SOME ASPECTS OF SEISMIC HAZARD STUDIES IN WESTERN CANADA

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ABSTRACT

The seismic zoning maps and design requirements are currently being revised. Results of a seismic hazard study in northern Canada have pointed out some of the ramifications of using the attenuation forms on which the revisions are based. Comparison of the attenuation equations with available Canadian and western U.S. strong motion data and with attenuation equations based on strong motion data indicate a bias towards distant events. This will result in an overall conservatism in the zoning maps for acceleration and especially velocity from large magnitude and distant events. Limiting the attenuation of events larger than magnitude 7.5 such that they attenuate at magnitude 7.5 is a positive move insofar as it models the tendency towards saturation in the near-field. Response spectra based on the v/a ratio computed from these equations and results of comparative seismic risk studies for Juneau, Alaska illustrate this conservatism.

INTRODUCTION

Effective development of seismic design requirements for major structures requires the services of the disciplines of seismology, geophysics, geology and geotechnical and structural engineering. Even though the extent of effort required by each discipline and the interaction between the disciplines will vary from project to project, it is only rarely that understanding between groups is such that the implications of decisions reached by one discipline or another are understood.

The authors have recently been involved in an extensive seismic hazard study for a major project in northern Canada. As this work is still in progress specific details and results of the project cannot be made available. However, during the course of the studies some specific items which could be considered generic in detail have been investigated. As the Canadian seismic zoning maps are being revised together with the seismic design requirements for structures, those items which may be considered of some importance to the revisions are discussed below.

GROUND MOTION ATTENUATION

Considerable interest has been aroused over the attenuation of ground motion in Canada following the development of attenuation equations for peak acceleration and velocity by Hasegawa, Basham and Berry (14). These equations have been used by the Earth Physics Branch of Energy, Mines and Resources to produce revised seismic zoning maps for the entire country. Some implications of the use of these equations were discussed by Atkinson (1) and concerned the effects of the extremely large values given by the attenuation equations in the near field. This is a serious question as the justifications for the western Canadian equations recommended by Hasegawa et al are based on very small data values recorded at large source distances. Figure 1 shows the data set used by Joyner and Boore (16) with the data used by Hasegawa et al added. Figures 1a and 1b have an arithmetic scale for acceleration and velocity, respectively and show the extent of the data extrapolation necessary without the distortions that are produced by logarithmic scaling. The cross-hatched areas bound the Canadian data points. The data are presented again on Figures 2a and 2b with logarithmic motion scales. This in effect spreads over a wider range the small values which mostly occur at long distances. The apparent spreading will affect the resulting attenuation equation even in the near field.

The most direct way to avoid excessive values predicted by an attenuation equation in the near field is by the use of an additive constant to the distance term. Although Hasegawa et al recognize western earthquakes have generally shallow focal depths, they used a minimum depth of 20 kilometers throughout. If the Canadian data in Figures 1 and 2 were reduced using the Joyner and Boore distance constant, the cross-hatched area representing the range of the Canadian data would be transposed horizontally to the left. In addition, they assumed that the attenuation rate and the values of ground motion obtained for events of size large than M_s of 7.5 would be equal to events with an M_s of 7.5. Bolt and Abrahamson (3) by using a less restrictive equation form showed that a freer regression on the data can demonstrate the tendency towards saturation of values in the near field.

The motion parameter and earthquake magnitude differ exponentially in almost all attenuation relationships. The most common equation form is

$$y = b_1 \exp(b_2 M) X^{-b_3}$$

where b_1, b_2 and b_3 are coefficients, M is magnitude, and X is the distance term. Data to which an equation form is fitted are generally one of three types: isoseismal Intensity data, direct strong motion record data, or data based on some theoretical assumptions. A survey of magnitude coefficient b_2 from equations developed by various investigators is illuminating. For acceleration attenuation, the magnitude coefficients based on Intensity data and theory have a mean of about 1.1 $\pm$ 0.2 (14,19,21,23) but direct data based coefficients have a mean of about 0.7 $\pm$ 0.2 (4,5,7,8,9,11,12,13,16,17,24). For velocity attenuation, the Intensity and theoretical mean b_2 is about 1.9 $\pm$ 0.6 (10,14,19,23) and the direct data based mean is about 1.0 $\pm$ 0.2 (12,13,16,17,24). Although the means have no direct significance, they do show decisively that when Intensity or theoretical based approaches are used the magnitude term is given much greater significance than when developed directly from strong motion data. The result is that, when a magnitude coefficient is obtained independent of the strong motion data and the equation is then fitted to strong motion data which are usually available close to magnitude 6, the equation will overestimate ground motion values at high magnitudes and underestimate ground motions at lower magnitudes. This is demonstrated on Figures 3 and 4 where the Hasegawa et al equation, which has Intensity based magnitude parameters, is compared with strong motion data based relationships at different magnitude levels. With the assumed focal depth of 20 kilometers, the Hasegawa et al relationships give reasonable agreement at magnitude 6.0 but estimate values at higher magnitudes which exceed the other equations by significant amounts. This is especially so for velocity where values are assumed to increase by an order of magnitude for each magnitude step.

