Earthquake scenario in Western Liguria, Italy, and strategies for the preservation of historic centres

Coordinator: Sergio Lagomarsino

Introduction

The project intends to compare and integrate different methods, considering both the well-established and original ones, for the development of scenarios of earthquake ground shaking, vulnerability and damage, in regions of medium extension (about 2000 km^2), which are characterised by a complex geomorphology and with different urban tissues. The application is focused on the Western Liguria, a region of great interest from the point of view of seismic history and vulnerability, due to a wide variety of the potential site effects and the characteristics of the built environment.
The Research Units (RU) of the project are the following:

RU	*Responsible*	*Affiliation*
1	EVA Claudio	DIPTERIS, University of Genoa
2	GUIDOBONI Emanuela	SGA - History, Geophysics and Environment
3	FACCIOLI Ezio	DIS, Technical University of Milan
4	BINDA Luigia	DIS, Technical University of Milan
5	BAGGIO Carlo	DiPSA, III University of Rome
6	MAGENES Guido	DIPMEC, University of Pavia
7	LAGOMARSINO Sergio	DISEG, University of Genoa
8	DALAI Maria Luisa EMILIANI	Department of Art History, Univ. *La Sapienza* of Rome

1. Seismicity and source characterisation

Responsible: Claudio Eva, University of Genoa

The scope of this section is to achieve new information on seismicity of the Western Liguria and the surrounding regions, in order to define the scenario earthquakes. Our study dealt with the following issues: 1) seismicity analysis; 2) probabilistic seismic hazard analysis (PSHA); 3) scenario earthquakes; 4) analysis of local effects.

Seismicity

The actual seismicity, recorded by the seismic net operating in Liguria and Northern Italy, has been studied and analysed in the aim to define close correlation with seismogenetic sources. The density of the seismic station allowed to locate with a good precision all event greater then M=2. The inversion of collected data has permitted to determine an 1D model that has been used, new waves propagation models have been determined and used to relocate instrumentals seismic events. The review of the seismicity occurred in the last 20 years demonstrate the existence of a cluster distribution of earthquakes, that appears mainly concentrated along a fault system bordering the continental slope of Ligurian coast, well evidenced by the

seismic reflection profiles. This fault system marks a very sharp discontinuity between the continental and oceanic crust and, according to the focal depth distribution, appears completely seismogenetic.
The historical earthquake revision, made in the frame of our project, indicated that most part of the major events that affected the Western Liguria might belong to this seismogenetic structure. Similarly the inland events also appear strongly correlated with some activity clusters connected with a fault system known as Saorge-Taggia line. The revision of historical and instrumental seismicity has modified some aspect of the earthquake distribution affecting also the seismic zonation for seismic hazard analysis.

Probabilistic Seismic Hazard Analysis (PSHA)

Western Liguria is characterized by moderate to strong seismicity, distributed both in well-defined onshore areas and along the main active faults in the Ligurian Sea. The historical seismicity shows that large events occurred in the past. Given the considerable uncertainty existing in the seismotectonic characterization of the active sources, in the recurrence of events of different magnitudes, and in the parameters of each recurrence models, seismic hazard estimates have been performed using a logic tree approach made of several weighted branches. Two alternative seismogenetic zonations have been considered: the first is the source zone model used for the Italian seismic hazard map; the second, which is derived from the first, takes into consideration the recent regional seismicity and the offshore seismogenetic structures. Different ground motion attenuation relations for Peak Ground Acceleration (PGA), along with different seismicity parameter and maximum magnitude values have been considered too. In particular we have used Sabetta–Pugliese (1996) and Ambraseys (1996) attenuation relations. This approach has allowed us to quantify the effects of the epistemic and aleatory uncertainties associated to the input data on the seismic hazard. For example, the “true” value of the PGA for a given mean return period (MRP) at a site is, in general, unknown. This approach can find for that MRP not only the mean PGA, but also the median and other percentiles that can bracket the “true” but unknown value. The final results are cast in terms of 1) mean hazard maps for PGA values corresponding to different MRP’s (100, 475, 975 years), 2) hazard maps for other percentiles (e.g., 16%, 50%, and 84%) of PGA corresponding to the same mean return periods, and 3) mean spectral accelerations for 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0 second periods corresponding to the same MRP’s.

Scenario earthquake modelling

The earthquake scenario for North Western Italy has been generated, using as reference event the one which occurred on February 1887 and called “Bussana earthquake”. In particular, on the basis of recent seismotectonic investigations and macroseismic studies carried out by other research units, numerical simulations of the strong ground motion was used to investigate the source properties of this hypothetic earthquake scenario.
Numerical simulation was performed using a finite difference technique, using staggered grid, which solves the full 3D elastic wave equations in heterogeneous

