Earthquake Engineering, Tenth World Conference © 1994 Balkema, Rotterdam. ISBN 90 5410 060 5

Falsification of hazard analysis

Giuseppe Grandori
Department of Structural Engineering, Politecnico di Milano, Italy

Abstract: Attention is paid to the scientific reliability of seismic hazard analysis at a particular site, following the teachings of modern philosophy of science. The problem is discussed in the frame of the theory of falsification, due to K.Popper and I.Lakatos: it is recognised that the results of a seismic hazard analysis are not falsifiable; hence, they would not have a scientific status. In order to overcome this problem, it is proposed to shift the attention from the final results of the hazard analysis, which are not directly falsifiable, to the procedures which lead to that result. A method for falsifying these procedures is proposed.

The following criterion is frequently adopted for the design of ordinary buildings in earthquake prone areas: a building should resist with non destructive damage an earthquake whose intensity has 10% exceedance probability in 50 years at the site of the building. This probability corresponds approximately to 500 years return period for local intensity.

The choice of the reference return period is obviously debatable and may be somewhat different in different countries. However, a discussion of this choice is not among the aims of my presentation.

I wish just to lay stress on the fact that seismic hazard analysis, for engineering purposes, involves the estimate of intensities with very long return period. For instance, a recent hazard analysis carried out in Italy reached the following conclusion: the peak ground acceleration with 500 years return period at the Messina Straits is 0.35 g.

A twofold problem arises from a proposition of this type: has the proposition a scientific status? and in the case the answer is yes, what is the reliability of the proposition from the quantitative point of wiew?

The object of my presentation is a discussion of the aforesaid problem, whose importance is emphasized by the results of the TERESA research project (Mayer-Rosa and Schenk, Ed., 1989). In the frame of this project, six European research groups evaluated seismic hazard at a location of Southern Italy using a common data base. Table 1 shows the computed return period for intensity 8.

Significant differences in the computed probability where obtained by the different groups, and obviously nobody knows which method gives the most reliable result. Moreover,

TABLE 1 - Return period T(8) at a location of Southern Italy (from TERESA Project).

Reference	Method	T(8), years
Barbano et al.	SRAMSC	73
	Gumbel-1	238
Garcia and Egozcue	Egozcue	51
	counting	40
Lapajne et al.	SRAMSC	88
Mayer-Rosa	SRAMSC mod.	27
Schenk et al.	SRAMSC	65
Siro and Slejko	Cornell	24
	Gumbel-1	83
	Gumbel-3	91

we must remember that the data-base regards a limited time period. All the information contained in the data-base can be considered as an "historical sample" of the earthquake process, and we dont know the sampling distribution of the quantity T(8) corresponding to each method. This fact obviously increases our uncertainty.

It seems then appropriate (coming back to the general) to discuss the first aspect of the problem I mentioned before: do the results of hazard analysis have a scientific status?

Contemporary philosophers of science generally agree in regarding a theory, an assumption or a sentence as "scientific" if and only if it is "falsifiable", i.e. if one can specify an experiment such that, when its results