SEISMIC RISK MODELLING AND RESULTS

The seismic zoning maps prepared by the Earth Physics Branch of Energy, Mines and Resources used the Hasegawa et al attenuation equation with an assumed logarithmic error of 0.7. The source zones were based on seismologic and tectonic information. The seismic risk levels were then computed using the McGuire (18) risk program to provide estimated values of both acceleration and velocity.

The Hasegawa et al attenuation equations when used within a seismic source region of moderate activity will give results which are conservative when compared with results obtained by others. This is demonstrated in results presented by Basham et al (2) where they extended their contours into the Seattle, Washington area. Their value of 0.32g is approximately 50 percent larger than the value of 0.20g given by Donovan and Bornstein (9). The velocity to acceleration ratio from the Basham et al results of 100 cm/sec/g agrees with commonly accepted values. Difficulties arise, however, when the site being studied lies outside the major seismic source zone. This can be demonstrated by applying the Canadian source model and attenuation relationship to Juneau, Alaska. The values obtained for 10 percent exceedance in 50 years are 0.16g for acceleration and 25 cm/sec for velocity. The velocity to acceleration value in this case becomes 156 cm/sec/g, a value which is inconsistent with observed earthquake records.

The reasons for this imbalance can be found by examining the seismic source model and comparing the percentage contributions of the ground motion probabilities from each source. Percentage values were computed using the Canadian and Joyner and Boore (15) attenuation equations for acceleration and velocity. The source zones were established by the Earth Physics Branch and used for their revised seismic risk mapping. Events larger than magnitude 7.5 were assumed to attenuate as magnitude 7.5 in all cases. For both acceleration and velocity, the major contributors when the Canadian equations are used are the Fairweather-Yakutat and the Queen Charlotte Fault, two sources with high limiting magnitudes which are over 100 kilometers from Juneau. Using Joyner and Boore attenuation, the primary contributor is the Denali-Shakwak zone which is only about 13 kilometers from Juneau. Recognizing that the Hasegawa et al attenuation equations are considered to be compatible with the western North American data, examination of those data on Figure 1 suggests that such a high level of contribution for distances greater than 100 kilometers is not reasonable. The contributions from the distant sources are directly attributed to the larger exponential magnitude terms. These bias the risk contributions even though the attenuation of events larger than 7.5 magnitude is truncated.

The implications of this problem for the zoning maps of Western Canada will be an overall conservatism of the maps for acceleration and even greater conservatism together with a spreading bias for maps of velocity. Whether this will have significance to the seismic design code will depend on how the maps are interpreted and to which quantities and which locations the design values will be keyed.

DESIGN SPECTRA

Because seismic risk contributions come from several distinct sources, the choice of an acceleration time history for deterministic design at a site such as Juneau is very difficult. Hasegawa et al in response to the discussion of their work by Atkinson (1) suggested that design earthquakes be selected according to a procedure proposed by Cluff et al (6). The procedure, however, is inconsistent with detailed studies of faulting behavior by Sieh (25). Although the overall seismic activity in a region usually follows the Gutenburg-Richter relationship, paleoseismology is showing that most faults have repeated occurrences of similarly-sized events.

Spectra selected for a major structure should consider combined characteristics of several different earthquakes and if possible involve seismological participation. Fortunately, there are relatively simple procedures available for construction of design response spectra. The procedures we have used were first proposed by Newmark and Hall (22) who later modified the procedure and were further extended by Mohraz (20). Recent studies on direct attenuation of spectral parameters by Joyner and Boore (15) have confirmed the validity of the procedure provided both peak ground acceleration and peak ground velocity values are considered.

