The Umbria-Marche Microzonation Project: outline of the project and the example of Fabriano results


Summary

The Gruppo Nazionale per la Difesa dai Terremoti together with the Servizio Sismico Nazionale performed the microzonation of 3 localities struck by the 1997 Central Italy sequence, characterized by at least 6 shocks with magnitude greater than 5 with a maximum value of Ml 5.8.

The 3 localities were:

- Fabriano, situated in Marche region, at the foothills of Appenninic chain, that suffered moderate damages, but relevant for the area from an economic point of view; Nocera Umbra (Umbria Region), characterized by significant differences from a geological point of view, that suffered heavy damages; Sellano (Umbria Region) strongly affected by the quake, is a small village situated at the top of a hill in the Appenninic chain.

The microzonation program was based on the following investigations:
- hazard analysis via probabilistic and deterministic approach;
- detailed geological (1:5000 scale) and geotechnical investigations both in field and in laboratory;
- site effects analysis: temporary dense seismic networks were placed in the 3 localities to record both aftershocks and noise.

Results were provided taking into account local administration requirements as well as national seismic code.

As an example of the procedure adopted to summarize the results in order to prepare the microzonation map and to issue recommendations for reconstruction, the case history of Fabriano is here presented.

1. Introduction

The Umbria Marche earthquake sequence started on September 26, 1997 with a Ml 5.6 shock, followed 9 hours later by a stronger Ml 5.8 earthquake. Actually a foreshock occurred on September 3 with a Ml 4.5 shock and the whole sequence lasted till mid of October with a total of 6 shocks with magnitude between 5 and 6 [Amato et al., 1998].

Despite of moderate magnitude values, the repeated shocks, coupled with the high vulnerability of several buildings, caused significant damages and several localities were estimated MCS Intensity greater than VIII [Camassi et al., 1997], moreover this long sequence caused troubles in the emergency operations and one of the principal income sources of the zone, that is the tourism, dropped to zero; this was also due to the media, and TV in particular, that broadcasted an image of a disaster highly amplified with respect to actual damages.

National and local authorities started immediately the emergency operations and planned both the initiatives to construct temporary shelters and to plan the reconstruction of stricken villages. In this framework the Gruppo Nazionale per la Difesa dai Terremoti (GNDT) was asked to set up a special task group to perform microzonations of the most important ruined villages. Three localities were selected: Fabriano, Nocera Umbra and Sellano (Fig. 1). Fabriano, a town of 29,358 inhabitants situated at the foothills of the Appenninic chain within the Marche Region, reported light damages, mainly to old brick houses and churches; very few reinforced concrete buildings were affected by the shocks [Dolce and Larotonda, this issue]. Nevertheless these damages must be considered significant, in the light of risk reduction, if we consider the magnitude values and the epicentral distances (around 30 km).

Nocera Umbra Municipality, situated in Umbria region, is composed by several localities, with different characters from a geological point of view. The old Nocera core is built on outcropping formations of the Umbro Marchigiana sequence: very stiff marls and sandstones, but with alluvium and colluvium materials at the slopes of the hill. Nocera Scalo is characterized by recent alluvial deposits with a
2. Outline of the Project

The program, synthesized in the block diagram (see Fig. 2), encompasses detailed studies in the seismological, geological and geotechnical fields as well as a damage survey and analysis.

The 1997 earthquake showed an irregular pattern both in strong motion [FRANCESCHINA et al., this issue] and in the damage pattern; anisotropic distribution of damage pattern is clearly identifiable [CA-MASSI et al., 1997]. This variability cannot probably be attributed only to local site conditions: sources and crustal inhomogeneities could have played a major role. Therefore, special attention has been paid to the evaluation of expected ground motion at the site, that is, to the estimation of reference or input motion.

