(1 - \frac{\varepsilon}{\pi}) - R$$

The effects of several years operation can be studied as in Benjamin (1986).

Suppose that $R = 10\mu_L$, the yardstick proposed in Section 9, the ruin probability becomes

$$\pi[1 - \Phi((9+\pi)\mu_L/\sigma_L)]$$

This is seen to increase with the coefficient of variation σ_L/μ_L. The expression can be used to study ruin probabilities.

Other premium rules can be investigated in a similar fashion. Note that the effects of employing estimates for parameters, rather than actual values, remains to be addressed generally.

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UCB/EERC-92/12 "Application of a Mass Damping System to Bridge Structures," by Hasegawa, K. and Kelly, J.M., August 1992.

UCB/EERC-92/13 "Earthquake Engineering Research at Berkeley - 1992," by , October 1992.

UCB/EERC-92/14 "Earthquake Risk and Insurance," by Brillinger, D.R., October 1992.