medium which simulate the elastodynamic propagation ruptures with constant slip on extended faults in the frequency range of 0 – 2 Hz.
The elastic propagation model discretises the North Eastern part of the Ligurian Sea encompassing the main localities affected by the 1887 event and the main offshore fault structures. Absorbing Boundary Conditions (ABC, Clayton and Engquist, 1977) were applied on the sides in order to reduce artificial reflections. In addition to that the boundaries are padded with a 5 Km wide zone of dissipative material using the Perfectly Matched Layer technique.
The extended fault model has the dimensions of 20 Km on the longitudinal direction and 7 Km on the vertical one for a total area of 140 Km^2. On the fault the slip rate function is constant everywhere with an effective rise time of 1 sec. Slip rate, as well as slip, taper to zero over a distance of 1 Km around the edges of the fault.
One of the main results of this research confirms, as pointed out in other studies, the offshore location of the Bussana earthquake at about 20 km from the shore line of Imperia city on a dip-slip fault with strike direction nearly parallel to the coast.
In addiction, in the last year of the research activities, simulations studies were devoted to investigate the influence of the Ligurian continental scarp on the synthetic shaking scenarios.
In order to simulate frequencies up to 2 Hz, the simulation software was parallelised.
Moreover, the influence of the rupture mechanism was also investigated adopting both a circular crack rupture model and an Haskell rupture model. The preliminary results show that the continental scarp and the water layer play an important role in wave propagation. In particular, numerical simulation results shows a remarkable ground motion amplification on the coast, due to focusing effects, which could explain very high values of the MCS intensity in this area.

Analysis of local effects

A seismic microzonation of the Argentina valley was carried out on the basis of seismic measurements, geological and geophysical information, to provide a detailed map of the zones that exhibit site effects in terms of resonance frequencies and approximated amplification of the ground shaking.
The available seismic data set consists of weak motion recordings, collected by velocimetric and accelerometric temporary networks, and microtremor data recorded at 150 noise measurements points.
The reliability of site response estimation obtained by the H/V technique was checked by means of cross-validation with the ratio of the horizontal spectra of earthquake weak motion (Ml<2.5) with respect to a reference site (Standard Spectral Ratio technique)
In addiction, numerical transfer function (1D) from soil columns, defined by geotechnical characteristics inside the studied region, was computed.
One of the main results consists of a map of the fundamental resonance frequency for the Argentina valley derived by noise measurements.
Moreover, on the basis of the thickness of sedimentary cover derived by a subsurface model, the fundamental frequency of the H/V spectral ratio was used to derive a preliminary estimate of the average shear wave velocity Vs.
The resonance frequency is generally greater than 4 Hz clearly shifted towards higher frequencies with decreasing of the thickness of the cover.

