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On the attenuation of ground accelerations in Europe

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ABSTRACT: New attenuation laws predicting peak values of horizontal and vertical acceleration have been derived from a data set of more than 500 strong-motion records from Europe and adjacent regions. These regressions have been slightly improved, particularly for close, small magnitude events, by incorporation of the focal depth. The data set, although large and based only on consistently determined parameters, is insufficient to support a more sophisticated attenuation model or allow the inclusion of further parameters. The result is that although the predicted mean values are reliable, they are associated with a very appreciable scatter which the engineer must take into account in their use.

1 NEW ATTENUATION RELATIONS FOR EUROPE

1.1 Attenuation of peak horizontal and vertical accelerations

A set of attenuation laws have recently been developed for the estimation of peak ground accelerations in Europe, (Ambraseys & Bommer 1991). The data used have been obtained from earthquakes, chiefly in the European area, for the period 1967 to 1990, and consist of 529 free-field strong-motion records produced by 219 crustal events, (Ambraseys & Bommer, 992). In this set of data, the bulk of which was recorded by standard Kinemetrics SMA-1 type of accelerographs, surface-wave magnitudes M_s range from 4.0 to 7.3, and source-site distances, d, from 0 to 313 km. Recorded accelerations vary between trigger level and 0.99g horizontally, a_h, and 1.30g vertically, a_v.

From these data and from the recalculated or re-assessed source parameters of the causative earthquakes, such as magnitude, focal depth, and source-to-site distance, a set of empirical laws have been derived for the attenuation of peak ground acceleration as a function of the size and distance of the seismic source. For crustal events (h<30 km), if no account is taken of the focal depth, the attenuation of peak horizontal and vertical accelerations, in g, are given by

$$\log(a_h) = -1.09 + 0.238M_s - \log(r) - 0.00050(r) + 0.28P \quad ...(1)$$

$$\log(a_v) = -1.34 + 0.230M_s - \log(r) + 0.27P \quad ...(2)$$

where $r^2=(d^2+6.0^2)$, d being the source distance in km and M_s the surface-wave magnitude. P is 0 for 50-percentile values and 1 for 84-percentiles. These equations have been derived by restricting the coefficient for geometric attenuation to -1.0, which corresponds to a spherical model of energy spreading. It is of interest how similar these results are to those obtained from 182 selected recordings of ground motions generated by 23 well-studied North American earthquakes, (Joyner & Boore 1981):

$$\log(a_h) = -1.02 + 0.249M - \log(r) - 0.00255(r) + 0.26P \quad ...(3)$$

with $r^2=(d^2+7.3^2)$, and M being the moment magnitude. Figure 1 compares values predicted by the North American and European data sets for magnitude values of 5, 6 and 7.

1.2 Depth controlled accelerations

It was thought that the same simple model might be applied to assess the effect of focal depth on the attenuation of acceleration, an important parameter, usually not taken into consideration. In fact the introduction of h directly into the same attenuation model proved effective . In spite of the uncertainties involved in the determination of this parameter, particularly for small magnitude events, if its effect is allowed for, the equations corresponding to (1) and (2) become:

$$\log(a_h) = -0.87 + 0.217M_s - \log(r) - 0.00117(r) + 0.26P \quad ...(4)$$

$$\log(a_v) = -1.10 + 0.200M_s - \log(r) - 0.00015(r) + 0.26P \quad ...(5)$$

where now $r^2=(d^2+h^2)$, valid for h<25 km.

The introduction of the focal depth into the regression model accounted for most of the accelerations that had been grossly underestimated by equation (1), which were chiefly from very shallow earthquakes. One outlier, however, is still underestimated by almost an order of magnitude, and its association is therefore doubtful; its removal from the data set results in an equation which is essentially identical to equation (4).

These relationships show that at short source distances from medium to small magnitude events the focal depth, as it should, has a strong influence on ground motions. For large crustal earthquakes this effect on peak ground acceleration should be less important at close distances. However, it is difficult to estimate this effect because of lack of near source data. Figure 2 compares values predicted by equations (1) and (4) for a magnitude of 6 and different focal depths.

We have included the effect of focal depth in the data used to derive equation (3) with the following results:

$$\log(a_h) = -1.00 + 0.251M_s - \log(r) - 0.00268(r) + 0.26P \quad ...(7)$$

where r is defined as in equations (4) and (5). However, the range of depth values in this data set is too narrow for the results to be representative, with 15 of the 23 earthquakes having focal depths between 5 and 10 km. In the North American data set, only two accelerations a re underestimated by a factor of more than 3 using equation (3); they remain as outliers using equation (7), but are less severely underestimated.

