SEISMIC RISK FOR MULTIPLE SITES

by

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SYNOPSIS

The probability that site shaking will exceed some threshold level is computed for 2 and 3 dispersed sites within a large uniform source of earthquake epicenters. Results include the probability that the threshold will be exceeded for at least one site and that it will be exceeded at several sites simultaneously. Results of a parametric study are useful for preliminary studies of the siting of key facilities.

INTRODUCTION

Conventional seismic risk analysis (1) evaluates the liklihood of earthquake shaking at a site, often by a curve giving the expected number of events per year with intensity equalling or exceeding various values of intensity. Such a result may be used to estimate annualized losses or probability-of-failure for a single facility at that site, or for a city spread over a geographical area small enough so that the entire area will receive the same nominal level of shaking during any one earthquake.

Often, however, it is desirable to evaluate the seismic risk to a series of interrelated facilities spread over a larger geographical area, so as to learn the probability that several of the facilities might be seriously shaken by the same earthquake. Examples would be generating or switching stations on an electric power grid, key locations for coordination of disaster recovery operations, manufacturing plants operated by a single company, or simply a set of cities.

METHOD OF ANALYSIS

As with the conventional seismic risk analysis, the first step is to establish source faults or areas, plus seismicity parameters (rate of occurrence, maximum magnitude, attenuation law) for each source area. In addition it is necessary to establish the threshold of shaking which is critical to each site. Then, for each possible epicentral location and magnitude (that is, for each possible "event" with its particular probability of occurrence) the number of sites which "fail" is determined. The probability that a particular number of sites will fail is computed by summing over all events.

For two sites within a large uniform source area, an analytical expression can be developed (5). A computer program has been written which permits use of multiple source areas and a large number of sites (4). In this program, the distribution of earthquake magnitudes m, given an event with magnitude m_o or greater, is

$$F_M(m) = K\,(1 - e^{-\beta(m - m_o)}); \quad m_o \leq m \leq m_1 \qquad (1)$$

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where $\kappa = [1 - e^{-\beta(m_1 - m_o)}]^{-1}$ and m_1 is the maximum magnitude. Attenuation of ground shaking y is expressed by

$$y = b_1 e^{b_2 m} (R + 25)^{-b_3} \quad (2)$$

where m is magnitude, R is hypocentral distance in kilometers and b_1, b_2, b_3 are parameters. The program has been applied to a problem involving nine sites located unevenly within four contiguous but different source areas.

In this paper, all results are for the case of a large uniform source area; that is, a case in which earthquake epicenters are equally likely to occur anywhere within a very large area surrounding the sites. The rate of occurrence of earthquakes with $m \geq m_o$ is denoted by ν, expressed in events per unit time per unit area. Unless otherwise noted, all results are for the case $m_o = 4$, $m_1 = 8.3$, $\beta = 1.65$, $\nu = 7 \times 10^{-6}$ events/yr/km^2, $b_1 = 1100$, $b_2 = 0.5$, $b_3 = -1.32$, and a focal depth of 25 km. These attenuation parameters (2) give y as accceleration in cm/sec^2. The critical threshold is the same at all sites: 100 cm/sec^2. If the ground motion exceeds this threshold, it is said that a site "fails". An important quantity is the greatest epicentral distance ρ_Y for which the largest earthquake just causes y = 100 cm/sec^2 at a site. ρ_Y is found by solving Eq. 2 for R using y = Y and $m = m_1$, and then converting the hypocentral distance R to the corresponding epicentral distance. For the standard assumed values, ρ_Y is 115 km.

RESULTS FOR TWO SITES

Fig. 1 shows two sites (N = 2) with equal resistance, separated by a distance D. Figs. 2 thru 6 present results for this case.

Fig. 2 contains results for the standard set of parameters listed above. The upper curve gives the annual probability $P[\geq 1/2]$ that at least one site fails ($n_f \geq 1$), while the lower curve gives the annual probablity $P[= 2/2]$that both sites fail simultaneously ($n_f = 2$) during the same earthquake. For zero spacing, $P[= 1/1] = P[= 2/2]$ is just the probability of failure $P[= 1/1]$ for a single site within a large uniform source. As D increases, $P[\geq 1/2]$ increases to $2P[= 1/1]$; this limit is reached exactly at $D = 2\rho_Y$, but for practical purposes is reached at much smaller D. $P[= 2/2]$ deceases rapidly as D increases, and is zero for $D \geq 2\rho_Y$. By $D \simeq \rho_Y$, $P[= 2/2]$ has decreased by an order of magnitude.