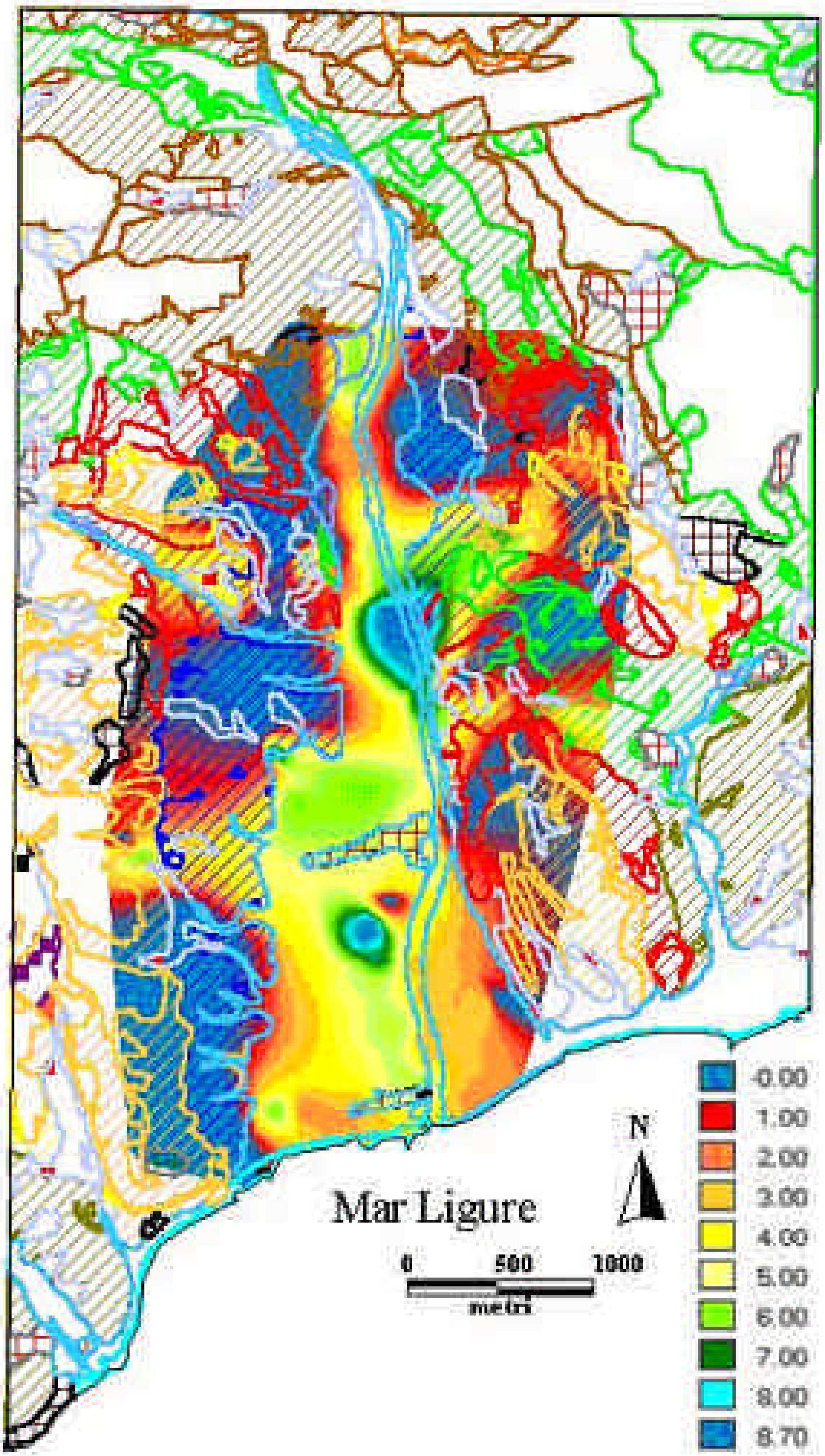

Figure 1.1 – Predominant frequencies in Taggia area, derived by noise measurements.

2. Earthquake ground motion, site effects and interaction

Responsible: Ezio Faccioli, Technical University of Milan

The main Task objective, fully achieved, consisted of the calculation and map representation of the ground shaking for appropriate scenario earthquakes, providing the input to estimate the building damage, both at the sub-regional scale (Imperia province) and the urban scale (in the small town of Taggia).

First-year activities were focused on: (*a*) studies for the identification of the source of the 1887 destructive earthquake (RU3), assumed as the main scenario event, and generation of a regional deterministic ground shaking map; (*b*) probabilistic hazard analyses carried out in the Taggia - Valle Argentina zone (RU1, Geodeco S.p.a.); (*c*) measurements and analyses of seismic background noise in Valle Argentina by the H/V (Nakamura) method (RU1).
During the second year: (*a)* the most likely 1887 earthquake source was identified through a combination of seismological, seismotectonics and macroseismic approaches (RU1, RU3); (*b)* an attenuation relation for peak acceleration was developed for low energy earthquakes (RU1); (*c*) a simplified geotechnical zonation was performed for the study region using the 1:10.000 scale geological maps provided by Regione Liguria, properly treated in GIS environment (RU3); (*d*) the seismic response of the local alluvium deposits in the Valle Argentina zone was calculated, using a representative cross-section of the valley sediments based on previous geotechnical borings, and on 2 down-hole geophysical surveys expressly carried out in this area (RU1, RU3).

Activities carried out in the third year included:

- Further analyses on the 1887 earthquake: on one side, ground velocity synthetics were calculated (in 3D) by modelling the source and the crustal propagation through a wavenumber decomposition method by Hisada (RU3); on the other side, a model has been implemented that takes into account seismic wave propagation both in the sea-water and in the earth's crust, given the likely offshore location of the1887 event (RU1).
- The creation of a deterministic scenario for a small (M = 4.8) earthquake, chosen as a replica of the onshore May 1831 shock, on the Saorge - Taggia fault (RU3).
- The generation of a probabilistic regional map of ground shaking (for T_r=475 years) on the basis of hazard calculations at 4631 points, representing the centres of gravity of population census tracts (RU1), taken as reference units for the damage estimations (RU7).
- A intensity scenario evaluated for the 1887 event on the basis of the mentioned velocity synthetics: macroseismic intensities values have been estimated from the peak velocity values with a new relationship, produced for this purpose (RU3).
- Two further intensity scenarios, respectively for first and second level earthquake (RU1), using attenuation relations calibrated on the 1887 and 1831 earthquakes.
- Evaluation of topographic amplification factors for sites located on hill or mountain ridges (with slope angle >15°). Local 3D DEMs, generated via GIS, enabled to adequately represent the ground morphology for all villages located on hilltops; the

amplification factor was assigned to each site based on the maximum slope angle, in agreement with Eurocode 8 recommendations (RU3), see Figure 1.

- The ground shaking maps previously obtained have been upgraded by including topographic amplification effects (RU3).

Results achieved

The different studies on seismic ground shaking enabled the Task to produce the following hazard maps, involved in building damage evaluation:

- Peak ground accelerations for the 1887 event, generated by an attenuation relation, including topographic amplification (Fig. 1)
- Same, but generated through the UNIGE (RU1) model
- Probabilistic ground acceleration map for T_r=475 years
- Peak ground accelerations values for the 1831 event, generated by an attenuation relation, including topographic amplification
- Intensity scenario for the 1887 event, from an attenuation relation
- Same, but obtained from a correlation between peak ground velocity (derived from 3D synthetics) and macroseismic intensity
- Intensity scenario for 1831 event, generated by an attenuation relation.