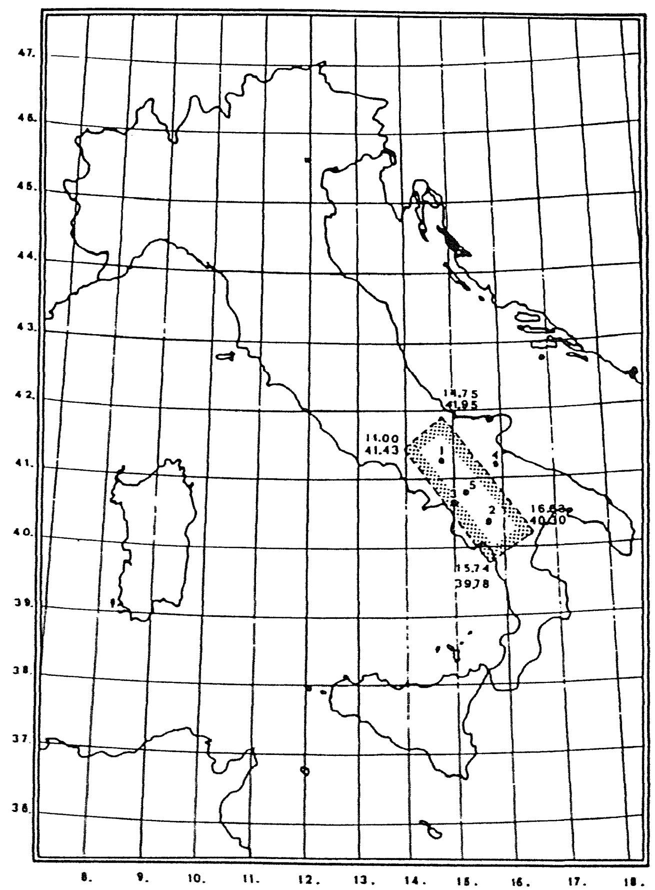


Fig.1 Historical seismic zone in Southern Italy.

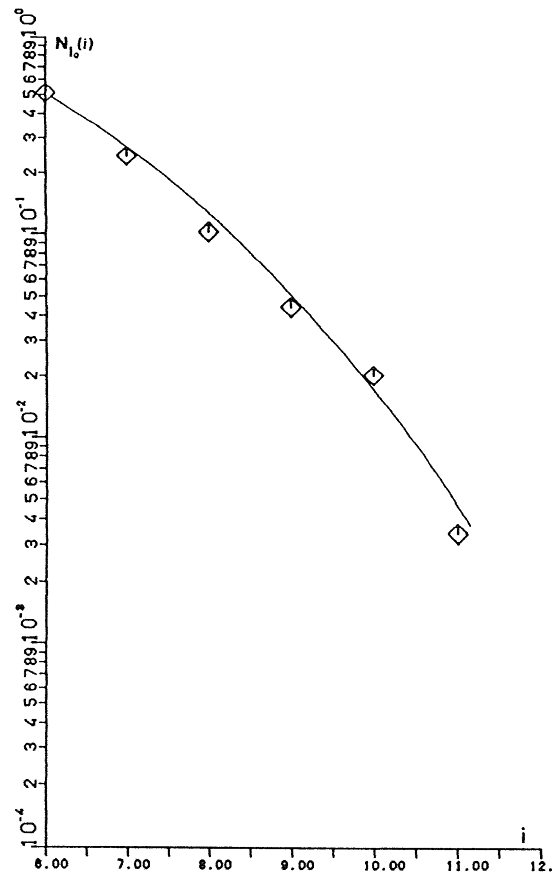


Fig.2 $N_{I_0}(i)$ versus i for historical earthquakes of the zone of Fig.1 .

contradict that statement, the latter must be rejected.

Note the dissimmetry: one negative result is sufficient to prove that a theory is false; no sequence of positive results (no matter how long) is able to prove that a theory is true. To say it with H. Weyl, "Nature knows well how to meet our theories with a decisive No.... or with an inaudible Yes".

This early version of falsification has been criticized for being too dogmatic and rigid. In fact, for example, it would imply that no relationship between quantities, expressed through a probabilistic model, can have a scientific status.

However, the developments of the theory of falsification (see for instance Popper, 1959 and Lakatos, 1968) showed that the empirical basis is never completely objective. The interpretation of an experimental result requires the support of collateral judgements based on either auxiliary theories or experimental techniques. These theories or techniques are not in discussion during the falsification process. They are "background knowledge", are not considered as problematic and are used as an "extension of our senses".

This leads to the theory of methodological falsification. According to this version of falsificationism, a proposition expressed in probabilistic form is falsifiable if it is possible to run a large number of experiments, and if a collateral judgement is expressed about the degree of deviation beyond which evidence is considered as being in conflict with the model.