The procedure uses peak acceleration and velocity values obtained from a seismic risk analysis to construct response spectra using statistical spectral amplification factors. When this is done for the results of the Juneau seismic risk study, the spectra shown on

Figure 5 are obtained. The spectra are for 5 percent damping and show both soil and rock site spectra for the acceleration values obtained using the Hasegawa et al and Joyner and Boore equations. These show the critical importance of the velocity to acceleration ratio. Some inconsistent response spectra could result if the western Canadian zoning contours were used for sites distant from the major seismic source zones.

VELOCITY TO ACCELERATION RATIO

Velocity to acceleration ratios can be prepared directly from a strong motion data base or can be estimated from paired attenuation curves. Figure 6 shows the v/a values obtained from the data set shown in Figure 1 classified by soil type but not normalized with respect to magnitude. Superimposed on the figure are curves obtained by dividing paired attenuation equations and a directly derived relationship using the data points shown.

The conclusion could readily be drawn from Figure 6 that the v/a ratio is a widely varying and little understood parameter. Results of both methods of obtaining a relationship for the ratio consistently show that it increases both with increasing magnitude and increasing distance from the source. Spectral studies and developments for design codes which do not consider this variation are omitting a major parameter.

CONCLUSIONS

From the studies we have performed, some conclusions can be made. The principal conclusions are:

1. The Hasegawa et al attenuation equations developed for western Canada will overestimate ground motions during large earthquakes and underestimate the motion during small to moderate earthquakes.

2. The seismic zoning contours developed for the proposed revision to the Canadian Code by Basham et al (2) are conservative. The contour values in many areas may be more than 50 percent greater than would be obtained by others.

3. The assumption that large events produce ground motions which saturate at magnitude 7.5 is a positive step in the development of the seismic zoning criteria.

4. The development of design spectra from the results of the seismic zoning for acceleration and velocity are not recommended because of the excessive bias of the velocity results to contribution from distant seismic sources. An alternative procedure consistent with the conservatism of the acceleration contours would be to use the acceleration value and a v/a ratio represented by one of the less widely varying v/a relationships shown on Figure 5.

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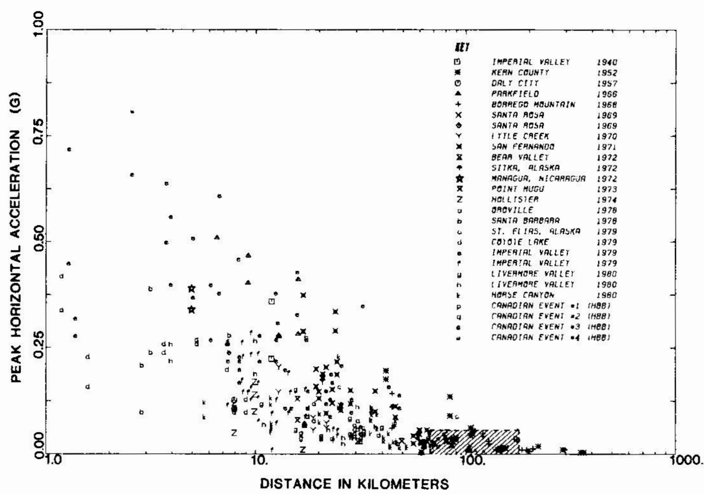


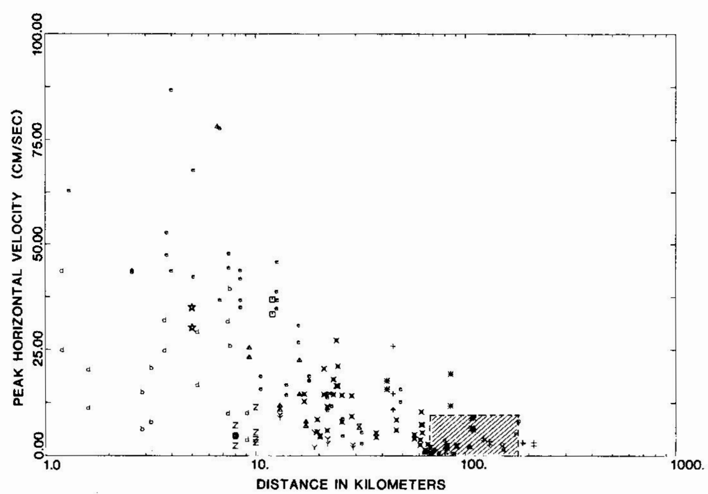
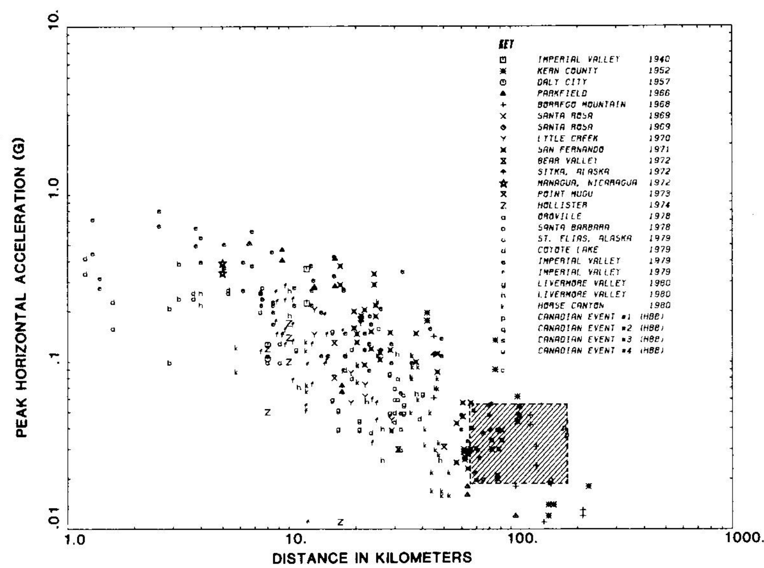


