Copyright © 1996 Elsevier Science Ltd
Paper No. 1843. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

A LARGE SCALE ASSESSMENT OF SEISMIC RISK

P. ANGELETTI *, A. BELLONI **, S. DE ANDREA ** , N. PADOVAN **,
F. PERGALANI ***, V. PETRINI ***, G. VINCIGUERRA ***

* Università di Perugia, Italy
** Regione Lombardia - Servizio Geologico, Milano, Italy
*** Istituto di Ricerca sul Rischio Sismico, CNR, Milano, Italy

ABSTRACT

An assessment on a large area (approximately 24000 Km^2) of an Italian region (Lombardia, Northern Italy), including 41 municipalities where the seismic code has been enforced, is presented. Four steps are performed:

1) determination of probabilistic distributions of occurrences and intensities;
2) definition of geomorphological and geological situations producing different local effects and estimation of the related coefficients of amplification using a finite elements method;
3) evaluation of vulnerability of buildings (on the basis of type of vertical and horizontal structure, number of floors, age) by direct survey and estimation of the vulnerability index of few samples and extrapolation of the results to the whole building stock;
4) final assessment of seismic risk as expected damages, in terms of average annual value, taking into account seismic hazard, amplification factors and vulnerability of buildings.

As a result, the values of seismic risk for the 41 municipalities, based on data and maps easily available, have been obtained. Regional officers should use the results to plan mitigation acts of the seismic risk; the risk assessment could be easily refined on smaller areas, once more detailed information on vulnerability and local geology is available.

KEYWORDS

urban planning, seismic hazard, coefficient of amplification, local effects, vulnerability of buildings, seismic risk, expected damages.

INTRODUCTION

The Italian law charges regional governments to enforce guidelines that give criteria for the reduction of seismic risk through urban planning and land use requirements. One of the aims of such guidelines is suggesting a standard procedure for risk evaluation that can be applied by the municipalities, mainly by smaller ones that can not afford the economical cost of highly refined approaches. In order to limit costs, the guideline must supply the hazard analysis and must suggest simplified procedures for the assessment of amplification effect due to site conditions and for risk evaluation. These procedures must be based on the data usually collected when preparing a new urban plan or updating existing plans; the standard survey activity usually produces geological, lithological and geomorphological maps; the commonly performed building stock analysis gives some characters that can be related to its seismic vulnerability. The study area is located in the Lombardia region (Northern Italy) and covers approximately 24000 km^2; it includes all the 41 municipalities in which the seismic code has been enforced.
The main results of this paper are three diagrams, one for each zone in which the study area has been subdivided according to the level of seismic hazard. The diagrams allow the risk evaluation in a very simple

way once typical situations resulting in amplification have been identified from the geological documentation of the site and once an estimate of the vulnerability distribution of the building stock has been made available.

Particular attention has been paid in identifying the set of typical geological and morphological situations present in the study area and in defining the range of variation of all significant parameters. At the same time an estimate of the vulnerability distribution for all municipality has been performed. It is worthy to note that the vulnerability data used in the study can be directly used for risk assessment, if more refined analysis are considered too expensive, while specific site survey are always needed to identify situations of possible amplification; this is mainly due to the scale of maps used in the study.

METHODOLOGY

As a first step the hazard has been evaluated determining on each site the probabilistic distribution of the peak ground acceleration at the bedrock. Given the large amount of intensity data and the relatively small amount of strong motion data, the analysis has been performed in terms of intensities and the results are finally transformed in acceleration through an empirical relation. The applied procedure (Grandori et al., 1984; 1991) is based on the following hypotheses:

- seismic hazard at site is fully described by the inter occurrence time distribution $F_t(t)$ and the local intensity distribution $F_I(i)$;
- inter occurrence times t and intensity I are assumed as independent random variables (Bernoulli model);
- the inter occurrence time probability density function as the form:

$$f_t(t) = p\, f_1(t) + (1-p)\, f_2(t) \qquad (1)$$

where the functions f_1 and f_2 may be different from site to site according the data and are chosen in a menu including Exponential, Lognormal, Weibull and Gamma distributions; the estimate of the parameters of equation 1, including p, is directly performed site by site on the basis of the sequence of the event at the site. The sequence of events at the site is derived from the epicentral parameters listed in an earthquake catalogue; only events producing at site an intensity I greater than or equal to a threshold I_s are used. The threshold value I_s = VI MCS has been assumed in order to consider the events that may produce damage to the buildings. Attenuation models are needed in order to derive local intensity I from epicentral intensity I_o: the attenuation model of Grandori et al. (1987) is assumed. The evaluation of the intensity distribution at the site is performed in two steps. The analysis of past seismicity enables to group the zones of the seismotectonic model that can be characterized by the same distribution $F_{Io}(i)$ of the epicentral intensity I_o. For each group of zones, the type of the distribution function $F_{Io}(i)$, leading to the best fitting, is automatically selected among the three following types and the parameters α and β are calculated:

$$F_{Io}(i) = 1 - \exp\left[-\alpha\,(i - I_{os})\right] \qquad (2)$$

$$F_{Io}(i) = 1 - \exp\left[\exp(\alpha I_{os}) - \exp(\alpha i)\right] \qquad (3)$$

$$F_{Io}(i) = 1 - \exp\left[\exp(\alpha I_{os} - \beta) - \exp(\alpha i - \beta)\right] \qquad (4)$$

Also the local intensity distributions $F_I(i)$ at the site assume one of the form shown in equations 2, 3 or 4; they are determined subdividing each zone in an appropriate number of elementary cells, assuming an uniform space distribution of the events inside the zone and applying to each zone the relevant attenuation model. Finally an empirical relation between intensity and ground acceleration lets derive the acceleration distribution $F_y(y)$ and the corresponding probability density function $f_y(y)$ from the intensity distribution $F_I(i)$.

The local modification of hazard, due to the influence of geological and geomorphological conditions, is taken in account through an amplification coefficient, that modifies the standard hazard. The geological and geomorphological conditions, producing variations on the expected motion, have been identified as: edge area and rocky ridge, producing amplification due to morphological condition; valley with incoherent alluvium and slope deposits or talus cone producing amplification due to loose soil overlying a bedrock, and showing high impedance contrast; area affected by lithologic discontinuities producing differential settlements in connection with characters of lithologies; very soft soil producing permanent deformations

(Bressan et al., 1986). The amplification coefficient or the permanent deformation are determined through numerical analysis using finite elements method (Angeletti et al., 1995).
The recent and ancient landslides, zone affected by superficial instability, excessive slope with debris mantle, and excessive slope with rock affected by fractures, that can produce active or potential landslide situations, have been considered to assess the vulnerability of physical environment (Bressan et al., 1986; Keefer, 1984). The evaluation of the instability under dynamic condition is performed applying simplified methods (Newmark, 1965) or of finite elements methods (Cividini and Pergalani, 1994). The results are expressed in terms of expected displacements (Pergalani and Luzi, 1994).

The vulnerability of buildings is defined through a function defining, in terms of damage, the seismic performance of the construction; it is assessed following a methodology that assigns a conventional index of vulnerability, V (Benedetti and Petrini, 1984) ranging from 0 (buildings in accordance with present code requirements) to 100 (very poor buildings), on the basis of some characteristic parameters. The vulnerability function d (V, y), relating expected damages d to the vulnerability index V and ground acceleration y, has the form:

$$d(y,V)\begin{cases} = 0 & \text{for } y \le y_i \\ = \dfrac{y - y_i}{y_c - y_i} & \text{for } y_i < y < y_c \\ = 1 & \text{for } y_c \le y \end{cases} \qquad (5)$$

where y_i e y_c are respectively the acceleration at which the first damage occurs and the acceleration causing the collapse of the building and are given by:

$$y_i = \alpha_i \exp(-\beta_i V) \qquad (6)$$
$$y_c = (\alpha_c + \beta_c V^{\gamma})^{-1} \qquad (7)$$

Statistical analysis of damage data collected after recent earthquakes allows the evaluation of the parameters α_i, β_i, α_c, β_c and γ (Angeletti et al., 1988; Guagenti and Petrini, 1989).