Figs. 3 thru 5 show the effect of variations in the parameters, using normalized annual probability $P[\geq n_f/N] \div P[= 1/1]$ vs. normalized spacing. In general, changing the parameters changes both $P[= 1/1]$ and ρ_Y: The solid curves in each figure are for the standard values of the parameters, while other curves are labelled by the value of the varied parameter. Fig. 3 shows the effect of decreasing m_1, while Fig. 4 gives results using a different attenuation law. Fig. 5 indicates the effect of using a different critical threshold intensity Y. The effect of these parameter variations is not great. In all cases, the normalized spacing for an order-of-magnitude reduction in $P[\geq 2/2]$ is less than 1.2.

Fig. 6 shows the effect of considering uncertainty in the attenuation law and in the resistance. Log normal distributions are assumed, and $\sigma^2 = \sigma_y^2 + \sigma_Y^2$ where σ_y and σ_Y are the standard deviations for intensity and resistance, respectively. P[= 1/1] is affected by σ, but ρ_Y is unchanged. The main effect of introducing uncertainty is that P[$\geq$ 2/2] > 0 for all D. However, the normalized spacing required to reduce P[$\geq$ 2/2] by one order of magnitude has increased only to 1.3.

RESULTS FOR THREE SITES

Three sites (N = 3) form a triangular pattern, and Fig. 7 shows the patterns considered.

Fig. 8 gives results for the equilateral triangle pattern, using the standard parameters. As D increases, P[$\geq$ 1/3] increases to 3P[= 1/1]. P[$\geq$ 2/3] is reduced by one order of magnitude at D = 135km, while P[= 3/3] is reduced by one order of magnitude by D = 80km. Fig. 9 illustrates the effect of varying the resistance. Fig. 10 gives a comparable set of results for the equal-legged right triangle.

Figs. 10 and 12 provide results for cases in which the spacing between two of the sites is held constant while the distance to the third site is varied. In the case of Fig. 10, zero offset means that the 3 sites fall on a line, while for Fig. 12 zero offset implies that there are two sites atop another with the third site by itself.

CONCLUSIONS

Increasing the number of sites increases the risk that at least one of the sites will fail. The sites become essentially independent, and hence the risks for the individual sites are additive, for D > 0.75 ρ_Y.

Increasing the spacing between sites decreases the risk that more than one site will fail simultaneously during the same earthquake. If the risk of multiple failures is to be decreased by an order of magnitude, then the following spacings should be used:

P[= 2/2]	D > 1.2ρ_Y
P[$\geq$ 2/3]	D > 1.5ρ_Y
P[= 3/3]	D > 0.9ρ_Y

These results may be used for preliminary guidance in siting studies.

ACKNOWLEDGEMENTS

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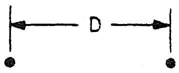


ALL RESULTS ON THIS SHEET ARE FOR THE 2-SITE CASE

FIGURE 1

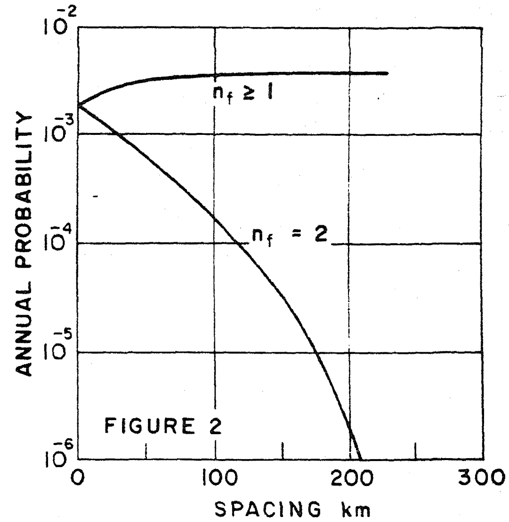
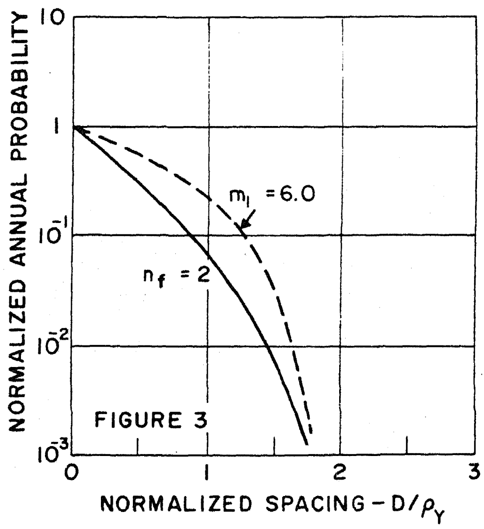