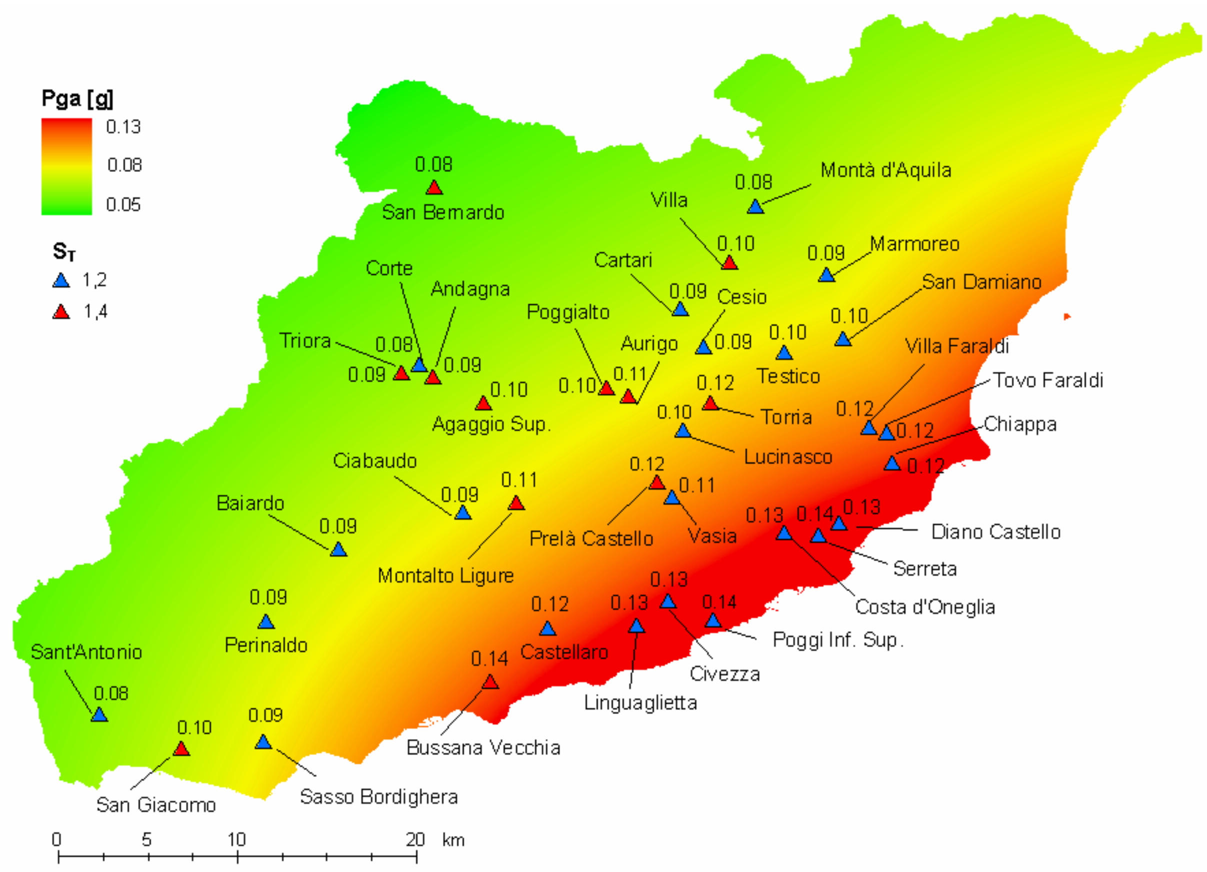

Figure 2.1 – Peak horizontal ground acceleration (Pga) map for the 1887 earthquake, including topographic amplification effects (through S_T values).

3. Assessment at sub-regional scale and vulnerability analysis

Responsible: Sergio Lagomarsino, University of Genoa

In a risk or scenario analysis, the inventory of the exposed vulnerable elements (current buildings, monuments, assets of artistic and historical value) represents a critical aspect, as it is necessary to profit by the existing data (Civil Services, Monuments and Fine Arts Office, bibliography) and integrate them with proper in-field survey. In this project a new integrated methodology for the vulnerability assessment has been developed, able to consider various vulnerable objects in an homogenous way. Obviously, the new models should be applicable to other territory, not only to the Western Liguria. In particular, in Task 3 macroseismic vulnerability models are developed to carry out analyses at sub-regional scale; in Task 5, instead, mechanical models have been considered for the urban scale. Nevertheless, both models can be used, in principle, at the two scales. With analogous criteria, it is possible to carry out a vulnerability analysis of the monumental heritage, with reference to structures and assets.