The knowledge of the functions $f_y(y)$ and $d(y,V)$ easily allows to evaluate, for a building of vulnerability V, the expected value of the damage for one expected earthquake:

$$D_m(V) = \int_0^{\infty} d(y,V) f_y(y)\,dy \qquad (8)$$

The quantity D_m is the basis for the computation of different risk measures. The simplest is the expected value of the annual rate of damage given by:

$$D_p(V) = \lambda_s D_m(V) \qquad (9)$$

where λ_s is the average annual number of events at a site with an acceleration greater then or equal to the threshold y_0 and is derived from the relevant probability density function of the inter occurrence time $f_\tau(t)$.
Other possible measures are (Guagenti et al., 1988):
- the expected value of the actual cost of damage caused by the first event:

$$D_1(V,\gamma,t_o) = D_m(V)\ {}_f f_\tau^*(\gamma,t_o) \qquad (10)$$

- the expected value of the actual cost of damage caused by all future events:

$$D(V,\gamma,t_o) = D_m(V)\ {}_f f_\tau^*(\gamma,t_o)\ [1 - f_\tau^*(\gamma)]^{-1} \qquad (11)$$

where ${}_f f_\tau^*(\gamma,t_o)$ and $f_\tau^*(\gamma)$ are:

$$
{}_f f_\tau^*(\gamma, t_o) = e^{-\gamma t_o}\left[1 - F_\tau(t_o)\right]^{-1}\int_{t_o}^{\infty} f_\tau(t)e^{-\gamma t}dt
$$

$$
{}_f f_\tau^*(\gamma) = \int_0^{\infty} f_\tau(t)e^{-\gamma t}dt \tag{12}
$$

and t_o is the time elapsed from the last event and γ is the discount rate
The decision to use D_p, D_l or D depends on the purposes of the analysis. D_p can be used when the risk analysis is the basis for mitigation action that will be undertaken at random instants; D_l is more suitable when priorities must be decided for immediate actions. The hypothesis that after each earthquake the only action is the repairing of damage, restoring the pre earthquake situation, is implicit in the definition of D; therefore it can be used when a satisfactory level of vulnerability as been reached and the aim is to estimate the residual risk. In the following, coherently with the main purpose of the paper, the expected value of the annual damage rate is considered. In fact the results are mainly oriented to support decision of urban planners that will be effective in unknown future time.

RESULTS

The described methodology has been applied to all the municipalities of the Lombardia region in which the building code has been enforced; the area is characterized by low to moderate seismicity. The whole area has been subdivided in three zones of increasing hazard, grouping the municipalities having similar levels of hazard; to this purpose the expected value of the annual rate of damage to a standard building of average vulnerability (V=50) has been used in order to take into account the entire distribution of the expected earthquakes at each site.
Geological, lithotechnical and geomorphological maps at the scale 1:25000 were produced. The area is characterized by limestones, marls, marls with clays, clays, alluvial deposits cemented and not. For the geomorphological aspect the recent and ancient landslides and the area affected by potential instability conditions have been mapped. The typical situations, able to produce local effects, as: ridge, edge, valley and slope deposits, have been identified; for each situations all possible variations in geometry have been considered.
Numerical analyses, using the finite elements program QUAD-4 (Idriss et al., 1973) and two expected artificial accelerograms, have been performed to quantify the possible amplifications. The first accelerogram (GNDT) has been derived from the response spectrum representative of the low seismicity areas of the Italian territory at outcropping bedrock; the second (OCC) is obtained from an uniform probability response spectrum directly derived from the data of the seismic catalogue for the Lombardia Region. The numerical analyses have been performed using values of geotechnical parameters varying in a range defined on the basis of all data available in the area. For ridge and edge the evaluation of the response was carried out considering constant damping ratio for the entire finite element representations. In the case of valley and slope deposits the response was obtained using different damping ratio for each individual element of the sections, taking in account the strain dependent relation of damping for soils. Two examples of the typical situations analyzed are presented in Fig. 1 a valley (1000 m wide and 170 m deep) filled by alluvial deposits and a ridge (1350 m wide and 360 m high). The results, expressed as the average of the obtained amplification coefficients, are used to estimate the variation of standard hazard. The values obtained are in the range from 1 to 6.
According to the approximation level required by the purposes of the analysis, all buildings have been roughly classified using parameters easily collectable by a very quick survey or by already available data. Parameters identified as significant are: age of construction, structural typology, architectural typology, number of floors, type of retrofitting interventions. For few samples of each class, the vulnerability index has been evaluated. An average evaluation of the vulnerability for the whole stock can be obtained extending the values computed for the samples to all buildings belonging to corresponding class: the extrapolation is based on the assumption of a fairly good relationship between the vulnerability index and above cited parameters. The quality of data used in computing the values of the vulnerability index for the samples, the amount of samples with respect to the number of vulnerability classes, the certainty of the knowledge of parameters for

