The Relationship between Macroseismic Intensity and the Physical Parameters of Ground Motion

A viewpoint by B. Mohammadioun and G. Mohammadioun

Prior to the advent of instrumental seismology, the consequences of earthquakes and specifically their impact on man and his constructions were characterized by macroseismic intensities. Subsequently, scientists and engineers endeavoured to relate this intensity, which is subjective in nature, to some ground motion parameter—most frequently to Peak Ground Acceleration (*PGA*). However, as the collection of instrumental data grew, the results became progressively more scattered, and the scientific community increasingly perplexed. The well-known graphs published by N. N. Ambraseys in 1974 effectively illustrate this development (Figure 1), and fired heated debate. What factors were responsible—the way the intensity scale was designed, the randomness of peak acceleration, the vulnerability of the structures analysed in the intensity assessment, or any combination thereof? Medvedev, in 1962, thought to introduce a third parameter in the correlation, namely the fundamental period of the buildings. This solution, albeit not a panacea, materially decreased the degree of scatter (Figure 2).

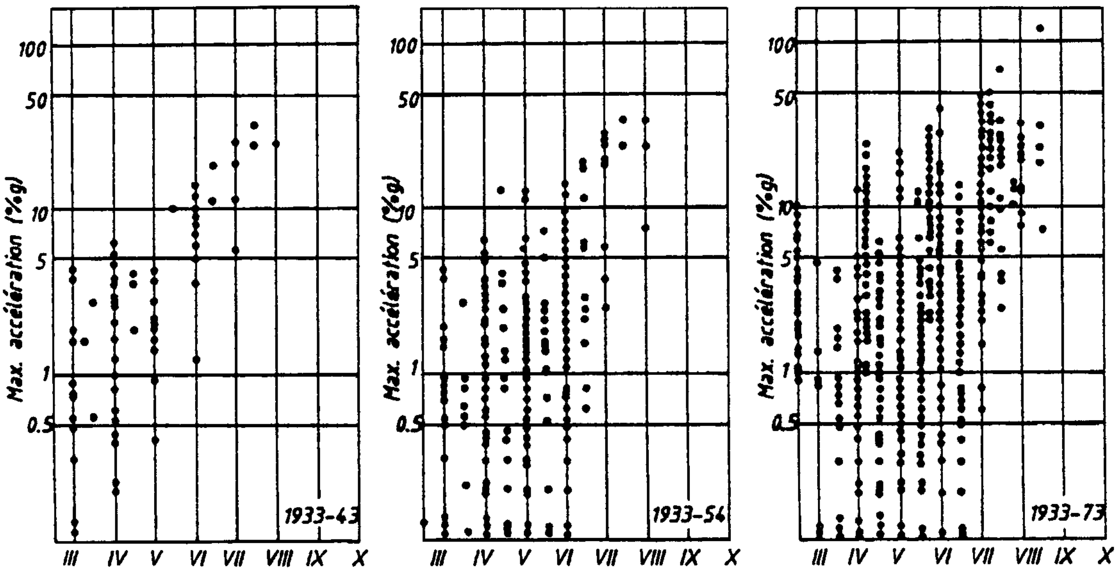

Figure 1. The evolution of acceleration/intensity correlation over time (from Ambraseys, 1974).

Another possible explanation that may not have come under as much scrutiny with respect to this issue could lie in the means used to assess the peak acceleration. It is a recognized fact that recording instrument technology has been revolutionized since 1933, with the historic record of the Long Beach, California, earthquake. At the same time, data processing methods and capabilities including sampling and the computation methods called upon have evolved to a very considerable extent, in parallel with the development of computer technology. In the early days of strong-motion seismology, these three factors would all have contributed jointly to the loss of information at high frequencies, the very ones liable to account for the actual peak acceleration. Thus, the observations during the first decade of strong-motion seismometers arguably correspond to accelerations measured at lower frequencies, that display less variability. Furthermore, with the passage of time and as the density of the networks increased, larger numbers of the accelerograms retrieved concerned lower-magnitude events, which may well behave differently from larger-magnitude ones, and the proportion of near-field data in the total database grew. All these elements are important sources of variability: high frequencies are not very predictable, influenced as they are by many factors, stress drop being prominent, but which also include effects only significant in the near field, such as fault geometry and directivity. As proof of the impact of this evolution, every few years witness new record-breaking peak accelerations that would have been deemed physically impossible just a few decades back. Initially believed to be limited to about 0.3 g, values today may top out at some eight times that figure, as in the most recent events in Japan (Oct. 28, 2004, M=6.8) and particularly at Parkfield, California (Sept. 28, 2004, M=6.0)!