This subject has been tackled using three different approaches [FRANCESCHINA et al., this issue]:

a) via probabilistic approach: standard hazard estimation techniques with seismic catalogue, seismotectonic zonation and attenuation law as input data (Fig. 2) has been used to compute expected acceleration response spectra, 5% damping, for 474 years return period at the 3 sites. Reference accelerograms were obtained via best fitting of the hazard response spectrum and response spectra of real accelerograms recorded by the Italian strong motion accelerometric network [TENTO, 1999];

b) via a pure deterministic approach based on wave propagation simulation using the wave number integration method [PRIOLA, this issue; HERMANN et al., 1985]; source characteristics of the scenario earthquake were computed based on the same considerations as for stochastic approach and ground motion was computed at the site both under the hypothesis of point as well as extended source;

c) via stochastic approach [BOORE, 1983] where the target spectrum has been determined on the basis of historical investigation, seismological researches on the recent 1997 earthquakes and tectonics considerations regarding the investigated zone.

Historical investigations have been conducted to analyze the principal earthquakes that struck the 3 localities in the past thousand years with the principal aim to establish the reference earthquake for deterministic and stochastic approach [see for example CASTELLI and MONACHEI, this issue]. We took the decision to choose the most damaging earthquake that happened in the past as a reference earthquake, after the adoption of empirical relations to compute source parameters by macroseismic intensity data.
Consistent field investigations have been planned and performed in the light of geological and seismological tasks.

The goal of the former was to draw, on 1:5000 scale, the geological map of the sites considered for microzonation. The lithotechnical map suitable for site effects analysis was prepared combining the mentioned detailed geological map with the existing geological data and additional information obtained by several borings performed in the three localities [PARRINI et al., this issue; BOZZANO et al., this issue; GUADAGNO and MAGALDI, this issue]. Moreover, ad hoc investigations have been performed to obtain information on dynamical characteristics of soils in particular down-hole and SASW techniques were used to estimate $V_s$ [CRESPIANI et al., this issue; NUNZIATA et al., this issue]. In some cases laboratory tests (mainly resonant column) were executed to obtain shear modulus and damping versus strain [CRESPIANI et al., 1999].

Aftershocks and noise recordings received particular attention with the installations of local dense 3-D short periods seismic arrays in the analyzed localities. Fabriano was monitored by 19 stations in the period 4-14 November 1997, more than 80 events were recorded; among them 40 events were selected on the basis of PGV threshold of 68 $\mu$m/sec. More than 10 stations were used for 3 microarrays in Nocera Umbra [TENTO et al., 1998]. The complex damage pattern of Sellano [DOLCE and LACOSTONIA, this issue], a small town located on the top of a hill, highly struck by the 1997 earthquakes, obliged to issue a particular experiment (called TOMOSEL - acronym for Sellano Tomography) in order to check the main structural and geophysical aspects of the hill. 54 digital stations equipped with 3-D 1 Hz and 5 s sensor, plus 2 (48 channels) and 1 (24 channels) recorders, registered both aftershocks and seismic signals generated artificially with Hydrapulse generator.

The arrays of Fabriano and Nocera were placed with the aim of computing site effects, therefore station sites were chosen on the basis of the lithology of the area. In so far both aftershocks and seismic noise were recorded and, after a careful data processing and qualification, were analyzed by standard techniques: in particular spectral ratios and H/V ratio.

Damage evaluation was performed in the 3 localities with the main purpose to analyze the correlation between actual damages and computed site effects. Damage pattern has been used as a validation of site effects results.

Seismic microzonation maps and recommendations for the 3 localities were prepared with particular care to the following 2 items:

1. **Scientific validation of the results**

The key role played in the present microzonation by aftershocks recordings presents the advantages of the good reliability of spectral ratios. Their inaccurate use indeed implies two risks: the first is the possibility of underestimation of non-linear soil behavior, the second is to give and excessive weight (in the light of microzonation) to the 1997 earthquake. These risks have been tackled using deterministic approach together with probabilistic approach for input motion evaluation (that is to evidence also direc-
tivity effects) and laboratory tests to characterize the dynamic soil behavior at strain level above $\gamma_t$.