each building are all relevant factors to define the reliability of the vulnerability assessment. In Fig. 2 is shown an example of these evaluations. The level of the vulnerability index is quite low in all considered municipalities. Of course higher values can be found in historical centers than in new buildings, but one cannot find values higher than 60 (excepting very few cases) with average values standing on 20-30. These low values depend, for historical buildings, on the frequent retrofitting in diaphragms, and, for new buildings, on the architectural typologies in most cases with a limited number of floors (2-3) and with good regularity in plan. This result allows a rough classification based on 3 levels (with threshold values at 20, 40, 60) covering, with a reasonable approximation, any case of the 41 municipality.

The final results are shown in Fig. 3. Each diagram refers to one of the three group of municipalities showing similar level of hazard: the site with average hazard has been assumed as representative of the whole group. For that site the expected value of the annual damage rate has been computed for all the values of the vulnerability index in the range from 1 to 100 and for six values of the amplification coefficient (from 1 to 6). It is worthy to note that in all the three cases the diagrams show a horizontal trend for higher amplification coefficients and for higher values of the vulnerability index: this indicate that under such conditions the collapse of the building will be reached even for an earthquake with a maximum acceleration at the bedrock not exceeding the threshold y_o. A typical use of such diagrams is as follows. For a given municipality the vulnerability of the building stock can be obtained from maps like those shown in Fig. 2 or from more detailed surveys; the typical amplification situation can be identified through a geological survey and the corresponding amplification coefficient can be derived from diagrams like those shown in Fig. 1; finally the relevant diagram of Fig. 3 allows to evaluate the expected value of the annual damage rate for the whole building stock of the municipality or for a part of it.

REFERENCES

Angeletti, P., A. Bellina, E. Guagenti, A. Moretti and V. Petrini (1988). Comparison between vulnerability assessment and damage index, some results. Proc. 9th World Conf. on Earthquake Engineering, 7, Tokyo-Kyoto.

Angeletti, P., F. Pergalani and V. Petrini (1995). A methodology for assessing seismic risk. Third National Earthquake Engineering Conference, March 27-31, Istanbul.

Benedetti, D. and V. Petrini (1984). On seismic vulnerability of masonry buildings: proposal of an evaluation procedure. L'Industria delle Costruzioni, 18.

Bressan, G., G. Poli, M. Sani and M. Stucchi (1896). Preliminary, low cost, urban planning oriented investigations in seismic areas: a methodology and some applications. Engineering Geology Problems in Seismic Areas - IAEG - vol. 4, Bari.

Cividini, A. and F. Pergalani (1994). Alcuni aspetti della modellazione numerica dei mezzi plurifase. III Convegno dei ricercatori di Ingegneria Geotecnica, Mondovì.

Grandori, G., E. Guagenti and V. Petrini (1984). On the use of renewal processes in seismic hazard analysis. Proc. 8th World Conf. on Earthquake Engineering, 1, San Francisco.

Grandori, G., F. Perotti and A.Tagliani (1987). On the attenuation of macroseismic intensity with epicentral distance. Ground Motion and Engineering Seismology, A.S. Cakmak Ed., Elsevier.

Grandori, G., E. Garavaglia and V. Petrini (1991). Analysis of some of uncertainties in the statistical elaboration of historical data for local seismic hazard evaluation. Proc. 6th International Conf. on Application of Statistic and Probability in Civil Engineering, Mexico City.

Guagenti, E., C. Molina and G. Mulas (1988). Seismic risk analysis with predictable models. Earthquake Engineering and Structural Dynamics.

Guagenti, E. and V. Petrini (1989). Il caso delle vecchie costruzioni: verso una legge danni intensità. Proc. 4th Italian National Conference on Earthquake Engineering, 1, Milano.