Our proposition on the return period of a given earthquake intensity, then, is falsifiable in principle. However, return period is the mean value of interoccurrence times: to falsify a 500 years return period would require a period of observation of many thousands of years. By contrast, the historical data that are available and statistically significant encompass at best a few hundreds of years. Our proposition is then, in practice, not falsifiable, at least if we reject the idea of devolving the solution of the problem upon our remote descendants.

Notwithstanding this, in my opinion hazard analysis can be restored to scientific dignity if attention is shifted from the final calculated result, which is not directly falsifiable, to the procedures which lead to that result. The idea is to devise a method for evaluating the order of magnitude of the expected errors associated with any given procedure for the statistical elaboration of historical data. In other words, what I propose is to falsify the procedures used for hazard analysis.

To this aim, let us consider as a first step the problem of the sampling distribution of the computed quantity. The problem can be tackled with the bootstrap method, introduced by Bradley Efron (1979).

In order to illustrate this first step, it is appropriate to show directly an example of application.

Consider the seismic zone of Southern Italy represented in Fig. 1 and suppose to take into account only the events with epicentral intensity $I_o \geq 6$. The Italian catalog for the period 1680-1980 leads to the mean annual number of events $N_{Io}(i)$ shown in Fig.2. The best fit curve has been obtained by assuming :

$$N_{Io}(i) = \lambda_o \left[1\text{-}F_{Io}(i)\right], \qquad (1)$$

$$1\text{-}F_{Io}(i) = \exp\left(\exp 6\ \beta_o - \exp i\ \beta_o\right). \qquad (2)$$

The following numerical values of λ_o and β_o have been estimated:

$$\lambda_o = 0.50\ ,\ \beta_o = 0{,}186. \qquad (3)$$

The seismic zone has been subdived into 96 cells. Fig. 3,a shows the number of historical events that occurred in each cell: Fig. 3,b shows a smoothed space distribution of epicenters (the epicenters of the events of one cell are supposed to coincide with the center of the cell).

The analysis of the isoseismal maps of 13 events of the zone led to the proposal of the following attenuation law, illustrated by Grandori et al., 1991:

$$I_o - I = \frac{1}{\ln\psi} \ln\left[1 + \frac{\psi - 1}{\psi_o}\left(\frac{D_i}{D_o} - 1\right)\right] \qquad (4)$$

$$\frac{D_o(I_o=j)}{D_o(I_o=j\text{-}1)} = \phi \qquad (5)$$

$$\psi_o=1,\ \psi=1.5,\ \phi=1.3,\ D_o(I_o=10)=9.5\ \text{km}, \qquad (6)$$

where D_o is the equivalent radius of the isoseismal line of maximum intensity I_o, and D_i is the equivalent radius of the isoseismal line of intensity $I=I_o$-i. Fig.4 shows the attenuation law together with the experimental data.

Formulas (1),(2),(3),(4),(5),(6) and Fig. 3,b, with the additional hypotheses that the earthquake occurence follows a stationary Poissonian process and that space, time and intensity distributions are independent of each other, completely define a model that I will call a "synthetic" seismic zone. At any point of this zone it is possible to evaluate the return period of a given intensity.

The synthetic process is (to say it with Efron's terminology) the "sample probability process". The real sampling distribution of a computed return period can be approximated by the "bootstrap distribution" derived from the synthetic process.

For the sake of simplicity, let us consider as constant both the space distribution and the attenuation law, and derive the bootstrap distribution of the return period originated by the different values of λ_o, β_o that are obtained

