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Notes on

The state-of-the-art and practice of long-term seismicity

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The interaction between different disciplines that constitute the basis for mitigation of earthquake risk can best be portrayed by the relation that describes seismic risk, which is the preoccupation of decision makers, planners, engineers and politicians alike. Seismic Risk can be defined by the following relation:

$$[\text{Seismic Risk}] = [\text{Earthquake Hazard}] * [\text{Structural Vulnerability}] \times [\text{Value}]$$

in which Earthquake Hazard is the probability of occurrence, within a specific period of time and given area, of a potentially damaging earthquake, which is beyond human control but knowledge of it is possible. Vulnerability is the degree of loss resulting from the occurrence of an earthquake of a given magnitude, and it is subject to human control. Value may be taken either in the sense of capital value or of production capacity of a vulnerable element. This definition makes a clear distinction between Earthquake Hazard, which includes tectonics, seismology, strong-ground motions, seismic regionalization and tsunamis, specialties which constitute engineering seismology, and Vulnerability, which includes building materials, foundations, structural engineering, and retrofitting, specialities which constitute earthquake engineering. It is the amalgamation of these specialities and their balanced and coordinated support that would lead to the mitigation of Seismic Risk.

To begin with, not all of the existing *regional and global parametric earthquake catalogues* from which the earth-scientist or engineer may cull the information he needs fulfil the condition of transparency. Some of these catalogues are fresh and pertinent, some out-of-date or at second hand, some misleading. It is not satisfactory, therefore to acquire information from the historian or seismologist and use that information without understanding fully the basic principles on which the information has been obtained and what really means in terms of completeness and uncertainties.

The user of catalogues must be aware of the *quality* of the data, of the *uncertainties* associated with them and of the *completeness* of the data. He should prefer data from reliable long-term datasets that give a far fuller understanding of earthquake hazard because they are based on human experience of earthquakes over a much greater segment of the geological time-scale.

Much of the information in such datasets comes from *historical data* and their use should aim to be indicative, to expose points for further analytical or field clarification rather than prescriptive, since in fact the prescriptions have to be based on rather arbitrary assumptions. It is not sufficient, therefore, merely to lay hand on a few historical earthquakes and use them to model seismicity.

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For the early period *mislocation of instrumental epicentres* is the norm, while for earthquakes before the 1940s macroseismic locations are more reliable but they must be used with caution. For the later period location accuracy is not better than 30 km, but improves to about 5-10 km for more recent events. However, bearing in mind that an earthquake of M_s, say between 6.5 and 7.5, will have ruptured faults 30 km to more than 100 km in length, the epicentre indicates nothing more than the general location of the event, and alone, without knowledge of the location of the causative fault, is of little use for design purposes. Focal depths are more uncertain.

Intensity, which was devised two centuries ago, is a convenient means of conveying in a single rating of the scale a measure of the effects of the ground motion on man-made structures and on the ground itself. By definition it is a vague measure, either of the strength of ground shaking or of the weakness of man-made structures or a combination of the two. Intensity tells us little about the nature and level of the ground motion.

Nevertheless the distribution of intensity may be used for the assessment of the magnitude of the associated event, for constraining the dimensions of the seismic source and for the identification of subcrustal events, particularly for earthquakes in the pre-instrumental period.

For the purpose of assessing intensity and reducing subjectivity it is important to distinguish between damage caused by dynamic or inertia earthquake loading, and damage caused by secondary, quasi-static after-effects such as foundation spreading, liquefaction, slides, rockfalls and aftershocks.

For instance I find that maximum intensity in any destructive historical or modern earthquake in rural areas in South-Eastern Europe and in the Middle East appears to be effectively the same; that is, intensity «saturates» at VII-VIII MSK at which all local type of constructions are destroyed or damaged beyond repair and any town or village would thus appear equally, but no more, devastated at so-called higher intensities.

Also landslides, spreading and liquefaction of the ground, are too much factors of other conditions besides the ground accelerations, and making appraisals of intensity on the basis of such ground effects, would be subjective and often misleading.

In spite of the subtleties, which are involved in its definition and assessment, which requires engineering knowledge, intensity values estimated by seismologists are adopted by the engineer as a means to assess ground accelerations and velocities. Modern textbooks and building codes feature tables and formulae for the conversion of intensity into ground acceleration, which is convenient but very unreliable. It is futile to seek a meaningful one-to-one relationship between intensity and any other single quantity which can be used for design purposes, a relationship that can best be described as a 21st century anachronism.

The method of *contouring intensity* data cannot be separated from the method of information collection and intensity allocation. If the information is sufficient then the method of contouring should be allowed to work with modal intensity values.

This procedure is particularly important when a few isolated high intensities exist within a background of many sites of much lower intensity, and conversely when isolated low intensities exist in the far-field within a background of «not felt». The use of low intensity radii that include the furthermost location from which the shock was reported, even by single observer, has a considerable bearing on the determination of the radius of perceptibility, which leads to grossly overestimated magnitude.

Homogeneously-defined isoseismals, may be used, however, to assign magnitudes to their causative earthquakes by calibrating sets of isoseismals against magnitudes, a method that gives stable results, but which must be applied to well-defined tectonic environments rather than to individual countries or global conditions. Having assessed the magnitude of the earthquakes in terms of magnitude, one may use an appropriate attenuation model to estimate ground motions.

The derivation of calibration functions between magnitudes and their corresponding sets of isoseismals for a specific tectonic environment needs internally consistent data on both; the isoseismals must be drawn on maps of intensity points assigned from examination of primary historical macroseismic information, and the magnitude data must be re-evaluated uniformly.