Idriss, I., J. Lysmer, R. Hwang and H. Seed (1973). QUAD-4: a computer program for evaluating the seismic response of soil structure by variable damping finite element procedure. Rep. E.E.R.C., Earthquake Engineering Research Center, Univ. California, Berkeley.

Keefer, D. K.(1984). Landslides caused by earthquakes. Geological Society of American Bulletin, vol. 95.

Newmark, N. M. (1965). Effect of earthquake on dams and embankments. Geotechnique, vol. 23.

Pergalani, F. and L. Luzi (1994). Influenza di alcuni parametri geotecnici e sismici sulla risposta dei pendii instabili attraverso un modello semplificato. Ingegneria Sismica, vol. 3.

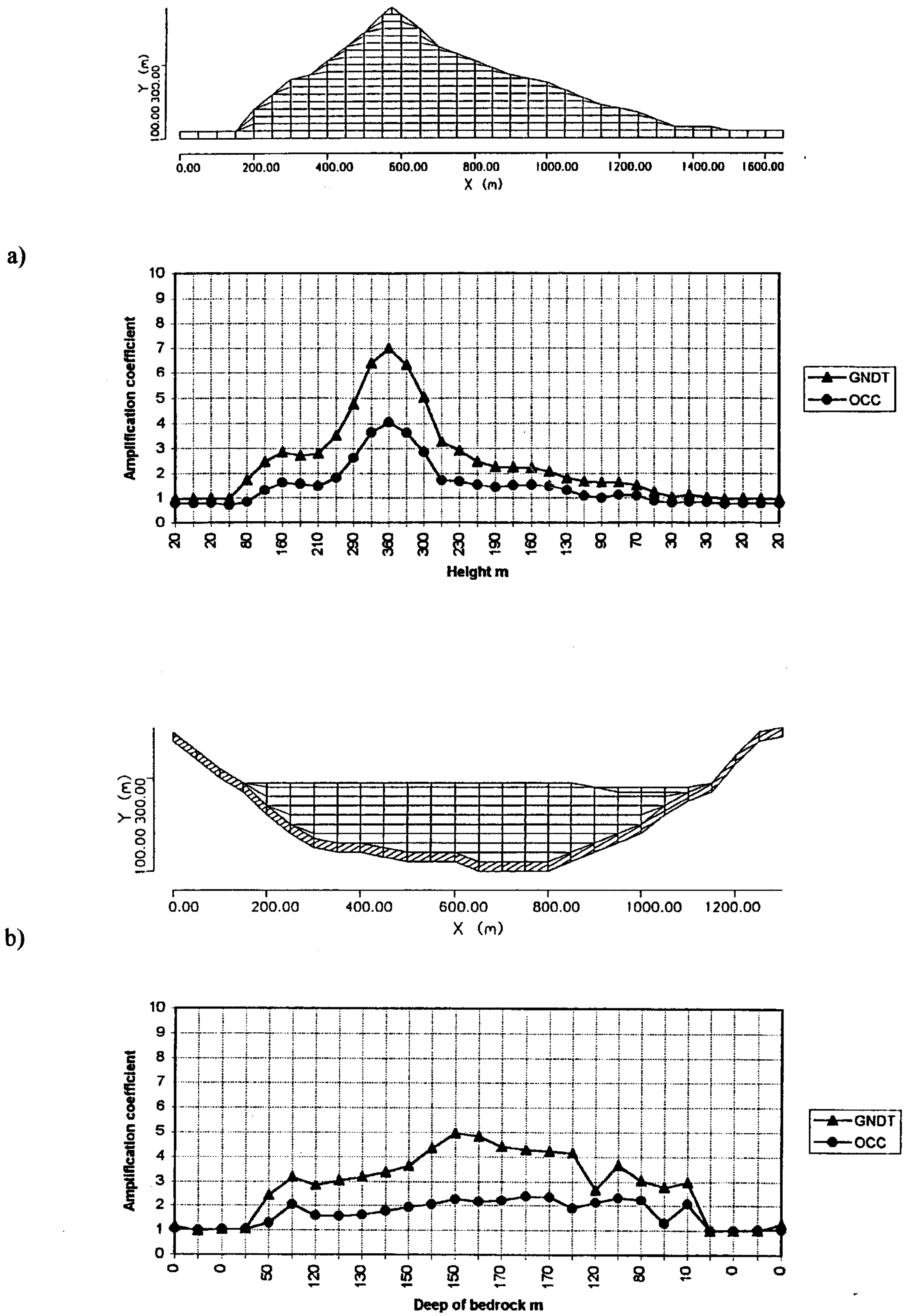

Fig. 1 - Finite element models and calculated values of the amplification coefficients for ridge (a) and valley (b)

