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Seismic vulnerability functions based on strong ground motion and their usefulness in risk studies and interpretation of historical data

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ABSTRACT: Earthquake risk studies despite the large increase in strong motion data are still relying in traditional intensity scales (MM in USA, JMA in Japan and MSK, MM in Europe) for estimating damage to buildings and effects on their occupants. No much effort has been made to build-up damage databases in correlation with strong motion records after damaging earthquakes. Such studies help improve our understanding of the damage potential of ground shaking to various types of structures (buildings, civil engineering structures, lifelines, equipment) in an increasingly complex urban infrastructure. Furthermore they can also be very useful in improving our estimations of what actually happened during historical earthquakes for which we have anecdotal damage descriptions.

1. Introduction

A significant amount of historical data is currently being extracted and analysed mostly in European and Middle Eastern countries in order to enhance the reliabilty of seismic hazard and risk assessment. Furthermore the amount of installed strong motion instruments and ground motion records has increased significantly. This has permitted to improve our understanding of attenuation of seismic ground motion with distance, magnitude and to a lesser degree different ground conditions or types of earthquake faulting. Nevertheless the question of prediction of damage to buildings and other structures in relation to different levels of ground motion severity remains underesearched. This is partly because the amount of strong earthquake records is limited and partly because there has rarely ever been a consistent attempt to investigate damage to buildings nearby the location of recording sites. On top of that the damage surveys tend to be less standardised and the information is rarely processed to a level higher than simple damage statistics and scarcely published in sufficient detail. Furthermore most surveys are done with intensity scales in mind and as a result the information is averaged to each intensity degree. Different intensity scales and methods of quantifying the damage (number of damage degrees or mean damage ratios or replacement cost percentages) further enhance the handicap in making such valuable information more useful.

2. Vulnerability functions based on ground motion severity.

Many researchers have obtained relationships between ground motion (mostly peak horizontal acceleration) and various intensity scales (mostly MM, MSK and MCS). Some of the most commonly used conversions between peak horizontal acceleration and intensity are shown in Figure 1.

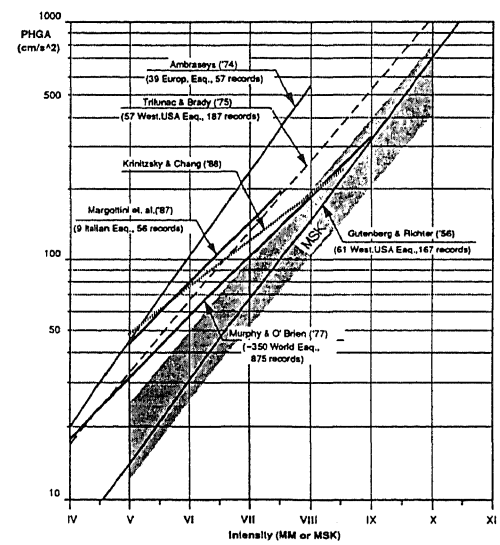

Figure 1: Correlation between Peak Horizontal Ground Acceleration (PHGA) and Seismic Intensity. The shaded area is that of the MSK'64 scale.

Although such relationships are useful for seismic risk assessment, it must be pointed out that the intensity values portray the average severity of the motion experienced over a given area while the ground motion parameters were recorded in just a point within this area. As it is shown in Fig. 1 there is a significant difference between the predicted values of acceleration for each intensity level. It is also shown that almost all of the studies predict higher peak accelerations for each intensity degree, than those values expected in the original definition of the MSK intensity scale (in 1964).

In order to investigate the damage potential of ground motion it is important to be able to correlate it with observed damage. To achieve this, the Martin Centre has carried out damage surveys in the vicinity of recording stations after damaging earthquakes. The surveyed areas were within a radius of at most 400 metres from the instrument location, if the soil conditions did not change significantly. All the buildings within the area were assigned a damage degree (using the 5 damage degrees of the MSK scale).