2. **Application of the results in the light of existing national and local seismic codes and regulations**

Because seismic risk reduction measures depend both on local and national seismic codes, and because other practical factors are relevant after an earthquake (necessity to start as soon as possible the reconstruction, choice of priorities by local and national authorities) there is not a standard procedure to cope with the best way to present the results in the light of practical application. In a word the solution must be found situation by situation (and the experience plays a major role).

As an example of the adopted procedure and the obtained results, conclusions of Fabriano microzonation are here presented.

3. **Fabriano microzonation main results**

3.2. **The 1997 earthquake in Fabriano**

Fabriano suffered only minor damages concentrated in two zones of the city: Borgo and Serralloggia situated at NW and East of the city, respectively. Considering that the magnitudes of the quakes were less than 6 and that Fabriano is situated at some 30 km North of the epicentral area, the damages were related to the elevated vulnerability of some typologies of structures when subjected to dynamic loading. Actually these evidences were supported by observations; only one reinforced concrete building (built in 1990) in Borgo and some buildings situated in Via Laini (Serralloggia zone) suffered heavy damages; the other damaged buildings could be retrofitted. Curious enough, the buildings in the core of the city, in spite of their elevated vulnerability did not suffer heavy damages. Actually this was the motivation to infer the possibility of a key role of local site conditions.

The dense network installed after the quake greatly evidenced the relevancy of site effects [see Tento et al., this issue]. For instance the recordings of a M4.5 earthquake generated at some 55 km epicentral distance showed 4 times difference in PGA between two stations of the dense network, situated 1 km apart; in terms of acceleration response spectrum the difference was even greater: for example at $T=0.1$ s the difference is about 6.5 times. Spectral ratios [see Tento et al., this issue] show remarkable amplification at Borgo and Serralloggia with respect to the reference site situated on Schlier formation.

In particular Borgo stations evidenced mean amplifications of 2.5 in the 2-8 Hz frequency range and in some cases in Serralloggia-La Spina area the amplifications reached the value of 6. To note that this last zone was characterized by a rather elevated inhomogeneity of soil conditions as confirmed also by geological [Parroni et al., this issue] and geotechnical investigations [Crespellani et al., this issue]. S-wave velocity has been measured with down-hole technique in Borgo: the values are around 130 m/s in the uppermost 6 meters.

3.2. **The seismicity of Fabriano**

A detailed historical investigation [Castelli and Monachesi, this issue] together with geological and geophysical observations [Scandone et al., 1992] show that Fabriano is surrounded by several seismic zones (Fabriano itself is situated inside a seismic zone). Castelli and Monachesi evidenced that the most dangerous earthquake in the past was probably the April 24, 1741 with epicenter at some 10 km North-East of the city; it struck Fabriano with an estimated IX MCS Intensity.

In order to establish the expected ground motion three approaches were adopted: a) classical probabilistic approach; b) deterministic approach; c) stochastic approach (for further details see Franchina et al., this issue).

a) **Probabilistic approach**

Seismic hazard has been evaluated both in terms of PGA and response spectra using seismic zones identified by Scandone et al. [1992], NT 4.1 earthquake catalog and different attenuation laws; SEISRISK III computer code was applied. Using Ambraesys [1995] attenuation law the PGA for 475 years Rp has been estimated in 0.25 g. To compare this value with the expected strong motion of the strongest earthquake occurred in the past, let us assume that the April 24, 1741 earthquake will strike again: using the Tento et al. [1992] attenuation law and considering an estimated magnitude of 6.2 we will obtain at Fabriano the following values: 50% probability of PGA greater than 0.2 g, 16% probability of PGA greater than 0.4g and 10% of PGA greater than 0.48g. Reference accelerograms were obtained via best fitting of the hazard response spectrum and response spectra of real accelerograms recorded by the Italian strong motion accelerometric network [Tento, 1999].