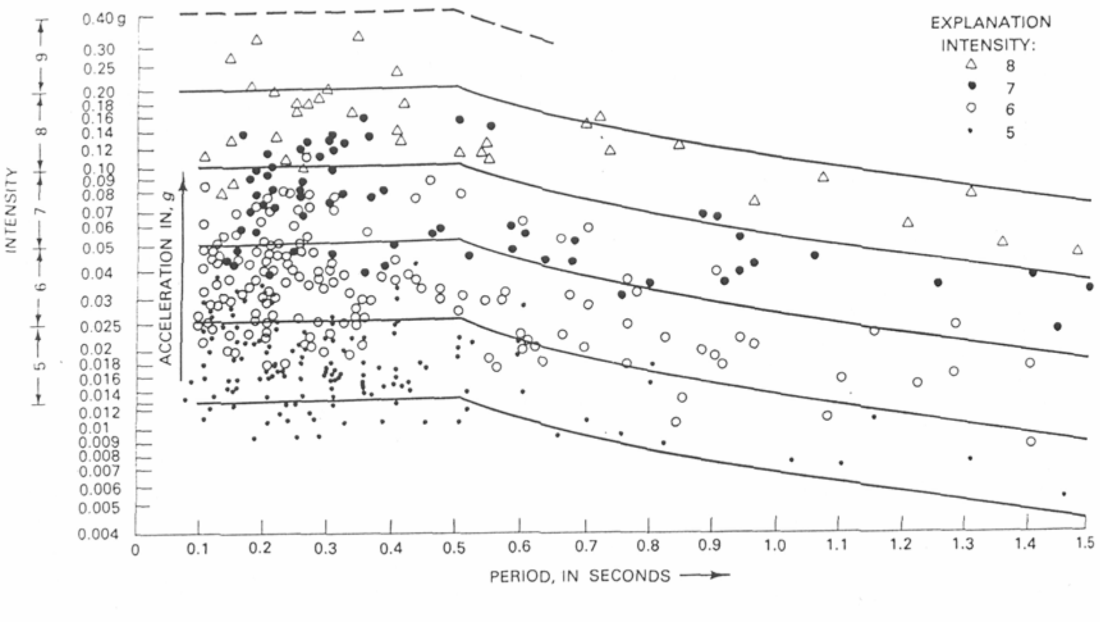

Figure 2. The correlation between intensity and acceleration corrected by the predominant period of the structures.

On the other hand, the correlation between macroseismic intensity and velocity displayed less scatter, as will be observed on Figure 3 (Menu, 1991), which depicts the variation between peak ground velocities (*PGV*) recorded during the 1971 San Fernando earthquake and the intensities assigned to the recording sites. This will hardly come as a surprise: the damaging effects of earthquake ground motion are known to relate to the energy flux in a structure, which is characterized by particle velocity and more particularly by the duration of strong ground motion (expressed by Arias intensity, among others). A short-duration earthquake with a single large acceleration peak does not cause significant damage, as observed with the Ancona, Italy, swarm in 1972, where an event with a recorded acceleration of 0.6 g was assigned a macroseismic intensity of less than VII. Lately, Panza *& al.* (1997, 1999) have determined new relations between intensity (*I*) and the peak values of acceleration, velocity, and displacement, valid for Italy and which appear promising.

