

AFTERSHOCKS IN ENGINEERING SEISMIC RISK ANALYSIS

by

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SYNOPSIS

The influence of spatially distributed aftershocks on calculated seismic risks is investigated. The conclusions are that to ignore aftershocks is unconservative and that to treat all events as mainshocks is conservative.

The purpose of seismic risk analysis as defined here is to assess the probability p_a that the maximum seismic intensity experienced at a structural site in a time period of T years will exceed a units (e.g., 0.2g). Seismic risk analysis has been studied by the senior author⁽¹⁾, by Esteva⁽²⁾ and by others for several years; reported analyses account for uncertainty in the times, locations and magnitudes of mainshocks as well as uncertainty in the attenuation "laws" (correlations) which estimate site intensity as a function of event magnitude and distance. In several historical events it has been noted that certain sites located at some distance from the mainshock epicenter have experienced more severe shaking during the temporally and spatially distributed aftershock sequence than during the larger mainshock itself. The cause is apparently the closer proximity of a particular aftershock to the site. This study is aimed at evaluating this "additional aftershock risk" and at determining under what conditions it might prove important (e.g., be of the same order as the risk due to mainshocks). The results are compared with a simple method that does not distinguish between main- and aftershocks, but treats both as mainshock events, and with a simple method that considers only mainshocks as significant events in determining the seismic risk.

Seismologists such as Omori, Utsu, Aki and Vere-Jones have studied and modeled aftershock sequences in time. Utsu⁽³⁾ has, in addition, investigated the correlation between mainshock magnitude and the form and extent of the areal region around the mainshock epicenter in which aftershocks might occur. In our analysis, the temporal characteristics of aftershocks are represented as seismologists have done before, as a non-homogeneous Poisson process in time, triggered by a mainshock and with parameters dependent on the mainshock magnitude. Specifically, the modified Omori law is used to account for the decay of the rate of aftershock events in time, and the mainshock magnitude is assumed to be the upper bound on the magnitudes of the aftershocks. Furthermore, the aftershocks are assumed here to occur at random spatially in a region whose location and extent depend upon the (random) mainshock location and magnitude. For

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these relationships the empirical laws from Utsu⁽³⁾ are used. Mainshock characteristics as well as the attenuation "law" with an error term have been taken from Cornell⁽¹⁾. Based upon these assumptions, the probability p_a that the maximum seismic intensity experienced at a site in a time span of T years, caused either by a main- or an aftershock, will exceed a units can be calculated⁽⁴⁾. However, the evaluation of the mathematical expressions is extremely difficult and time consuming. It is comparatively easy to calculate an upper bound on the risk from main- and aftershocks, which is still a significant improvement over the results from the present models. An upper bound is obtained when the risk is approximated by the expected number of main- or aftershocks in T years, which cause a seismic intensity at the site above a certain level.

An analytical model has been derived for the simplest case, where it is assumed that both the main- and the aftershock epicenters lie on the same "line" fault. Because of this simplistic assumption, the results cannot yet be generalized with confidence, however they provide new insights and understanding. Future efforts will include models with spatial assumptions that reflect more accurately the real world situation.

Example: Numerical results (upper bounds) from an analytical model where main- and aftershocks occur only on a fault line are presented in Figures 2 and 3 for a fault-site configuration as shown in Figure 1. After dividing the fault line into many smaller pieces, the expected number of main- and aftershocks of interest at the site in each of these pieces was calculated. The total expected number (upper bound on risk) was then obtained by addition. In this example the parameters in the modified Omori law were chosen such that the expected number of aftershocks greater than magnitude 4.5 in a time period of 10 years is equal to the expected number of mainshocks greater than magnitude 4.5 in 10 years; both were assumed to be 0.5. Figure 2 shows the (mathematically exact) seismic risk at the site for different upper bounds on the mainshock magnitude and for different distances d if only mainshocks are taken into account (mainshock model). These risks were obtained by the analytical model described in Cornell⁽¹⁾. If the mean main- and aftershock rates are added and treated simply as a mean mainshock rate, the risks in this example are approximately twice the ones shown in Figure 2. Because the mainshock magnitudes are truncated at an upper bound, there is also an effective upper bound on the seismic intensity at the site which depends on the upper bound on the mainshock magnitude and the distance d. In Figure 3 the risks from Figure 2 are compared with the ones obtained from the described analytical model for main- and aftershocks. It can be observed that, except for very small ground accelerations, simply treating main- and aftershocks as equivalent independent events gives conservative risk estimates, the results being especially conservative if the level of the ground acceleration is near the upper bound on the ground acceleration at the site. On the other hand, simply treating mainshocks alone as significant events in evaluating the seismic risk yields too low risk estimates. Independent of upper bounds on the magnitudes of mainshocks, the relative contribution of aftershocks to the risk at the site decreased with increasing ground acceleration, as indicated by the dashed lines. However, for a fixed level of ground acceleration, the absolute contributions are smaller for smaller upper bounds.

The most significant parameters that influence the relative contribution of the aftershocks have been found to be the ratio of the expected number of mainshocks to the expected number of aftershocks, and the upper bound on the mainshock magnitude. Other parameters, such as d , affected the absolute risk levels but not significantly the relative contribution of the aftershocks to the total risk. It is anticipated, however, that a more realistic two-dimensional spatial assumption for aftershock locations in future analytical models will demonstrate further influences of parameters on the contributions of aftershocks.