b) **Deterministic approach**

We employed this approach with the principal aim to obtain a credible upper boundary of the expected ground shaking at Fabriano. While probabilistic approach is more suitable for micro-
zonation, deterministic approach can be an useful support in special situations; i.e. to check the possibility of liquefaction of some particular soils. As scenario earthquake the cited 1741 has been considered with source parameters of $M_0 = 3.1 \times 10^{18}$ Nm, stress drop 13 MPa and normal focal mechanism with NW-SE strike. Synthetic seismograms have been computed considering different hypocentral depths at different points in and around Fabriano using the Wavenumber Integration Method. Both point source and extended source modelisation have been accounted for. As shown in Franceschina et al. [this issue], in spite of some unavoidable arbitrariness of the structural model employed, the results exhibited a response spectrum similar to the one obtained via probabilistic approach. To note that both point source and extended source produce results comparable with that obtained via the simple adoption of the median values of attenuation law (0.21 g and 0.2 g for point and extended source, respectively), but for particular near field situation where PGA can reach values as high as 0.8 g. A detailed description of the deterministic approach is reported in Priolo [this issue].

c) Stochastic approach

The Boore [1983] stochastic approach [Franceschina et al., this issue] has been employed feeding the model with the same source parameters as adopted by the deterministic approach. Obtained values do have the same behavior as the common attenuation laws, but they are highly dependent on stress drop: with 13 MPa stress drop the values are comparable with the median + 1 standard deviation of attenuation law. To obtain the same values as predicted by the median of attenuation laws a lower stress drop is required. In particular with 7 MPa stress drop we obtained results very similar to the ones predicted by Ambraseys [1995] attenuation law.

3.3. Fabriano Zonation

3.3.1. Introduction

The seismicity of Fabriano can be classified as medium-high with respect to the seismic zones of Italy [Siekm et al., 1998]. Actually Fabriano, according to Italian code, belongs to the second category zone, that is the intermediate category (Italian seismic law subdivides the seismic zones with increasing severity of prescription from III to I). Damage pattern of 1997 earthquake, together with soil properties and differences in amplification factors suggest the opportunity of microzonation application for reconstruction and land use planning. Following the Italian seismic code, there are two ways to apply microzonation results: a) to assign each zone a value of the foundation coefficient (this is a coefficient multiplicative of seismic action and can take values between 1 and 1.3); b) to define an appropriate and specific design spectrum, zone by zone.

Actually, after an earthquake, things are not so simple; in particular the typologies of results must fulfil local administration’s requirements. According to Marche Region administration the results were synthesized in terms of differentiation of zones on the basis of lithology and seismic wave amplification. Amplification has been characterized by the amplification factor FA, whose variation could exceed 1.3, and with the suggestion to adopt this FA coefficient as the common $\xi$ foundation coefficient. According to the Italian seismic code $\xi$ [D.M. 11.PP., 16.01.1996] is a multiplicative coefficient that must be used to assess seismic design forces: this coefficient, dependent on the type of soil, is equal to 1 for rock and stiff soil and can take greater values as the soil mechanical characteristics decrease.

3.3.2. The zonation of Fabriano

The zonation map is shown in Fig. 3: the whole area is subdivided into zones characterized by similarity as far as site effects are concerned. Each zone is assigned a specific FA coefficient as follows:

Zone A: FA = 1

It encompasses the areas where the following formations outcrop: Schlier, Bisclaro, Scaglia Cinerea, Scaglia Variegata and Scaglia Rosata. Generally they are formations with limestones and marls in different percentages generally showing good mechanical properties. The reference site for spectral ratio approach was placed on Schlier formation. No damages were reported after the 1997 earthquake for the buildings founded on these lithologies.

