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Damage *versus* ground acceleration correlations during the November 23 1980, Irpinia earthquake

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Abstract
This paper describes the correlation between felt reports and instrumental ground-motion parameters for the 1980 Irpinia earthquake. It is stressed that a correlation between intensity and peak ground acceleration estimated for engineering purposes does exist, but also that the accuracy of this correlation depends on the type of structure on which the intensity estimate was based. The paper also discusses the role of intensity observations, and how these should relate to instrumental data when both are available such as for modern earthquakes. The final goal is that of calibrating more and more precisely the intensity observations against the relevant ground-motion parameters, but it should also be clear that complicated intensity rating definitions may reduce our ability to evaluate historical earthquakes, for which macroseismic data are the only suitable source of information.

1. Introduction

Intensity experienced at a certain location is an index of the effects of the earthquake. There are a number of different intensity scales and these group the «felt» information into categories expressed as ordinal numbers. This is, in fact, similar to expressing the height of a building by the number of storeys that it possesses. Just as it is absurd to speak of a building with a non-integer number of storeys, it is equally meaningless to speak about non-integer intensity values, in the strict sense. On the other hand, the necessity of the transcription of these discrete valued intensities to a continuous measurement is real and immediate for the engineer-seismologist and the risk analyst.

Aside from the academic interest of the problem, there are two basic reasons for investigating intensity information to be used in seismic-risk assessments.

Firstly, for structures which are to be designed for relatively low risk levels (*i.e.* important public work structures, power plants, etc.) seismicity catalogues based on instrumental data only are inadequate for a reasonable description of the seismic history.

Secondly, in most parts of the world local attenuation relationships can only be based on intensity information.

Damage incurred on structures during an earthquake can be correlated to one or more of the ground-motion parameters: acceleration, velocity or displacement weakly or strongly depending mainly on the dynamic characteristics of the structure in question. This holds true only in the case where permanent deformation of soil (*i.e.* soil failure) is not a major issue.

The strong correlation of acceleration to damage is limited to «high-frequency» structures, such as low-rise rigid buildings on firm soil as well as monuments and memorials.

Damage to monuments is one of the more reliable indicators of the level of acceleration due to their simple geometry, good uniform construction and high frequency. The MSK scale refers to damage (translational movement and twisting) of monuments and tombstones for intensity VIII.

2. The case of Irpinia

In the case of the Irpinia earthquake of 23 November 1980, the fact that soil failures have played an important role in the type and extent of the damage cannot be denied (Gürpinar *et al.*, 1981).

The maximum acceleration was registered in Sturno where there was deep cracking of the reinforced concrete slab of the instrument building. To what extent this damage influenced the record itself is still an unanswered question.

If a «local» intensity were to be assigned to this building (please see next section), it would be at least VII.

As for monuments, Irpinia area is rich in these, each settlement possessing one in the village square. It is of interest to note that in villages which were largely damaged by the earthquake (such as Laviano, Lioni, S. Angelo dei Lombardi) the monuments were totally unharmed still standing in the middle of a hill of debris from destroyed rubble masonry houses. By contrast, the translational and torsional movement of similar structures can be seen in the epicentral area of a much smaller earthquake (M = 4.7) which took place in Liège, Belgium on 8 November 1983 (Gürpinar, 1984).

3. Improvement of correlation

Although damage to structures due to soil failure is of great importance, preventive measures can be taken using proper siting, microzonation or design criteria in order to minimize this effect for certain structures. When this is done, the database to be used in correlations should be determined selectively.

Margottini *et al.* (1989) have used a selective approach in determining the «local» intensity defined in the immediate vicinity of the strong-motion accelerograph station. This resulted in an improved correlation coefficient as compared to that between the «general» intensity (*e.g.*, defined for the whole village) and acceleration. Using the proposed «local» intensity values on the MSK scale for the fourteen recording stations for the Irpinia earthquake another simple test was made to check the correlation based on engineering practice, as follows:

i) estimate mean values for acceleration for each MSK intensity level,

ii) multiply and divide these by 2 in order to account for uncertainties in dynamic soil characteristics and to provide an appropriate interval,

iii) check whether or not the recorded acceleration value at each station is inside or outside this interval.