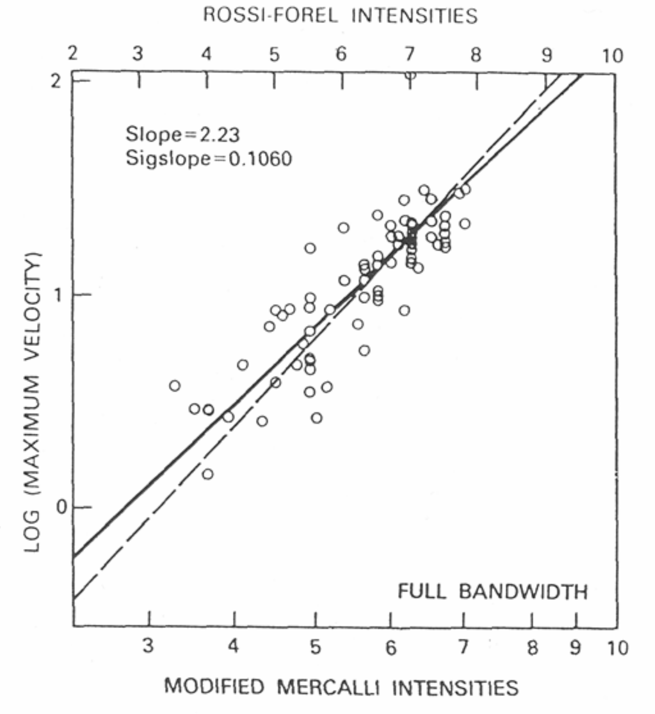

Figure 3. A correlation between peak ground velocity and intensity (from Menu, 1991).

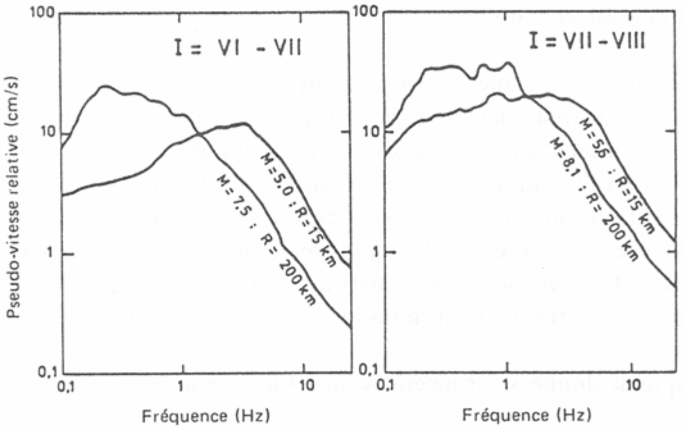

Figure 4. Synthetic spectra for shorter and longer-distance events corresponding to two intensity classes (from Mohammadioun, 1985).

Over recent decades, in response to the call for earthquake-resistant design suitable for critical structures such as nuclear power plants or dams, the need arose to predict reference spectra, such as the *Safe Shutdown Earthquake* (*SSE*) in U. S. Nuclear Regulatory Commission (USNRC) regulations, or *SL2* in International Atomic Energy Agency (IAEA) guides. But here, the drawback lies in how to make use of historical earthquakes characterized by macroseismic intensity alone. This data is of crucial importance insofar as it extends the window of observation enough to procure a meaningful seismicity sample.

As is seen on Figure 4 (Mohammadioun 1985), the earthquake recordings for a given intensity class and the spectra obtained from them are extremely variable with respect to magnitude and distance from the epicenter. One explanation for the scatter of the results, therefore, could be the spectral distribution of the ground motion: a distant large-magnitude event with a low-frequency spectrum and a nearby moderate-magnitude event with a high-frequency spectrum both represent the same intensity value. On Figure 5 (Levret & Mohammadioun, 1984) it will further be noted that the values for spectral velocity are fairly stable between 1 and 2 Hz, and a one-degree increase in intensity approximately doubles the velocity level.