Zone B: FA = 1.1

It circle two areas, situated North and South with respect to zone C. Quaternary deposits are of fluvial-lacustrine origin, mainly composed by gravel and coarse sand units. The natural period of the deposit is generally lower than inside zone C. The two seismic stations installed showed no significative amplification. No damages were reported after the 1997 earthquake.

Zone C: FA = 1.2

From a geological point of view the zone shows characters very similar to the ones observed for the zone B. The thickness of the deposits is comparable but natural periods estimated using Nakamura’s technique are about 0.1-0.2 s higher than zone B. A possible explanation of this dif-
amplification was evidenced analyzing the data collected by the seismic stations. The damages were very light, but it should be mentioned that the zone is scarcely built.

Zone F: FA=1.5

Under this zone the two more dangerous areas were grouped: they are situated West and East on the map (figure 3):

- (zone F) West Area

From a geological point of view it is characterized by the presence of the marls of the Gessoso-Solfifer formation, eluvial and colluvial deposits and landslide detrital deposits. Low $V_S$ values, less than 200 m/s in the uppermost 7 meters and around 300 m/s till 15 meters were measured by down-holes techniques. In the 1-10 Hz frequency band the four seismic stations reported average amplification around 2.5 with respect to the reference site, resulting as one of the zones with higher amplification values. In the locality called "Borgo" some recent RC buildings were badly damaged, even if no structural damage was reported. At a first sight it was impossible to establish whether damages were primarily due to bad construction quality or to soil characteristics. Detailed geophysical and geotechnical investigations were therefore conducted in the area. They consisted mainly in: (1) a borehole accelerometric experiment (BHE) based on the recordings of sensors placed at the surface, at 5 m and 25 m depth respectively (2) in field and laboratory dynamic testing. Close to the BHE site, geotechnical and geophysical parameters were obtained by standard down hole test and SASW techniques [Crespellani et al., this issue; Nunziata et al., this issue]. The stratigraphy evidenced a three layers profile: silty inorganic clays up to 6 m, clayey silt from 6 to 15 m and marls from 15 m. Shear wave velocities increases monotonically from 100 m/s near the surface to 800 m/s at 25 m depth. Laboratory testing (mainly consisting on resonant column and torsional shear test) conducted on samples taken from this site, showed a linear threshold in the G-γ diagram at approx $γ_i=0.002%$ [Crespellani et al., 1999].

The analysis of weak motion data collected during the BHE and the validation of the results via 1-D modeling confirm high values of amplification. According to Crespellani et al. [1999] damages in Borgo might have been due to amplification effects rather than to non-linear behavior of soil or structural quality of buildings.

Fig. 3 – Seismic microzonation map of Fabriano. Amplification coefficient FA must be taken as the $ε$ coefficient prescribed by the Italian seismic code [D.M. LL.PP. 16.01.1996] to compute design forces.

Fig. 3 – Carta di microzonzazione di Fabriano. Si suggerisce di considerare il coefficiente di amplificazione FA come il coefficiente di fondazione $ε$ prescritto dalle norme sismiche [D.M. LL.PP. 16.01.1996].

ference could be the presence of fine-grained materials in correspondence of a wider depositional area.

The six seismic stations installed in the area showed remarkable amplifications at 2 Hz. An average amplification around 2-3 with respect to the reference site has been found. The south border with the zone B has been drawn on the basis of predominant soil period as determined from recorded seismological data. No significative damages were reported.

Zone D: FA=1.3

It runs along the Giano river and is characterized by the most recent fluvi-al lacustrine deposits. The zone was not monitored by seismological stations. Light damages (but larger with respect to zone C) were observed.

Zone E: FA=1.3

It comprises areas where eluvial and colluvial materials and terraced fluvi-al lacustrine deposits of the second order outcrop. A significant
- (zone F) East Area

Fluvio-lacustrine deposits and eluvial-colluvial materials are the main features from a geological point of view. Boreholes in Serraloggia-La Spina area evidenced the presence of clays with organic materials at depths less than 10 meters. Around Latinin street moderate slope instability phenomena were clearly visible. Significant amplifications were reported by the four seismic stations placed in the zone. This area was the most damaged by the 1997 earthquake.