FIGURE 2



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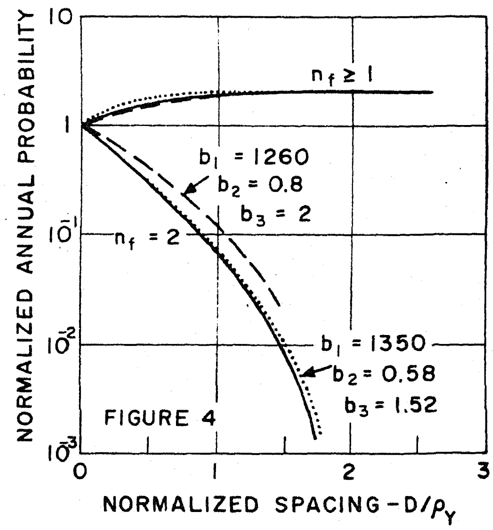

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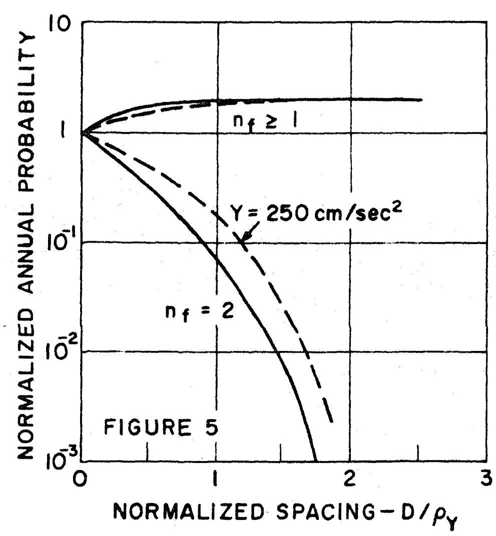

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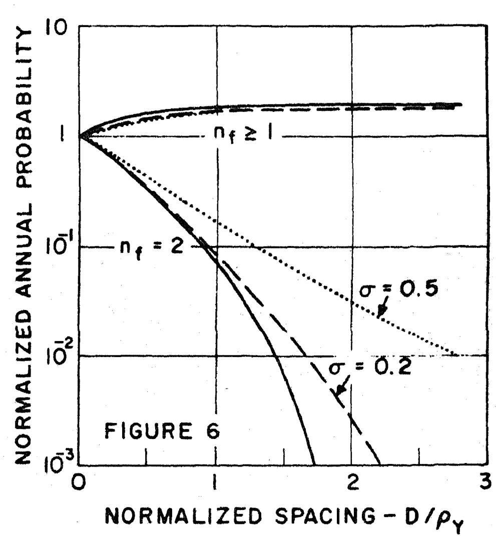

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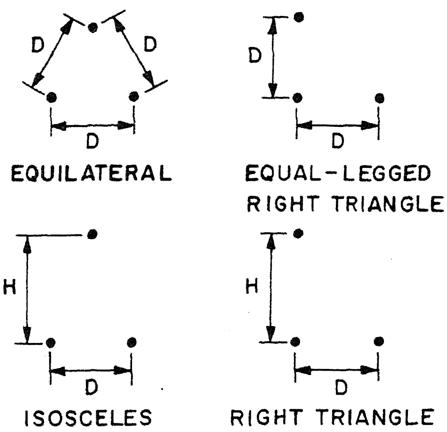