Figure 1. Instrumental Peak Acceleration and Velocity values of Western North American events. The data are an expanded list of the data prepared by Joyner and Boore with the Canadian data of Weichert and Milne added.



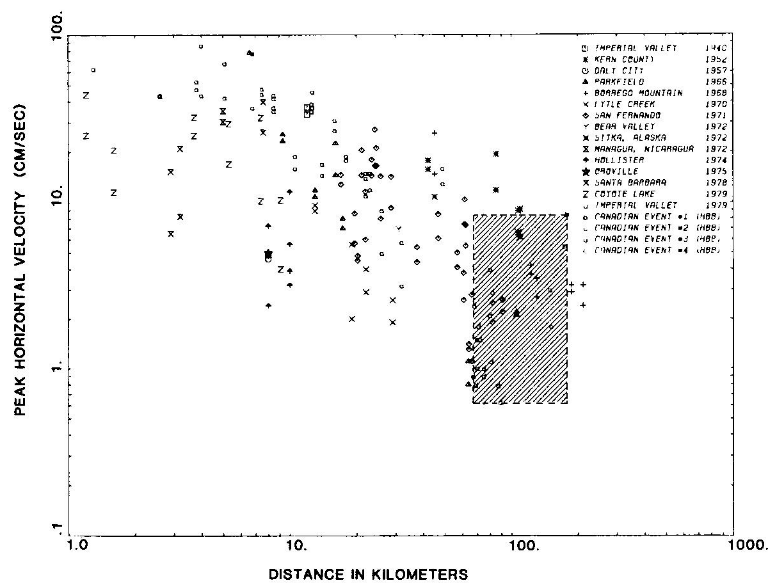
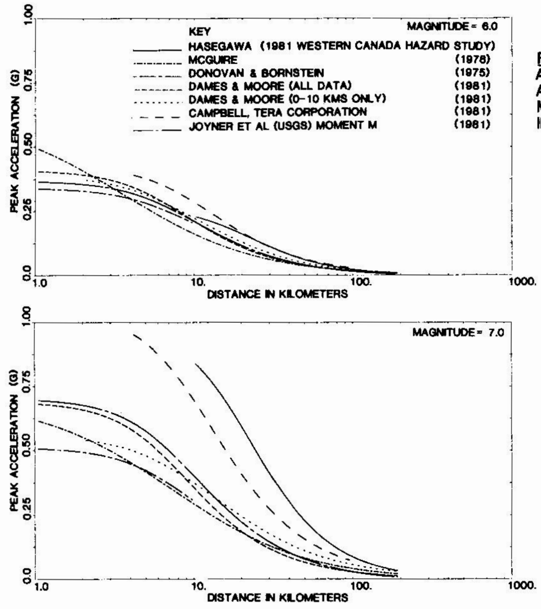
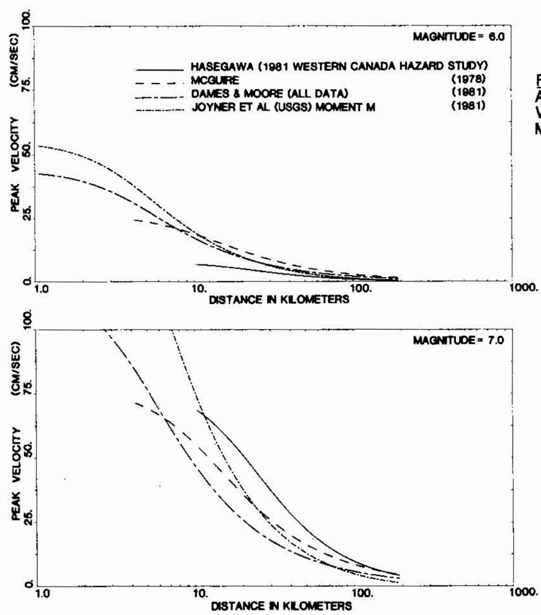