a) Results obtained in the previous years

- Collection of the available data on the Western Liguria, with reference to the exposed vulnerable elements (ordinary buildings, resident population): administrative borders, census tracts (Liguria Region); consistency of the buildings through ISTAT data (provided by Vincenzo Petrini). (RU7)
- Collection of the available data on the monumental heritage: in particular all the preserved monuments, catalogued in a list got from the *Monuments and Fine Arts Office*, has been georeferred in GIS. (RU7)
- Mapping of works of art catalogued by the *Monuments and Fine Arts Office*. Rational analysis of the bibliography of cultural heritage in the test area. (RU8)
- In field survey and creation of a database containing information about altars, frescoes, paintings, stucco-works, bells, statues and furnishings from cataloguing on sub-regional scale of 30 churches, 2 palaces, 6 sacristies, 2 monasteries, in the area of Taggia, Badalucco, Castellaro and Bussana Vecchia. Altogether, the following assets have been filed: 51 altars, about 1196 m^2 of frescoes, about 569 m^2 of stucco-works, 93 pieces of furniture, 23 bells, 8 organs, 62 sculptures, 231 paintings, 502 furnishings, 137 statues, 124 pieces of furniture. (RU8)
- Definition of a new methodology for the vulnerability analysis, through a macroseismic approach, starting from the EMS 98 (*European Macroseismic Scale*). This scale implicitly includes a vulnerability model, which is defined in a vague and incomplete way. The methodology has been obtained using the fuzzy sets theory. The vulnerability model can be used at different scales, with any database, taking into account the role of the uncertainties. (RU7)
- Processing of data relative to the monumental heritage at the sub-regional scale, through: collection of other available data (ICR – *Central Institute for Restoration*, Rome) and link to the list of the preserved monuments and assets (*Monuments and Fine Arts Office*); georeferentiation in GIS environment using the available cartography and bibliography. (RU7)
- Improvement and check of survey form for vulnerability analysis on the artistic assets. Revision of typologies. Definition of parameters for the damage levels in each typology. Definition of standard procedures for digital photographic survey. (RU8)

- Creation of a new relational database (*Historical and artistic assets*) integrating all collected data (catalogued works of art, bibliography references, documentary photos, results of survey and vulnerability analysis). (RU8)

b) <u>Results obtained in the third year</u>

- The reliability of the ISTAT data for buildings on the Imperia Province has been checked through in-field survey on some sampling census tracts, chosen in different part of the study area, both in the urban centre and in the suburbs. The number of buildings in each census tract results substantially correct. Moreover, it has been possible to define proper building typologies (starting from ISTAT data) and evaluate their vulnerability parameters (vulnerability index, vulnerability factors) through the methodology developed in the second year. (RU7)
- Vulnerability analysis at the sub-regional scale, first considering data at the lower level of aggregation (the census tract) and then unifying the results (vulnerability index) and the exposure data (number of inhabitants, number of buildings, surface of residential dwellings) at different size units, depending on the scale in which one wants to analyse data (a town, a group of neighbouring towns, the entire sub-region). (RU7)
- Damage scenarios at the sub-regional scale, considering the vulnerability at the lower geographic level (census tract) and the different hazard scenarios, given as a grid of points (with PGA or Intensity) and a map of site regions (according to the EC8 classification). In order to make the analysis, each census tract characterized by two or more sites has been split, assigning to each part a number of buildings and inhabitants proportional to the area. (RU7)
- Vulnerability analysis of monumental heritage at the sub-regional scale, using the methodology proposed in the Traiano project. (RU7)
- Statement of the parameters for the cultural significance of architectonic elements, fundamental for the definition of the value (and the evaluation of the risk) of the cultural heritage; some of them are: unitariness in the construction phase; significant element of the urban texture; symbolic value for the local community; unitariness between the building and the artistic assets; etc. (RU8)
- Improvement of the survey form for vulnerability analysis, with a revision of parameters related to the decay, subdivided into: 1) active processes (humidity, atmospheric agents, past damage); 2) activation cause (seepage, capillarity, structural instability); 3) damage progress. (RU8)
- New in-field survey, aimed at the awarding of the cultural significance parameters to the churches and the other monumental buildings already surveyed in Taggia, Baiardo, Castellaro, and Bussana Vecchia. (RU8)

Final results

Vulnerability scenarios have been produced, which show the propensity of the various exposed elements to be damaged by an earthquake. Ordinary buildings have been considered and aggregated at different levels in the sub-regional scale: census tracts, local built-up areas, municipality borders; in each case, masonry and r.c. buildings may be distinguished. The historical centres have been considered as an entity, taking into consideration both the vulnerability of the buildings and the significance of the centre, from the urbanistic point of view and considering the

presence of monuments inside. The vulnerability of more than one thousand georeferred monumental buildings has been obtained through some rough parameter on the state of maintenance and the typology.
Damage scenarios have been obtained by using the hazard scenarios produced in Task 2, considering the direct physical damage (probability of occurrence of the various damage state), the consequences to people (dead and injured; homeless) and the economic losses.