For step i), rounded engineering values were assigned to each intensity level, *i.e.* 0.05 g for I = VI, 0.1 g for I = VII, 0.2 g for I = VIII, etc. Therefore, the acceptance interval (step ii)) for I = VII would be from 0.05 g to 0.2 g. The results of this check are given in table I.

It can be seen in table I that for local intensity 13 out of 14 stations recorded accelerations within the interval of acceptance, five within 10 % of the average estimate. For general intensity only 4 out of 14 are accepted.

The above example illustrates the benefit of improving the database for correlation purposes. Since the original purpose of the intensity rating was not necessarily for correlation with ground-motion parameters, looking at the cause of damage and focusing on the station vicinity is a plausible method of getting improved results.

Table I. Acceptance/non-acceptance of acceleration values for local and general intensities.

Station	Local Intensity (MSK)	General Intensity (MSK)
Arienzo	A	N–
Bagnoli Irp.	A	N+
Brienza	N+	N+
Mercato S. Sev.	A	A
Sturno	A	N+
Calitri	A-C	N–
Auletta	A-C	N–
Rionero in V.	A-C	A
Bisaccia	A	A
Benevento	A-C	A
Torre del G.	A	N–
Tricario	A-C	N–
Bovino	A	N–

Legend: A: acceptable, N: not acceptable, C: close (*i.e.* within 10% of average value), +: acceleration too high, –: acceleration too low.

4. What should intensity measure

At present there is serious work going on in the scientific community to modify the MSK intensity scale. There may be several ways of proceeding in making this change. However, some basic questions should be answered beforehand:

— What should intensity measure?
— What instrumentally measurable quantity of the earthquake should intensity be well correlated with?
— Is there a need for intensity to be well correlated with an instrumentally measurable quantity?

The answers to these questions should be given in a historical context. First of all, the importance of the macroseismic data for non-instrumental earthquakes should remain or maybe even enhanced. This requires that intensity rating has to be such that it encompasses historical as well as future data. Overly exigent and ambitious rating definitions will mean the loss of historical data if these data cannot satisfy the «precision» required by new ratings.

Secondly, in the light of future trends in seismic instrumentation, repetition should be avoided. Why, for example, should we want to have a perfect correlation between intensity and acceleration when we have the possibility of placing a strong-motion accelerometer at any desired location in the first place?

It is clear that the effects of the earthquake on a) persons and surroundings, b) structures, and c) nature, as indicated in the MSK scale, cannot be well correlated with peak acceleration alone, or for that matter, with any of the ground-motion parameters. An accurately drawn isoseismal map should contain the total sum of all the effects of the earthquake. The one important point of possible clarification is the type of effect (a, b, or c, or all) which dominated the decision in a particular intensity rating. Although guidance in this regard is generally quite clear for b-type effects (*i.e.* structural damage), the same is not true for c-type effects (*i.e.* nature). That is to say that for b-type effects, both structures and damage to structures are classified and the meaning of a «few», «many» and «most» is quantified at least approximately. For c-type effects, this degree of precision is not feasible due to lack of data.

Nevertheless, the c-type effects are extremely important in intensity rating for several reasons:

1) For very rare events only c-type effects yield significant distinction in intensity. When a large percentage of structures is destroyed (see *e.g.*, MSK X, XI, XII) the b-type effect loses its precision rapidly.

2) For medium to large events in remote areas where structural damage cannot be used effectively, field observations may still yield significant c-type effects for a better intensity rating.

3) For large off-shore events which may cause tsunamis (associated with sea floor faulting or slumping), c-type effects are more appropriate.

4) In seismic-hazard studies, where maximum potential magnitude for a seismic source is required, paleoseismic information (*i.e.* c-type effects) is the best-preserved objective evidence for large rare events.

5) Impact of ground failures (*i.e.* c-type effects) to structural damage (*i.e.* b-type effects) is very often dominating the damage pattern in areas of $I \geq$ VIII.

For the Irpinia earthquake of 1980, ground effects are of extreme importance. Surface faulting (in a limited area), hydrogeological conditions and slope instabilities have dominated the pattern of structural damage in the area of $I \geq$ VIII.

The fact that the intensity ratings in this area does not correlate well with the observed acceleration is not surprising and should not be seen as a major problem.

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