1.3 Other factors

It was found, incorporating the soil classification into the regression, that average accelerations at soil sites are only 8% larger than those at rock sites, whereas the standard deviation of the regression is 80% of the mean. Other studies, such as Sabetta & Pugliese (1987), have found that to identify the effect of soil sites it is necessary to separate very shallow and very deep deposits from intermediate depth layers. This suggests that it is important to obtain more detailed information about the site conditions at Eurasian stations, but the availability of this data is limited.

We find that for the European data the regression for the same attenuation model gives a mean ratio of the peak vertical to horizontal acceleration (a_v/a_h) which is almost independent of magnitude and distance, and equal to 0.5 with a standard deviation of 0.19P of the log of the ratio.

2 DISCUSSION AND FURTHER CONSIDERATIONS

2.1 Attenuation model and engineering applications

For engineering applications attenuation laws must be simple and they must involve design variables that can be assessed by the engineer a priori with some confidence. The uncertainties associated with predicted values may be large, but provided the engineer is aware of this he can always balance his design using appropriate factors of safety.

Equation (1) represents the simplest model that involves only two of the many variables that control attenuation, namely the size of the event and the site-source distance. This equation is a linear function of magnitude, with a magnitude independent shape, and of two distance dependent terms; the first representing geometric losses, while the second term accounts for anelastic losses, with a coefficient which is independent of distance and magnitude.

It is obvious, therefore, that this model does not take into account the size of the source and associated mechanism, the local foundation conditions, source-to-site path effects, frequency content of the record or source depth. Consequently, this model cannot be expected to estimate peak ground accelerations better than within a factor that we find to be about two and the scatter does not seem to improve much by refining the model without increasing the number of variables. The introduction of additional variables on the other hand may improve the fit of the data but this will put the onus on the selection of the appropriate values for these variables.

Some indication of the site effect can be obtained by examining the levels of acceleration recorded at stations which have been triggered by several earthquakes in order to examine whether they are consistently in disagreement with the values predicted by the regressions.

2.2 Anelastic and geometric attenuation

In the regression model used the geometrical spreading has been constrained to a spherical model. It has been found, as would be expected, that if an alternative model, such as the Airy phase - with a coefficient of -0.83 instead of -1.0 - is used, then much higher values for the coefficient of anelastic attenuation are obtained. In equation (4) the coefficient of anelastic attenuation becomes -0.00223, but the mean values predicted by the equation remain almost unchanged.

Joyner & Boore (1983) reasoned that their data set was insufficient to simultaneously determine admissible values of both coefficients. This is partly due to the poor distribution of the data sets, and particularly the correlation between magnitude and the logarithm of distance, which for the North American data set is 0.38 and 0.51 for the European data set.

For both the European and North American data sets, allowing both coefficients to be determined simultaneously results in values for the geometric exponent smaller than -1, for the attenuation of amplitude. This is formally inadmissible, and such values suggest that the data set, the model or both, are inadequate.

The use of data from the far-field also presents some problems, and can lead to a positive bias in the estimation of the accelerations of events that are near the detection threshold of the network. One may exclude records at distances from the earthquake source greater than the shortest distance to an operational but non-triggered instrument. However, the level of information available from European networks does not permit the rigorous application of such a criterion.

2.3 Distribution of data sets

One of the most important factors that influence the derivation of a representative but simple attenuation law is the distribution of the input data, as well as their quality.

Different data sets used for the derivation of global or local attenuation laws have different bias in their distribution. These data sets may lack information from large events, large accelerations at close distances or the range of magnitudes may be narrow or derived from different scales (M_L, M_D, m_b, M_s, M_w).

In many of the derivations of local attenuation laws, use is often made of all the available data, sometimes from different regions, regardless of their quality, homogeneity and range of variables with the result that whatever law might be under consideration some of the data are found to agree with it. This attitude only contributes to the proliferation of local attenuation laws of ephimeral validity which confuse the unitiated engineer or give a wide choice to the designer for the selection of convenient design ground motions. Our approach has been to use all the available data from one particular region, provided uniform magnitude and distance determinations were available for the record, and other than applying a lower cut-off on magnitude values no other exclusion criteria were applied.

Some of the outliers in our data set show that abnormally large peak accelerations of a few cycles at high frequency seem to come from genuinely free-field records. Although no data is yet on hand, it is likely that the fact that in other records from the same events these high amplitudes are not present, these high frequency spikes have been filtered out by relatively large foundations on which instruments were located, or simply because of the limitation of analogue instruments to faithfully record amplitudes associated with frequencies beyond the 25 Hz fundamental of their transducers.