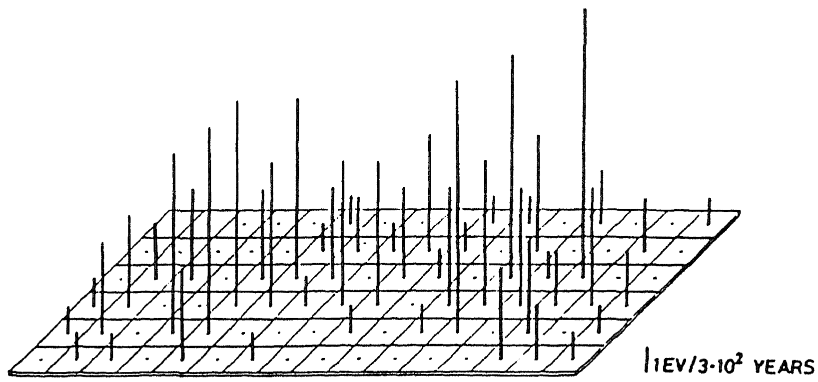


Fig. 3, a Space distribution of historical earthquakes.

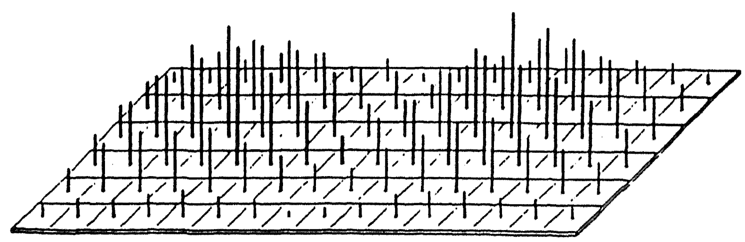


Fig. 3, b Smoothed space distribution

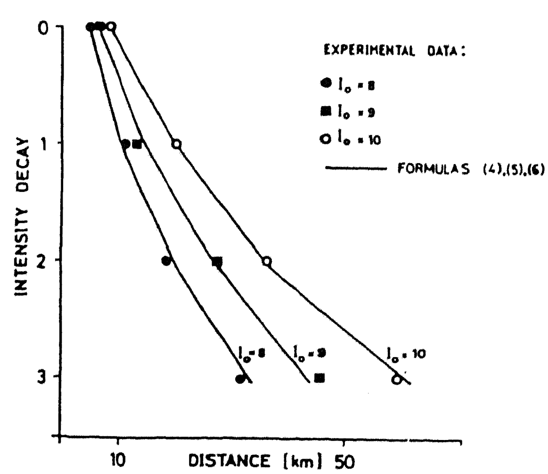
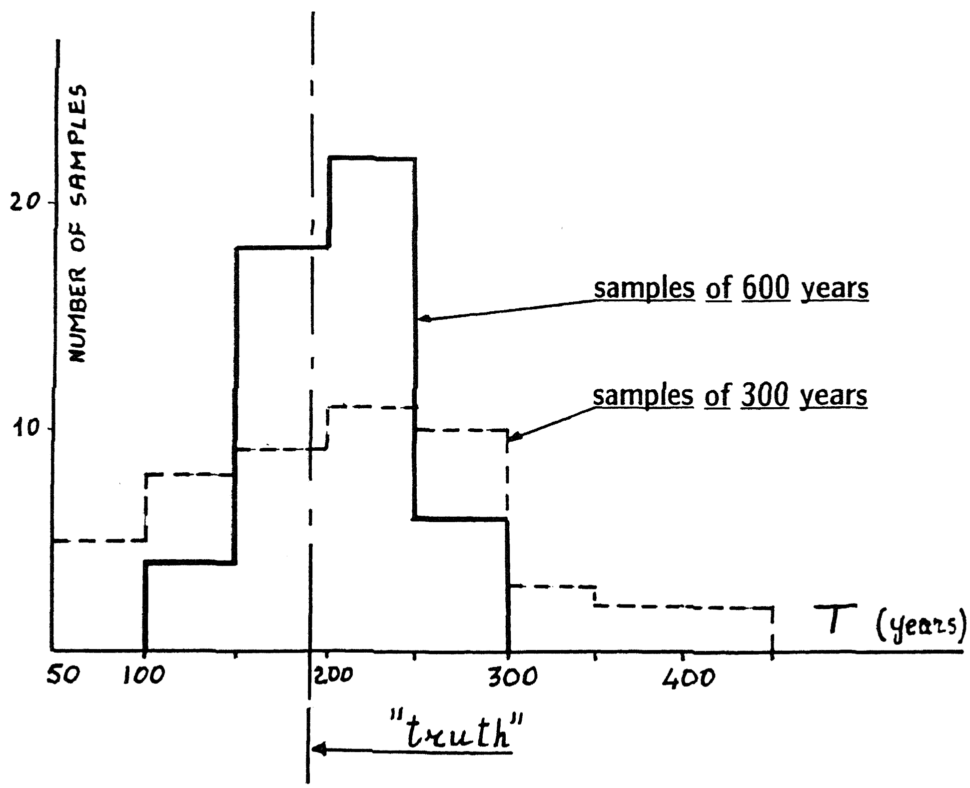


