STRONG MOTION INVESTIGATIONS IN THE CENTRAL UNITED STATES

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SUMMARY

The central and eastern United States have had a history of large earthquakes, with magnitudes greater than 6.5. Aseismic design of critical structures must be performed, even though an adequate strong motion data base is not available. In order to make up for the lack of an adequate strong motion data base, complete synthetic seismograms are used to obtain a proper ground motion scaling relation. The scaling relation is found to fit the western United States and central United States strong ground motion data bases, once corrections are made for differences in anelastic attenuation and effort is made to reduce observations to a uniform magnitude scale.

INTRODUCTION

The need for proper input for earthquake resistant design of structures in the central and eastern United States is very real and immediate. This need is compounded by the lack of an adequate strong motion data base upon which to make decisions. As a consequence input data from other earthquake source regions are being used without a real understanding of the validity of applying that data to the central and eastern United States.

A technique widely used involves the specification of seismic intensity at the affected structure site. An empirical relationship between acceleration and intensity (1,2) is used to establish the maximum acceleration for the site. If a time history is required, scaling to fit a prescribed response spectrum shape is used, either from real or synthetic acceleration time histories. This particular method has its imperfections. First, there is the inherent scatter in the data base upon which the empirical relationships are based. Second, the only correction for differences in earthquake effects in the eastern and western United States is the use of different attenuation relations for intensity as a function of distance. Finally, the appropriateness of the time histories used is plainly in question, especially when the most important earthquake for design purposes may be several hundred kilometers away, as is the case for sites within a 500 kilometer radius of New Madrid, Missouri. Unfortunately it is easier to point out the imperfections in the present earthquake resistant design process than it is to quantify and correct the imperfections. It is because of this problem that several approaches are being taken to solve it.

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THEORETICAL AND EMPIRICAL STUDIES

The time history of an earthquake can be thought of in terms of a net offset on the fault as a function of time, y(t). The functional form of y(t) is such that it is zero prior to the earthquake, that it monotonically increases during the earthquake, and that it reach a final static value after the earthquake. For a point dislocation in an infinite medium, the ground displacement near the fault is approximately y(t), while at distances large when compared to the fault dimension, the ground displacement is proportional to dy/dt. Thus a seismologist will say that the far-field displacement reflects particle velocity on the fault, that far-field velocity is proportional to acceleration on the fault, and that the far-field acceleration is proportional to the rate of change of acceleration on the fault. Given a simple shape for y(t), different earthquakes can be modeled by specifying the parameters of final offset and rise time.

Consider the following though experiment on ground motion scaling. Given two earthquakes with the same final static offset on the fault, but with the rise times differing by a factor of two and with the same mathematical function of fault offset, e.g. y(t) and y(2t). Even though the peak near-field displacements will be the same, the far-field displacements will differ by a factor of two, the pulse with the longer duration possessing half the maximum displacement of the shorter pulse. Likewise, the corresponding far-field velocities will differ by a factor of four, and the far-field accelerations will differ by a factor of eight.

As long as the similarity of pulse shapes holds and only an infinite elastic medium is considered, the peak ground motions may be expressed as follow:

$$\begin{aligned} a_{max} &= A\, M_0\, f_c^3\, G(R) \\ v_{max} &= B\, M_0\, f_c^2\, G(R) \qquad (1) \\ d_{max} &= C\, M_0\, f_c\, G(R)\ , \end{aligned}$$

where a_{max}, v_{max}, and d_{max} are the maximum far-field acceleration, velocity and displacement, respectively. The seismic moment M_0 is related to the final static offset, the corner frequency f_c is inversely proportional to the pulse duration, and G(R) is the geometrical spreading factor for the range of interest. For tangential ground motion due to vertical strike-slip faulting, G(R) = 1/R for distances greater than one source depth.

To express equation 1 in a more usable form, special studies are required on the relationship between M_0 and f_c as a function of magnitude m_b (m_b is used since it refers to 1.0 Hz ground motion, which is a frequency near that used by engineers, as opposed to M_S which refers to 0.05 Hz). A definite relationship seems to exist between seismic moment M_0 and corner frequency f_c in the central United States (3) and in the northeastern United States (4). Spectral studies indicate that a tenfold decrease in f_c is accompanied by an increase in M_0 by 10,000 and by a corresponding increase in m_b by 2.0 magnitude unites. Thus equation (1) can be written as

$$\log_{10} a_{max} = D + 0.5\, m_b - \log_{10} G(R)$$
$$\log_{10} v_{max} = E + 1.0\, m_b - \log_{10} G(R) \qquad (2)$$
$$\log_{10} d_{max} = F + 1.5\, m_b - \log_{10} G(R).$$

Implicit in this formulation is the requirement that m_b be directly proportional to the logarithm of the far-field displacement source spectrum at a frequency of 1.0 Hz, that the observation point is several source depths away from the source, and that the basic shape of the faulting displacement with time is the same, except for simple time scaling.

This then represents the model for ground motion. It does fit the existing central United States strong ground motion data base. However that data base is not large enough to critically test the scaling coefficients. To do that computer programs were written to compute complete synthetic seismograms for point displcation sources in a layered halfspace (the seismograms are complete in the sense that all arrivals, body and surface wave, are included). A suite of such seismograms were computed for several functional forms of y(t) and for a corner frequency-seismic moment scaling appropriate to the central United States. The seismograms were passed through a seismograph response to estimate magnitude, which was in agreement with empirical observations. The synthetic ground motion acceleration, velocity and displacement time histories were searched for peak valueswhich were used in a regression analysis. The regression analysis indicated that equation 2 is a good model. It is interesting to note that the standard deviation of fit corresponded to a factor of 1.5, comparable to that observed for real data, except that this was due solely to wave propagation effects.

As another test of the model of equation 2, the strong motion data base of southern California was examined. Peak and sustained (third largest peak) levels of gound acceleration and velocity were examined. At the same time m_b magnitudes were computed for all earthquakes used. Two important conclusions arose. First, that the scaling of peak acceleration and velocity with magnitude is as suggested by equation 2. Second, it was found that the geometrical spreading factor G(R) has a magnitude dependence. The strong motion records of smaller magnitude earthquakes are richer in high frequencies, which attenuate more rapidly than the lower frequencies generated by larger magnitude earthquakes.

Another test of equation 2, comes from a recent empirical study of worldwide maximum horizontal accelerations (2), a_H, site intensity, I_{MM}, magnitude, M, and distance, R. The following relationship was obtained:

$$\log_{10} a_H = 0.14\, I_{MM} + 0.24\, M - 0.6 \log_{10} R + K. \qquad (3)$$

Using relations between site intensity and magnitude for the central United States (5), the following relationship was obtained:

$$\log_{10} a_H = -0.06 + 0.52\, m_b - 1.02 \log_{10} R + K,$$

which is similar to the form based on theoretical grounds (equation 2).

CONCLUSIONS

Initial attempts have been made to develop appropriate strong ground motion scaling relations for the central United States, a region with acknowledged earthquake hazard but without a suitable or extensive strong ground motion data base. The preliminary scaling relationships are made possible by a synthesis of all possible data including strong motion data, seismicity, spectral scaling and theoretical studies.

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