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BIBLIOGRAPHY

1. Cornell, C. A., "Probabilistic Analysis of Damage to Structures under Seismic Loads," Chapter 27 of Dynamic Waves in Civil Engineering, edited by D. A. Howells, I. P. Haigh and C. Taylor; John Wiley & Sons, 1971.
2. Esteva, L., "Seismicity Prediction: A Bayesian Approach," Proceedings 4th World Conf. Eq. Eng., Santiago, Chile, January 1969.
3. Utsu, T., "Aftershocks and Earthquake Statistics," Journal of the Faculty of Science, Hokkaido University, Japan, Ser. VII, Vol. III, No. 3, 1969.
4. Merz, H. A., "Aftershocks in Engineering Seismic Risk Analysis," Master's Thesis, Mass. Inst. of Tech., Cambridge, Mass., USA, to be published June 1973.

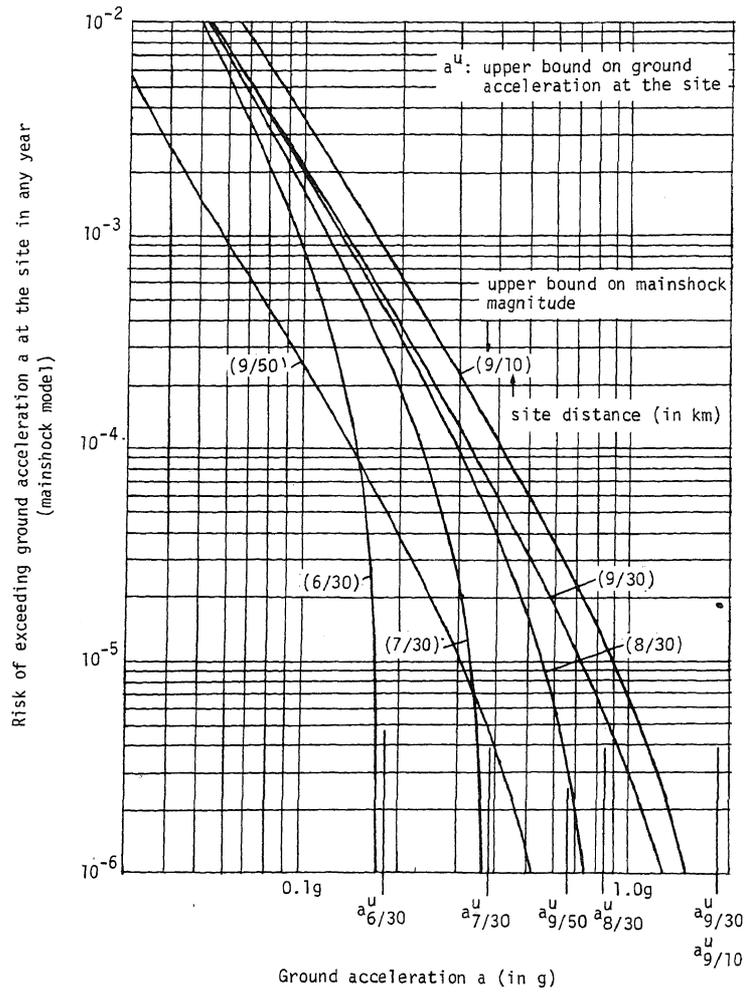


Figure 2

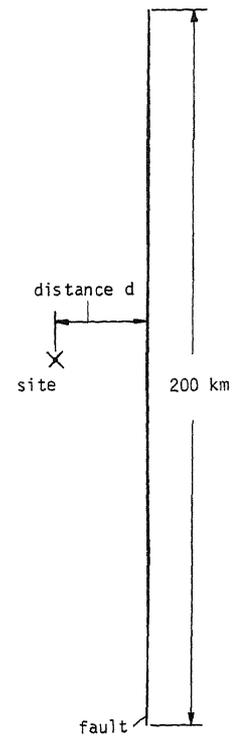


Figure 1

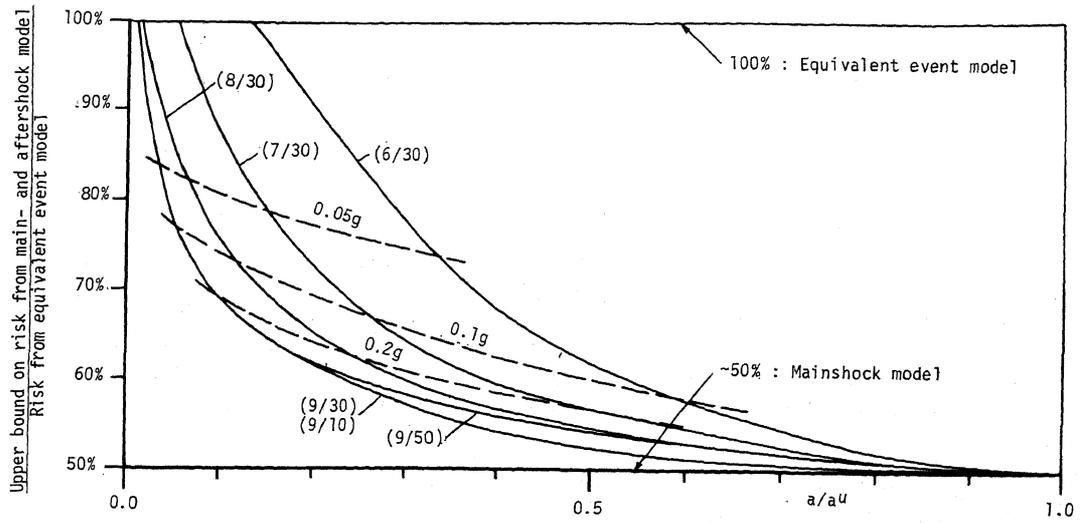


Figure 3