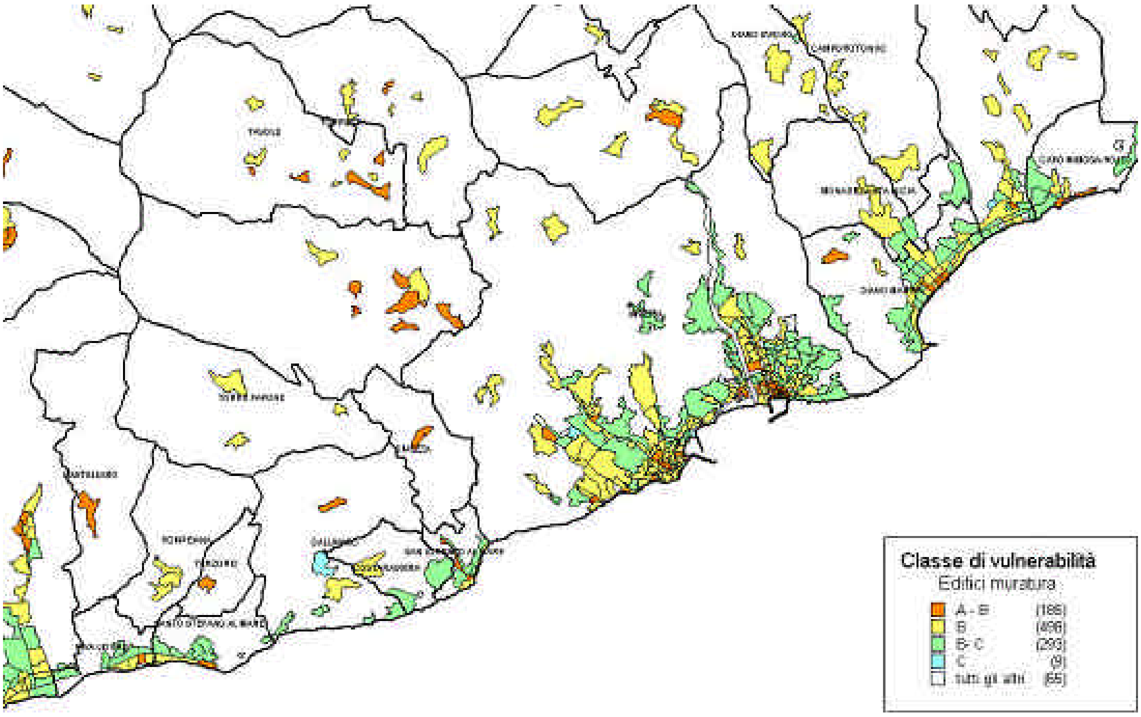

Figure 3.1 – Vulnerability index for masonry buildings in some built-up areas near Imperia.

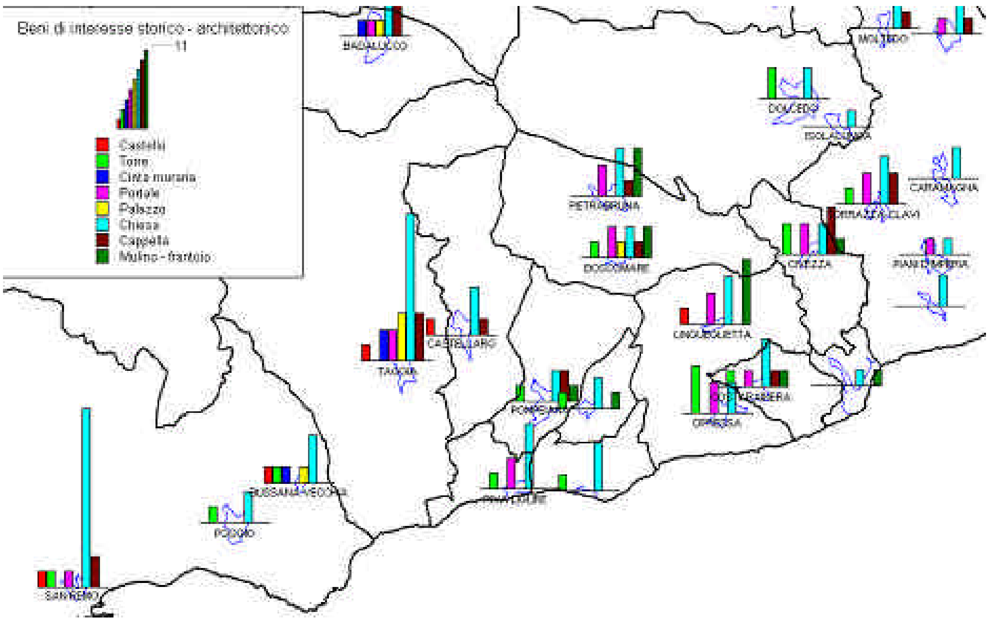

Figure 3.2 – Map of the monumental buildings in an area close to Taggia.

4. Typological classification and survey of the buildings

Responsible: Luigia Binda, Technical University of Milan

The vulnerability models are characterised by the need of a typological classification. RU4 aimed at individuating recurrent building and masonry typologies and their vulnerability, singling out some useful parameters for quick on site identification.
In order to better understand the picture of the effects regarding the highest degree of intensity due to the 1887 earthquake, elements of building vulnerability at that time have been looked for (RU2).
In particular, for the historic centre of Taggia, different typologies have been recognized in different areas of the urban centre: via Tages, via S. Dalmazzo, via Soleri, via Lercari, via S. Lucia (RU5).
Moreover, the attention has been focused on the street urban ornaments of the historical centres (decorated portals, shrines, fountains, etc.), by the definition of a proper form for the damage and vulnerability assessment (RU8).