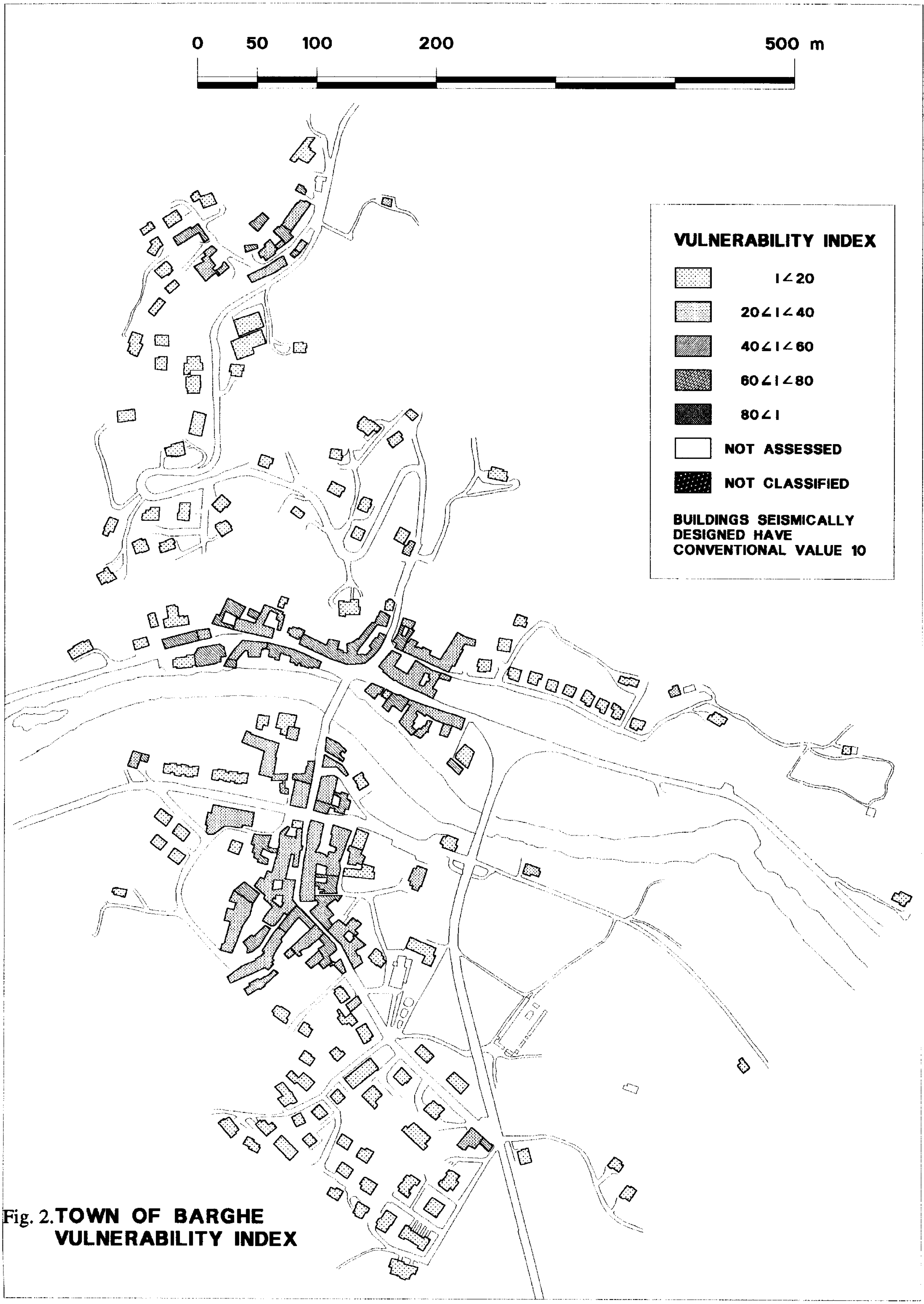

Fig. 2. **TOWN OF BARGHE VULNERABILITY INDEX**

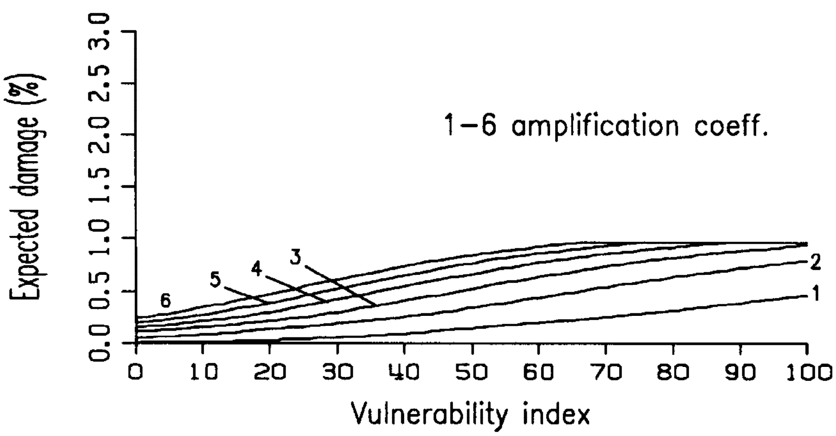

Fig. 3a. Expected value of the annual damage rate as a function of the vulnerability index and the amplification coefficient. Hazard level of the first group of municipalities.

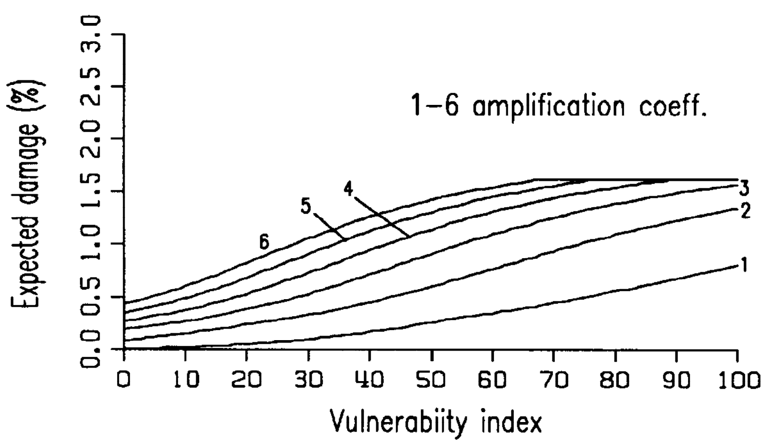