Figure 2. **Instrumental Peak Acceleration and Velocity values from Figure 1 plotted to a logarithmic motion scale.**



<u>FIGURE 3.</u> COMPARISON OF RECENT ATTENUATION EQUATIONS FOR PEAK ACCELERATION AT TWO DIFFERENT MAGNITUDE LEVELS. THE DISTANCES IN THE EQUATIONS VARY SLIGHTLY.



<u>FIGURE 4.</u> COMPARISON OF RECENT ATTENUATION EQUATIONS FOR PEAK VELOCITY AT TWO DIFFERENT MAGNITUDE LEVELS.

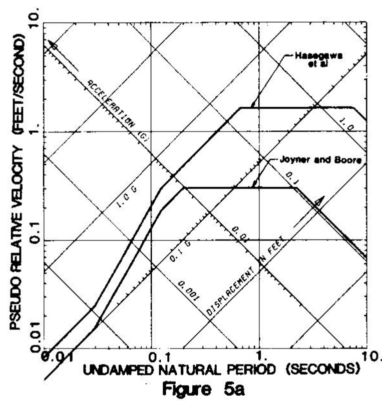


Figure 5a

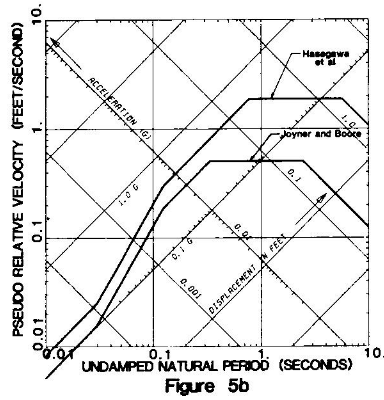


Figure 5b

Figure 5. Response spectra developed from the acceleration and velocity values obtained from seismic risk analyses using the Hasegawa et al and Joyner and Boore attenuation equations. The effect of the high velocity values obtained by Hasegawa et al model are readily apparent. Figure 5a shows spectra for a rock site and Figure 5b for a soil site.

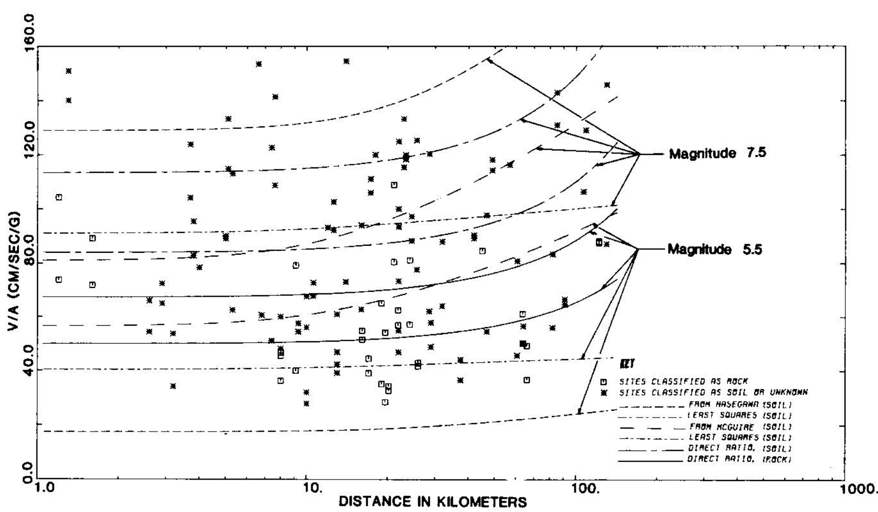


Figure 6. Velocity/Acceleration ratios obtained from data on Figure 1 with superimposed curves of various V/A equations. The Hasegawa, McGuire and Least Squares curves were obtained by division of velocity and acceleration attenuation equations. The direct ratio curves were obtained by multiple regression of the data shown on the Figure.