Description of the activities

A classification of masonry was performed, with the evaluation of the mechanical properties of different kinds of masonry, by *in situ* non-destructive tests and laboratory tests and a comparison with the results obtained in Umbria, within another GNDT Project, was performed. Detailed surveys of the historic evolution of the built complex by considering the growth and transformation phases was carried out, together with a study of its constructive techniques (RU4).
A large number of technical and scientific reports was analysed indicating the state of the built environment before the earthquake. These reports enlightened some specific elements like loss of connection between the walls, excessive dead load of roofs, weakness of vaults, too heavy up to the last floor, the great thickness of non load-bearing walls, the weakness of materials, etc. (RU2).
Plan and front view for “via Tages” were elaborated by a street survey; a completely new survey was performed for a little block in the older upper part of the Taggia centre bordered by via Tages, via Segneri, salita alla torre, vicolo N. Calvi. From the street survey front views and sections of the block were elaborated. Survey of traditional roofing and vaulting techniques in Taggia was carried out (RU5).
The street urban ornaments of Taggia historical centre have been surveyed, after a classification of the historical street networks (RU8); altogether, 170 cultural assets have been located in GIS, and a database has been realised with many information and photographs (64 portals, 11 balustrades, 18 decorated facades, 21 shrines, 14 decorated architectonic elements, 7 fountains, 12 ancient inscriptions, 9 bas-reliefs, 1 loggia, 1 sundial, 5 statues, …).

Final products

<u>Contribution of RU4, Politecnico di Milano - Responsible: Luigia Binda</u>

Investigation on the masonry of Western Liguria: in-situ testing

<u>Description.</u> An extensive survey has been carried out with in-situ testing carried out on masonry, starting from the technological survey of prospects and sections,

including non-destructive testing aimed at the characterization of the masonry (flat-jack tests, sonic tests).
Final version. CD containing charts with the results of single tests and synthetic tables with the different masonry typologies, with reference values of the physical-mechanical properties.
Utility for the Department of Civil Protection. Reference data for designing seismic *improvements* and *retrofitting* interventions on existing buildings.

Investigation on the masonry of Western Liguria: laboratory testing
Description. An extensive in-situ sampling on the masonry materials (mortars, stones) has been carried out, in the same sites of the non-destructive testing, for their chemical-physical, petrographic and mechanical characterisation.
Final version. CD containing templates with the results of single tests and synthetic tables with the results of the petrographic characterisation and the reference values of the chemical-physical and mechanical properties.
Utility for the Department of Civil Protection. Reference data for the choice of the materials within seismic *improvements* and *retrofitting* interventions on existing buildings.

Templates of the historic centre of Taggia
Description. Starting from the results obtained by detailed investigations (see above), a chart has been set up and applied aimed at the vulnerability evaluation of the historic centre of Taggia, that takes into account the elements of specific vulnerability typical of the area.
Final version. CD containing a database with georefences of the collected data through the Templates, with photographic pictures connected to GIS, results of in-situ and laboratory testing, elaborations on the vulnerability evaluation.
Utility for the Department of Civil Protection. Paradigmatic example of the application of a methodology of interest for the Department of Civil Protection, having as an objective the evaluation of the vulnerability at the scale of the historic centre.

Templates of the historic centre of Bajardo
Description. Starting from the results obtained by detailed investigations (see above), a chart has been set up and applied aimed at the vulnerability evaluation of the historic centre of Bajardo, that takes into account the elements of specific vulnerability typical of the area.
Final version. CD containing a database with georefences of the collected data through the Templates, with photographic pictures connected to GIS, results of in-situ and laboratory testing, elaborations on the vulnerability evaluation.
Utility for the Department of Civil Protection. Paradigmatic example of the application of a methodology of interest for the Department of Civil Protection, having as an objective the evaluation of the vulnerability at the scale of the historic centre.

Templates of the historic centre of Bussana
Description. Starting from the results obtained by detailed in-situ survey of the building typologies, the masonry prospects and sections, and the weakness elements of the complex of buildings, a chart has been set up and applied aimed at the vulnerability evaluation of the historic centre of Bussana.

Final version. CD with templates and tables of the parameters collected by a qualitative survey. Instruments and procedures for the analysis.
Utility for the Department of Civil Protection. Paradigmatic example of the application of a methodology of interest for the Department of Civil Protection, having as an objective the evaluation of the vulnerability at the scale of the historic centre.

Methodology for vulnerability analysis
Description. An integrated system of methodologies for vulnerability analysis has been set up, calibrated on observed vulnerability data and applicable to data of different nature and detail.
Final version. CD with templates and tables of the necessary parameters for a vulnerability analysis. Instruments and analysis procedures.
Utility for the Department of Civil Protection. New methodology, useful for the application on complex buildings within the historical centres.

Templates for complex buildings
Description. Starting from the results obtained by detailed investigations, a chart has been set up and applied for surveying complex buildings, which pose some difficulties of modelling and of defining vulnerability, and for guiding possible prevention and retrofitting interventions (parts of the historic centres of Taggia and Bajardo).
Final version. CD with templates and tables of the necessary parameters for a vulnerability analysis. Instruments and analysis procedures.
Utility for the Department of Civil Protection. New methodology, useful for the application on complex buildings within the historical centres.