Fig.4 Intensity decay versus epicentral distance.

SYNTHETIC ZONE
30,000 YEARS POISSONIAN CATALOGUE
RETURN PERIOD FOR INTENSITY VIII AT A SITE

	μ	σ/μ	MIN	MAX
"TRUTH"	193	-	-	-
50 SAMPLES OF 600 YEARS	199	0,20	121	263
50 SAMPLES OF 300 YEARS	209	0,42	62	452



from different historical samples of the synthetic process.

This has been done in the following way. By using a library program, the drawing of a random number, included between 1 and 15,000 has been repeated 15,000 times running. To each drawn number m, position, epicentral intensity and date have been assigned following the probalistic distributions of the synthetic process. A 30,000 years long synthetic catalog has been obtained in this way (for the synthetic process, λ_o=0.5 means that the return period in the area, for I_o=6, is 2 years).

The "observation period" of the whole synthetic catalog has been subdivided in a sequence of 50 subperiods of 600 years each. On the basis of the data contained in each single sample of 600 years, the coefficients λ_o, β_o of formulas (1), (2) have been estimated. Then, by using always the same space distribution and the same attenuation law, the sampling distribution of the return period for intensity 8 has been derived at a given site. With the same procedure, the sampling distribution of the same quantity has been obtained for the case in which historical samples of 300 years are used.

The results are summarized in Fig.5. They give an idea of the uncertainties involved in local hazard analysis, even when the earthquake occurrence follows a stationary Poissonian process and the "true" form is assumed for all together with the experimental data.

Formulas (1),(2),(3),(4),(5),(6) and Fig. 3,b, with the additional hypotheses that the earthquake occurence follows a stationary Poissonian process and that space, time and intensity distributions are independent of each other, completely define a model that I will call a "synthetic" seismic zone. At any point of this zone it is possible to evaluate the return period of a given intensity.

The synthetic process is (to say it with Efron's terminology) the "sample probability process". The real sampling distribution of a computed return period can be approximated by the "bootstrap distribution" derived from the synthetic process.

For the sake of simplicity, let us consider as constant both the space distribution and the attenuation law, and derive the bootstrap distribution of the return period originated by the different values of λ_o, β_o that are obtained from different historical samples of the synthetic process.

This has been done in the following way. By using a library program, the drawing of a random number, included between 1 and 15,000 has been repeated 15,000 times running. To each drawn number m, position, epicentral intensity and date have been assigned following the probalistic distributions of the synthetic process. A 30,000 years long synthetic catalog has been obtained in this way (for the synthetic process, λ_o=0.5 means that the return period in the area, for I_o=6, is 2 years).

The "observation period" of the whole synthetic catalog has been subdivided in a sequence of 50 subperiods of 600 years each. On the basis of the data contained in each single sample of 600 years, the coefficients λ_o, β_o of formulas (1), (2) have been estimated. Then, by using always the same space distribution and the same attenuation law, the sampling distribution of the return period for intensity 8 has been derived at a given site. With the same procedure, the sampling distribution of the same quantity has been obtained for the case in which historical samples of 300 years are used.