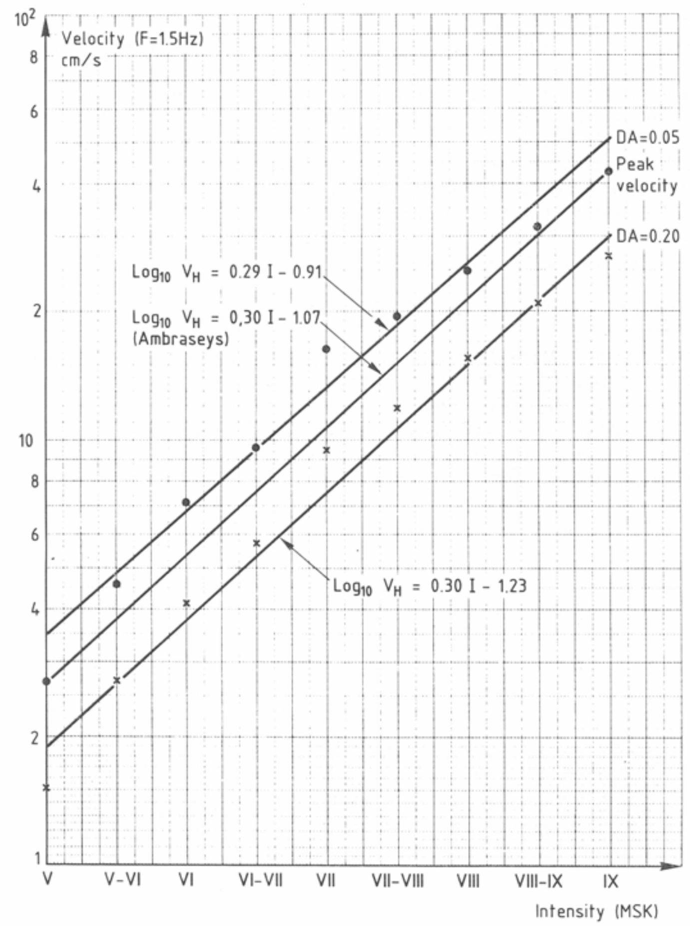

Figure 5. Correlation between intensity and velocity (from Levret & Mohammadioun, 1984).

Synthetic ground-motion spectra are calculated from attenuation models derived from strong-motion data, now plentiful enough to support statistical correlations (Boore & *al.*, 1997, among others). This approach again seemingly bypasses the wealth of historical data essential in regions lacking accelerometric data, for whatever reason (absence of networks or low levels of seismic activity). However, there is an approach allowing this gap to be bridged: if a data bank can be established where the parameters of magnitude, M, recording-site intensity, I, and focal distance, R, have been determined in a uniform manner, correlations can be established linking the three parameters, as in Mohammadioun, 1995:

$$M_L = 0.54\,I + 1.40 \log R + 0.57$$

or Ambraseys, 1991:

$$M_S = A + B\,(I_i) + C\,(Ri) + D \log R_i$$

based on 20th century crustal earthquakes, where teleseismic M_S values were correlated with observed macroseismic estimates of R_i and I_i. In this study, sets of constants were computed for three different regions of Europe, as shown on the following table:

	A	B	C	D	r^2	n
Balkans	-0.902	0.578	1.10×10^{-3}	2.11	0.78	354
Turkey	-0.529	0.528	1.96×10^{-3}	1.83	0.94	494
NE Europe	-1.100	0.620	1.30×10^{-3}	1.62	0.92	300

where r^2 is the coefficient of correlation and n, the sample size.

Conclusion—which ground-motion parameter? As will have been understood from the foregoing discussion, *PGA* is actually a very imperfect parameter to use in earthquake-resistant design. If it still continues to be in demand amongst the engineering community, the simple reason is that the static calculation of conventional structures requires it. For the more sophisticated treatment of engineered structures, a dynamic analysis is performed using response spectra or acceleration time histories, which do provide important information on signal duration. The suitability of velocity as a parameter was looked into above, and a tendency is currently emerging that resorts to displacement-based design.

And which intensity? As stated above, the evaluation of whichever ground motion parameter is chosen, whether this is performed directly, from classical intensities, or by using a magnitude/intensity correlation, cannot avoid being biased notably by structural response (*cf.* Figure 2) and the influence of the magnitude/distance pair (*cf.* Figure 4). In contrast, the INQUA intensity scale, since it relies mainly on source effects in the near field, will in all probability prove to be a better "candidate" for establishing a correlation between intensity and either a ground motion parameter or magnitude.

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