As for the use of synthetic isoseismal maps for engineering purposes, this reminds me of Leo Pomerance who once said about the person who was searching under a street lamp for his house key, which he had dropped some distance away, but he searches there because there is more light.

Reliable *magnitudes* are essential for the derivation of recurrence relations, particularly at large magnitudes where recurrence curves steepen. They are also important for the scaling of ground motions and for placing constraints on the bounds of rupture zones. A cause for concern is the reliability of magnitudes reported in different parametric catalogues, particularly for events before the advent of the magnitude scale in the 1950s.

No formal method can be devised to test the *completeness of long-term data* other than by testing their implications. Formal statistical tests are as valid as the distributional assumptions on which they are based. Since these assumptions are rarely likely to be always satisfied, such tests may best be regarded as indicators to the extent to which a particular conclusion would be supported, or not, by the data, if in fact the assumptions were justified, and hence, of the extent to which that conclusion is likely to remain valid despite departure from those assumptions.

Frequency-magnitude relations calculated with different magnitude scales differ. They also differ when calculated in terms of M_s or moment magnitude M_w. The reason for this is, that because of scaling, M_s is not related linearly to log (M_0), and smaller events contribute proportionally more moment than large ones.

Regarding *ground motions*, we know how to assess uncertainties in defining them, but we know also that peak ground acceleration is a poor index by which to express the damage potential of a ground motion. At present, and for a broad class of structures, displacement is probably the most widely used parameter to limit damage and also to quantify it in terms of design criteria.

For the engineer, analysis of existing strong-motion recordings is the most common method used to estimate future ground shaking in terms of peak or spectral acceleration or displacement. This method must rely on good quality databases, uniformly processed records supported by reliable seismological and soil mechanics information and reliable associated data banks.

There is at present a multitude of CDs and Internet sites that can provide *strong motion data*. Whilst the availability of data via such mass media is extremely valuable, it must be recognised that use of this data cannot be made indiscriminately. And although there is a great need for data storage and dissemination on a European and World level, and that CD-ROMs or the Internet can provide the uninitiated engineer with readily available strong-motion time-histories, the indiscriminate use of some of the data in existing CD-ROMs or active Internet-sites is likely to generate misleading results. The derivation of attenuation laws and site-specific design parameters must rely on good quality databases and reliable associated data banks rather than on statistics of many records of questionable quality.

To the best of my knowledge there are at present world-wide 125 local or regional *attenuation laws* for peak ground accelerations, and 85 for response spectral ordinates, derived from the data available at the time, using different definitions for the variables involved and different procedures.

Uncertainties in the derivation of scaling laws depend on how well dependent variables are known. Teleseismic locations are known to have larger uncertainties compared with those from local networks and like epicentres, focal depths based on teleseismic arrival times alone lack precision.

The use of a unified magnitude scale in attenuation studies is also an important consideration. Adoption of M_s rather than M_L stems from the fact that the former is not only the best estimator of the size of a crustal earthquake, but also because seismicity in Europe is generally evaluated in terms of M_s.

While there can be no objection to modelling and calculating ground motions the best we can, but with so many uncertainties in the input data, whose accuracy for predictive purposes is little known, that there is a degree of precision beyond which refinement becomes pointless.

Moreover, a too sophisticated model carries with it the danger that its weaknesses and assumptions may not be appreciated. Conversely, a too simple model may be discredited just because it exposes the underlying assumptions too clearly. I would prefer a simple model in which the number of variables is justified by the available data. Over-parameterisation of the model alone is not recommended.

Recent studies show that *seismic activity* is both regional and long-time dependent, which renders particularly problematic the assessment of hazard from short-term observations. The true, long-term nature of the frequency-magnitude distribution is hampered not only because the 20th century record is too short but also because test areas may be too small to disclose the repeat time of large earthquakes as the shape of the frequency-magnitude distribution from short-term observations cannot be defined at large magnitudes. The implication is that large earthquakes in a test area are less frequent, when predicted from the long-term dataset than from the usual 100-year instrumental period, making the notion of recurrence time, in its usual definition questionable, and the characteristic model an artefact of incompleteness of data in space and time. Incomplete data and clustered seismicity is the principal reason why statistics from short-term data alone cannot quickly answer the question of seismic hazard evaluation.

Considering that most *major urban and industrial developments* are spreading into areas of little-known seismicity, and that time rarely allows for the acquisition of adequate data, the engineer is likely to be forced on occasions to step across that hazy borderline of safety by accepting an element of risk over and above what would otherwise have been considered to be normal.

To accept what is an acceptable risk, a certain amount of informed judgement, detailed technical evaluation of the structure and experience is needed, rather than results from a probabilistic treatment of short-term seismicity data.

Much statistical ingenuity has been spent on devising techniques for tackling this problem, but there are doubts about how useful and how well-founded some of these techniques really are, and the statistician here should take a background role. He can point to features in the data that look anomalous because they depart from some standard model, but whether the anomalies are to be ascribed to peculiarities of the model, or to peculiarities of the process by which the input data were recorded, is not a question the statistician should be asked to answer. It should be referred back to the seismologist, geophysicist or engineer. If an important effect is really present it should not take a statistician to bring it out.

Finally, to anyone who is really concerned with historical seismicity it is becoming increasingly apparent that *the site of a damaging earthquake is a full-scale laboratory* from which significant discoveries may be made, by historians, seismologists, geologists, engineers, sociologists or economists, not to mention politicians. As our knowledge of the complexity of earthquakes has increased, we become more and more aware of the limitations which nature has imposed in our capacity to model on purely theoretical bases. It is field observations and measurements that allow the interaction of ideas and the testing of theories. Through the field study of earthquake effects on structures and on the ground itself, a unique opportunity exists to develop an understanding of the behaviour of man-made structures, when tested by nature.