4. Conclusions

In principle microzonation should be done before the earthquake; in practice researches of this kind are generally asked after an earthquake. Fabriano could represent a good case history of a microzonation performed after an earthquake. Comparing this experience with a microzonation performed not in emergency situations (for example the microzonation of some municipalities of Emilia-Romagna region [Frassineti et al., 1999]), we observe that after an earthquake is easier to get more funds, but the researches are asked to produce applicable results in a very limited time to avoid delay in reconstruction. From a strictly scientific point of view, a microzonation investigation after an earthquake could benefit of seismological data obtained by recorded aftershocks with a consistent increase of reliability of site effects estimation. In addition a detailed description of damage pattern allows to check the validity of results.

Fabriano showed that a dense network installed after the main quake for a period of 15 days can be sufficient for collecting a statistical significant number of aftershocks. As far as site effects are concerned, Fabriano microzonation strongly relies on spectral ratio technique applied to aftershocks recordings, but a very few sites where Vs was measured by down holes (til a maximum depth less than 25 meters). As a result the zoning proposed should be considered very reliable, also because of the good matching with both geological map and damage pattern of the 1997 earthquake. In principle this weak motion approach leaves unsolved the problem of possible non linear behavior of some soils under strong dynamic loading; anyway this possibility is restricted to some particular sites in Borgo (Zone F west part) and around via Latinia (Zone F east part). Therefore additional geophysical and geotechnical tests were conducted in these sites. The results obtained favor the hypothesis that the damages were mainly due to soil amplification rather than to a non-linear behavior of soils (at least in Borgo area; in Serraloggia area geological investigations evidenced the presence of slope instabilities).

Acknowledgements

We thank all the participants to the Umbria-Marche microzonation Project. Regione Marche contributed to the project, in particular we would like to thank Prof. Tiberi. We thank two anonymous reviewers for their improvements. The research was supported by C.N.R.- Gruppo Nazionale per la Difesa dai Terremoti.

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Il progetto microzonazione sismica Umbria-Marche: linee guida del progetto e l'esempio Fabriano

Sommario

Il Gruppo Nazionale per la Difesa dei Terremoti e il Servizio Sismico Nazionale hanno elaborato, su richiesta della Protezione Civile, la microzonazione sismica di 3 delle località colpite dal terremoto del settembre 1997 (Italia Centrale) caratterizzato da almeno 6 scosse di magnitudo superiore a 5, con un valore massimo di Ml 5.8.

Lo studio ha riguardato le località di: Fabriano, situata ai piedi della catena Appenninica, nella Regione Marche. L'area, importante centro economico regionale, ha riportato danni modesti; Nocera Umbra (Regione Umbria), caratterizzata da significative differenze del punto di vista geologico, ha riportato un elevato grado di danneggiamento; Sellano (Regione Marche), piccolo centro situato in cima a una collina nella catena Appenninica, ha riportato danni gravisissimi.

Il programma di microzonazione si è basato sui seguenti studi: - analisi della pericolosità sismica, sia con approccio probabilistico che deterministico; - indagini geologiche di dettaglio (scala 1:5000) e prove geotecniche; - indagine di campagna che di laboratorio; - analisi degli effetti di sito: una rete sismica temporanea è stata installata nelle tre località per registrare aftershocks e rumori sismici.

I risultati sono stati elaborati sulla base sia delle esigenze delle amministrazioni locali che della normativa sismica nazionale. Viene qui riportato il lavoro svolto su Fabriano, come esempio della procedura adottata e dei risultati ottenuti, con la conseguente elaborazione della carta di microzonazione sismica e delle raccomandazioni per la ricostruzione.