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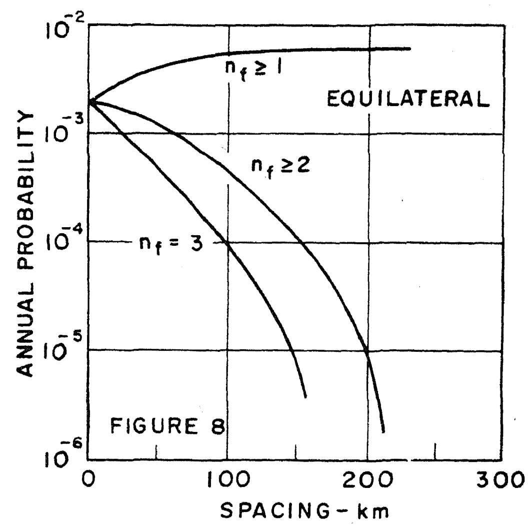

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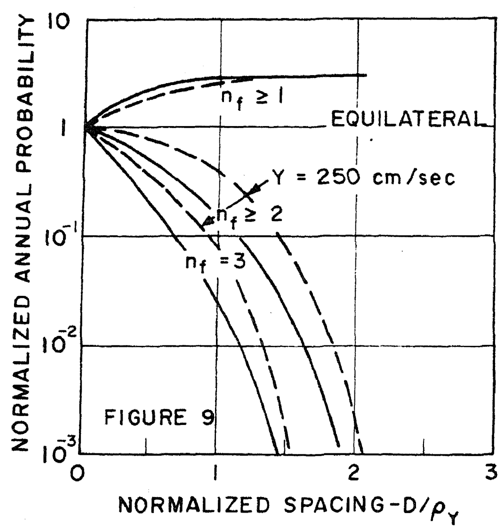

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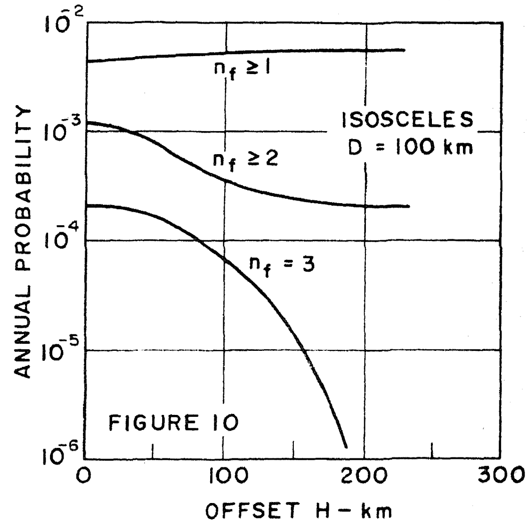

FIGURE 10

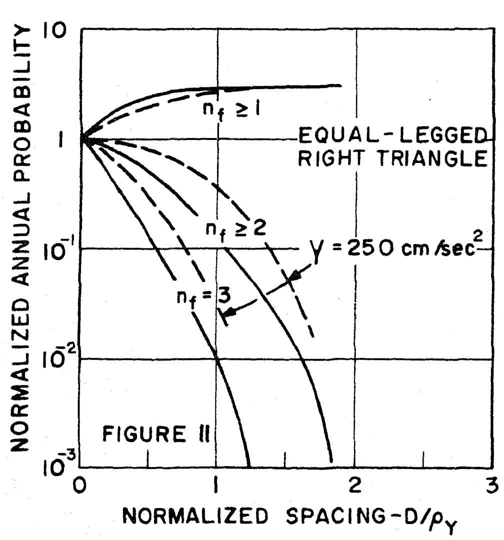

FIGURE 11

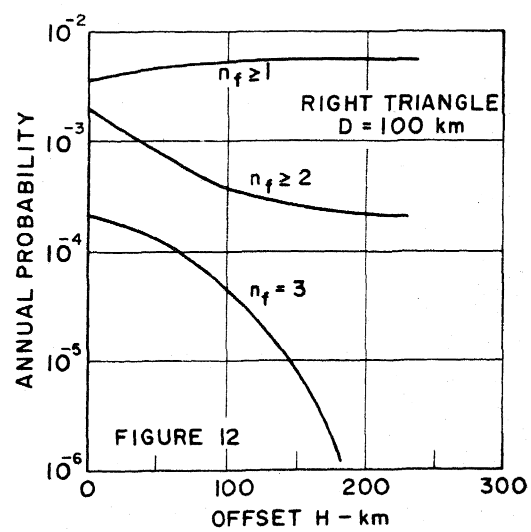

FIGURE 12