2.4 Measurement of source-site distance

Source-site distances may be epicentral for the smaller events, but for the larger shocks they must be distances measured from the nearest point on the volume of the source. For this latter case the distance from the nearest point on the surface projection of the causative fault rupture is a suitable measure of the source-site distance. The structure of r in our model is such that it does not allow the discrimination between source distance d and focal depth h, since in the expression for r these values are interchangeable. For instance, if the source were directly below the instrument, the focal depth would represent the distance of the source. In reality, however, the way in which h appears in the expression for r represents also the distance d for an event of zero depth.

In general, the errors associated with distances measured from the surface projection of the earthquake source or from a fault-break are small. However, for small magnitude events, where distances are controlled by the accuracy of the teleseismic location, errors can be much larger and difficult to assess. For relatively small earthquakes (M_S<5. 5) the source distance r is comparable to the focal distance. Its value, derived from the epicentral distance and focal depth, may be checked using the time interval between triggering and S arrival. When these t_{s-st} times can be interpreted as good approximations to (S-P) times, they can be used to check r values of small events, the location and depth of which are often uncertain. For events with h<20km and t_{s-st} <6 sec, we find that for the European area $r=4.0+6.8(t_{s-st})$ is a good approximation.

REFERENCES

Ambraseys, N.N. & J.J. Bommer 1991. The attenuation of ground accelerations in Europe, Earthquake Engineering & Structural Dynamics 20, 1179 -1202

Bommer, J.J. & N.N. Ambraseys 1992. An earthquake strong-motion databank and database. Proceedings, Tenth World Conference on Earthquake Engineering, Madrid.

Joyner, W.B. & D.M. Boore 1981. Peak horizontal acceleration and velocity from strong-motion records, including records from the 1979 Imperial Valley, California, earthquake, Bulletin of the Seismological Society of America 71, 2011-2038.

Joyner, W.B. & D.M. Boore 1983. Comments on "New attenuation relations for peak and expected accelerations of strong ground motion" by B.A. Bolt and N.A. Abrahamson. Bulletin of the Seismological Society of America 73, 1479-1480.

Sabetta, F. & A. Pugliese 1987. Attenuation of peak horizontal acceleration and velocity from Italian strong-motion records. Bulletin of the Seismological Society of America 77, 1491-1513.

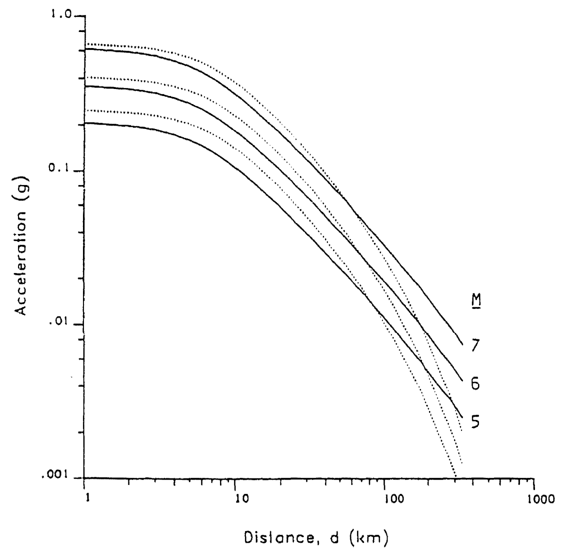

Figure 1. Predictive curves for mean peak horizontal acceleration as a function of source distance d from equation (1) for magnitude values of 5, 6 and 7 as indicated. The dotted lines are the curves derived from the North American data set of Joyner and Boore (1981) with re-calculated surface-wave magnitudes.

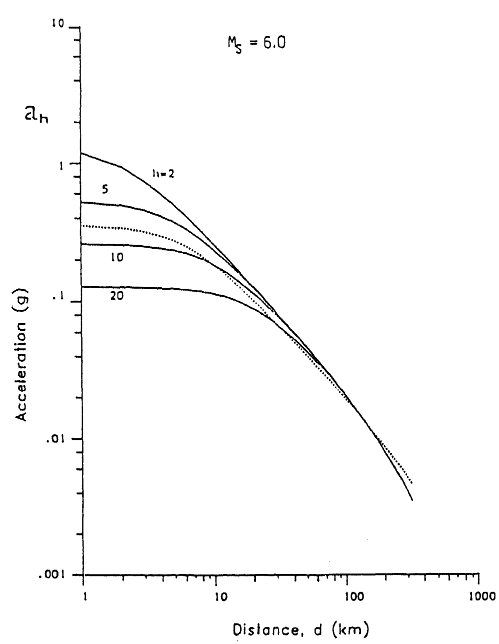

Figure 2. Curves predicting peak horizontal accelerations from equation (4) for magnitude 6 and h values as indicated. The dotted curve shows the values given by equation (1).