Fig. 3b. Expected value of the annual damage rate as a function of the vulnerability index and the amplification coefficient. Hazard level of the second group of municipalities.

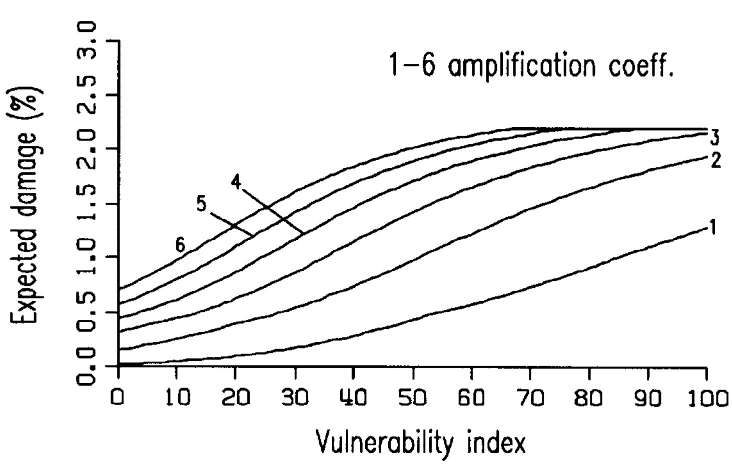

Fig. 3c. Expected value of the annual damage rate as a function of the vulnerability index and the amplification coefficient. Hazard level of the third group of municipalities.