In order to further enhance the accuracy of our damage-motion correlations we must also try to avoid aggregating the observed damage to a single intensity degree. The problem with all intensity scales is that they are incerememental, while all strong motion parameters are continuous. A new numerical methodology for quantifying the observed damage on a continuous damage severity scale has been proposed (Spence et. al., 1992, 10 WCEE Proceed.). This scale has been called PSI (ψ). Using a damage database of about 70,000 buildings, reliable vulnerability functions have been obtained for 11 construction types, ranging from low-strength rubble stone masonry to RC frame structures of aseismic design. Moreover the usefulness of this approach is that the vulnerability functions are relative to each other, meaning that we may be able to use damage information to a particular construction type (say dressed stone masonry, common in *historical data*) in order to extrapolate what might happen to modern building types (say brick masonry or RC frames).

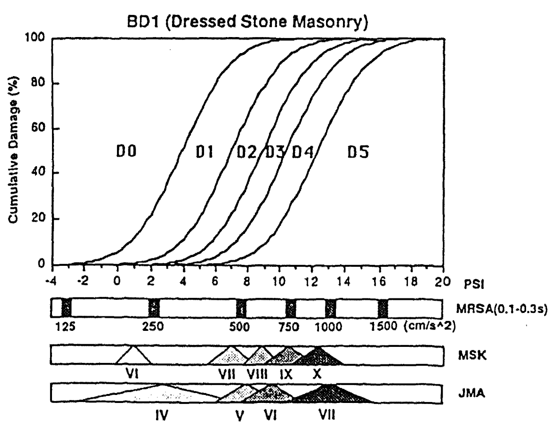

Figure 2: Example of vulnerability function for dressed stone masonry buildimgs. The curves represent the 50% probability in cumulative form.

At the same time using the data from the damage surveys around recording stations (about 2300 buildings) it was possible to create a database of damage to various building types strictly related with ground motion (PGA ranging from 6% to 65%g). Damage surveys in 15 sites, due to 8 earthquakes in Italy, Greece, Romania, Turkey, Armenia and Iran are included. The PSI value from each survey was correlated to 14 different ground motion parameters in order to investigate their appropriateness in seismic risk assessment. The best correlation (r=0.82) was obtained with mean response spectral acceleration in the 0.1 to 0.3 sec range (because most of the surveyed building stock was low-rise). The correlation between PSI and MRSA or PGA and MSK-81 intensity scale is shown in Figure 3.

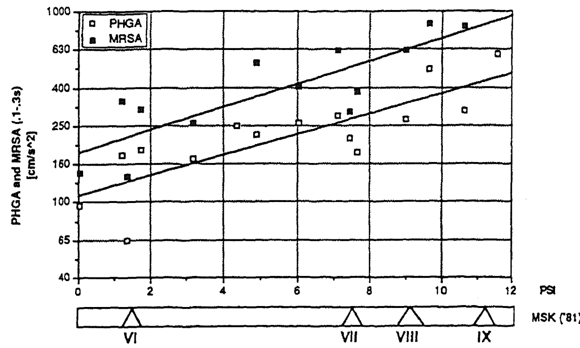

Figure 3: The correlation of PSI with peak horizontal acceleration and mean response spectral acceleration (period range: 0.1-0.3s).

Similar research was initiated in ITSAK Institute in Thessaloniki, Greece (Lekidis et. al., 1992, 10 WCEE Proccedings) and ENEA-ENEL in Roma, Italy (Engineering Geology: Margottini et. al., 1992).

3. Brief Conclusions

The results suggest that the frequency content and amplitude of the motion seem to be the most crucial factors in damage occurrence. Parameters that solely rely on record's energy release and duration can be misleading, since it seems that buildings are able to withstand moderate motions (less than 20%g peak acceleration) even when the duration of strong shaking exceeds 20 seconds. Response spectral acceleration and velocities as well as their product seem to correlate best with the extent of damage.

Historical data that contain descriptions of building damage in a quantifiable form (e.g. 1672 Rimini, 1743 Ionian Sea, 1887 Imperia earthquakes) can be gathered and a first attempt to obtain PSI values can be made. If this proves successful extrapolation to other contemporary building types may also be attempted.