The results are summarized in Fig.5. They give an idea of the uncertainties involved in local hazard analysis, even when the earthquake occurrence follows a stationary Poissonian process and the "true" form is assumed for all the probabilistic distributions, but the coefficient λ_o, β_o of formulas (1), (2) are derived from a limited historical sample. In particular, for the considered example, in the case of 600 years samples, 80% of the samples lead to a return period in the range 150-250 years, while in the case of 300 years samples only 40% of the samples lead to a return period within the same range.

Further uncertainties are obviously due to the fact that also the parameters that define the space distribution and the attenuation law are derived from a limited historical sample. These uncertainties, too, can be analysed with an analogous technique.

I wish to mention here that I had the first occasion of presenting the possible use of a long synthetic catalog at the ICASP meeting in Mexico City (1991). In that paper, there is no reference to the bootstrap method. This is simply due to the fact that we proposed this kind of analysis without knowing that it had been authoritatively introduced more than ten years before. Only later we discovered that our idea was not an original one.

However, the synthetic catalog is not only a tool for approximating the sampling distribution of the computed return period, follwing the bootstrapping technique. It may also serve as a test bench for the various simplified procedures that are commonly used in hazard analysis. This application, too, can be suitably illustrated with an example.

We compared two procedures, applied both to historical samples of 600 years. In the fisrt procedure we used again the values of λ_o, β_o derived from each sample, but the regional seismicity so defined has been uniformly distributed over the region, instead of using the "true" space distribution of Fig. 3,b (procedure of homogeneous zone).

For the second procedure, no modelling of the earthquake process is required: the events of each historical sample are transferred to the site with the attenuation law: then a simple counting gives the local values of $N_I(i)$.

Table 2 shows some results obtained for the site 2 of Fig. 1.

TABLE 2 - Mean error and coefficient of variation with two different procedures applied to historical samples of 600 years.

		PROCEDURE	
		homogeneous zone	counting
$N_I(8)$	mean error	-35	-1
	coeff. of var.	0.24	0.35
$N_I(10)$	mean errorr	-41	+1
	coeff. of var.	0.37	0.67

The mean error of the procedure of homogeneous zone is obviously due to the fact that the considered site is located where the "true" space distribution shows a maximum density. The simple counting, as expected, leads to a mean error practically zero. However, the coefficient of variation is larger than in the first procedure especially for high intensities.

I will not discuss deeper in detail these results and all the ways in which it is possible to "play" with a synthetic catalog. I wish sinply to conclude that a long synthetic catalog allows us to have a quantitative idea of the uncertainties involved in local hazard abalysis, and moroever to select the most reliable procedure for the analysis of zones which are "similar" to the synthetic one.

Should we then prepare a bank of synthetic zones, with a wide range of different characteristics, in order to cover nearly all possible conditions?

A more attractive alternative is to prepare a computer program able to: 1) incorporate the data available for a zone; 2) construct the "sample probability process", i.e. the synthetic zone, with many options as far as the form of the probabilistic distributions are concerned; 3) carry out a series of tests with different procedures, so that one can judge which procedure is the most reliable one, depending on the particular conditions and on the quantity upon which the interest of the analysis is focused.

This is what we are trying to do at present at the Politecnico di Milano.

References

Efron, B., 1979, "Bootstrap methods:another look at the Jackknife", The Annals of Statistics, vol.7, No 1,1-26.

Grandori, G., Drei, A., Perotti, F. and Tagliani, A., 1991, "Macroseismic intensity versus epicentral distance: the case of Central Italy". In: M. Stucchi, D. Postpischl and D. Slejko (Editors), Investigation of Historical Earthquakes in Europe, Tectonophysics, 193, 175-171.

Lakatos, I., 1968, "Criticism and the methodology of scientific research programmes", Proc. of the Aristotelian Society, 149-186.

Mayer-Rosa, D. and Schenk, V., Ed. (1989), "TERESA", Special Issue of Journ. of the Int. Soc. for the Prevention and Mitigation of Natural Hazards.

Popper, K., 1959, "The Logic of the Scientific Discovery", Popper K. Ed.