Contribution of RU2, SGA, Bologna - Responsible: Emanuela Guidoboni

Historic seismicity: redefinition of quoted plans, epicentres and magnitude
Description. For the main earthquakes, already studied, a revision of historical data, through the acquisition of new archive data, and consequent new attribution of local intensity, macroseismic epicentres and magnitude. Minor earthquakes have been analysed on the basis of an original archive research.
Final version. Quoted plans, macroseismic epicentres and associated magnitude.
Utility for the Department of Civil Protection. Localization of epicentres for the most significant scenario earthquakes.

Contribution of RU5, Roma Tre - Responsible: Carlo Baggio

Mapping of the urban tissues in Taggia and their vulnerability
Description. Individuation of the growing phases of the historical centre, through historic maps and in-situ survey of the urban-architectural characters. Way of growing, in plan and elevation of built aggregates
Final version. Descriptive maps at urban scale and architectural schemes of paradigmatic built units.
Utility for the Department of Civil Protection. Examples of historical-urban-constructive analysis of the historical centre, from which guide lines for similar analysis may be taken.

5. Vulnerability models and damage scenarios

Responsible: Guido Magenes, University of Pavia

In order to carry out homogeneous vulnerability analysis and compare damage scenarios, vulnerability models have to be based on a same conceptual approach for all kind of structures (masonry buildings, r.c. buildings, monuments). Macroseismic vulnerability models, which are developed and applied in Task 3, are very simple for the use and available for the analysis at sub-regional scale. A set of mechanical vulnerability models is defined on Task 5, differently expressed for each building typology and for the analysis at different scales. An advantage of a mechanical approach is the possibility to consider the seismic action in spectral terms, so that damage evaluation can take into account the interaction between building dynamic properties of geodynamic characteristics of the site.

a) <u>Results obtained in the previous years</u>

- Application of a preliminary "displacement-based" simplified seismic assessment procedure (Calvi, 1999) for existing r.c. buildings, to produce damage scenarios, using ISTAT data. (RU6)
- Development of a numerical model for the nonlinear dynamic analysis of multistorey r.c. frames, taking into account joint failure. Preliminary nonlinear dynamic analyses on multistorey r.c. frames, modelling joint failure (Calvi, Magenes and Pampanin 2001 & 2002). (RU6)
- Formulation of a new deformation-based simplified assessment procedure to be used in the scenario analyses (Glaister & Pinho, 2003). Calibration of a nonlinear model for the simulation of infills, through comparison with experimental data. (RU6)
- Nonlinear analyses on multistorey r.c. frames, with the simulation of weak joints and the presence of infills. The models were developed using the code "Ruaumoko" (Carr, 2001). (RU6)
- Development of a mechanical based vulnerability method for masonry buildings, based on the *capacity-spectrum* approach (Hazus, 1999): definition of capacity curves, joined to each typology (materials, height), and intersection with the earthquake spectral demand, properly reduced as the displacement increases (performance point). Comparison with the results of the macroseismic method. (RU7)
- Survey of the entire historical centre of Taggia, by means of a quick form (which doesn’t require to go into the building), containing information on the geometry, the regularity, the position in the building aggregate, the presence of traditional aseismic devices (tie rods, buttresses, foil arches, etc.). The collected data, together with a photographic documentation, have been implemented in GIS environment; they will be used both for macroseismic and mechanical based vulnerability analyses. (RU7)

b) <u>Results obtained in the third year activities</u>

- The survey of r.c. buildings in selected areas of Arma di Taggia was completed, using a survey form developed for the task. The form contains information common to other forms proposed in the past (e.g. GNDT level I and II forms) and additional information needed for the application of the newly developed mechanics-based procedure for seismic risk assessment.
- Detailed nonlinear analyses of selected representative r.c. buildings were made, taking into consideration the effect and performance of: one-way frame structural

systems, masonry infills, weak beam-column joints. Pushover and time-history analyses of two and three-dimensional models of existing multi-storey r.c. frame buildings were carried out, using a lumped plasticity approach developed and calibrated within the project (Magenes and Pampanin, 2004, Del Prete 2004).

- The new mechanic-based simplified assessment procedure proposed by Glaister and Pinho (2003) developed in the previous year was given a probabilistic formulation and implementation (Iaccino 2004, Crowley et al., 2004) to be applied to population of buildings at urban or territorial scale. The procedure was applied to the province of Imperia and to the town of Arma di Taggia, to produce damage scenarios. Comparisons with the "macroseismic" methodology developed by RU7 were made, as well with the results obtained by the mechanics-based procedure by Calvi (1997).
- Vulnerability analysis and damage scenarios of the historical centre of Taggia, based on the survey building by building. (RU7)
- Deep checking of the macroseismic and mechanical vulnerability models, in order to establish a theoretical correlation between them. By assuming an analytical relation between Intensity and PGA, it is possible to evaluate the vulnerability index given the capacity curve or define a capacity curve from the vulnerability index, in order to obtain the same damage distribution and probability for each damage state. Considering their complementary characteristics (observed vulnerability and mechanical aspects), the two methods have been cross-validated. (RU7)

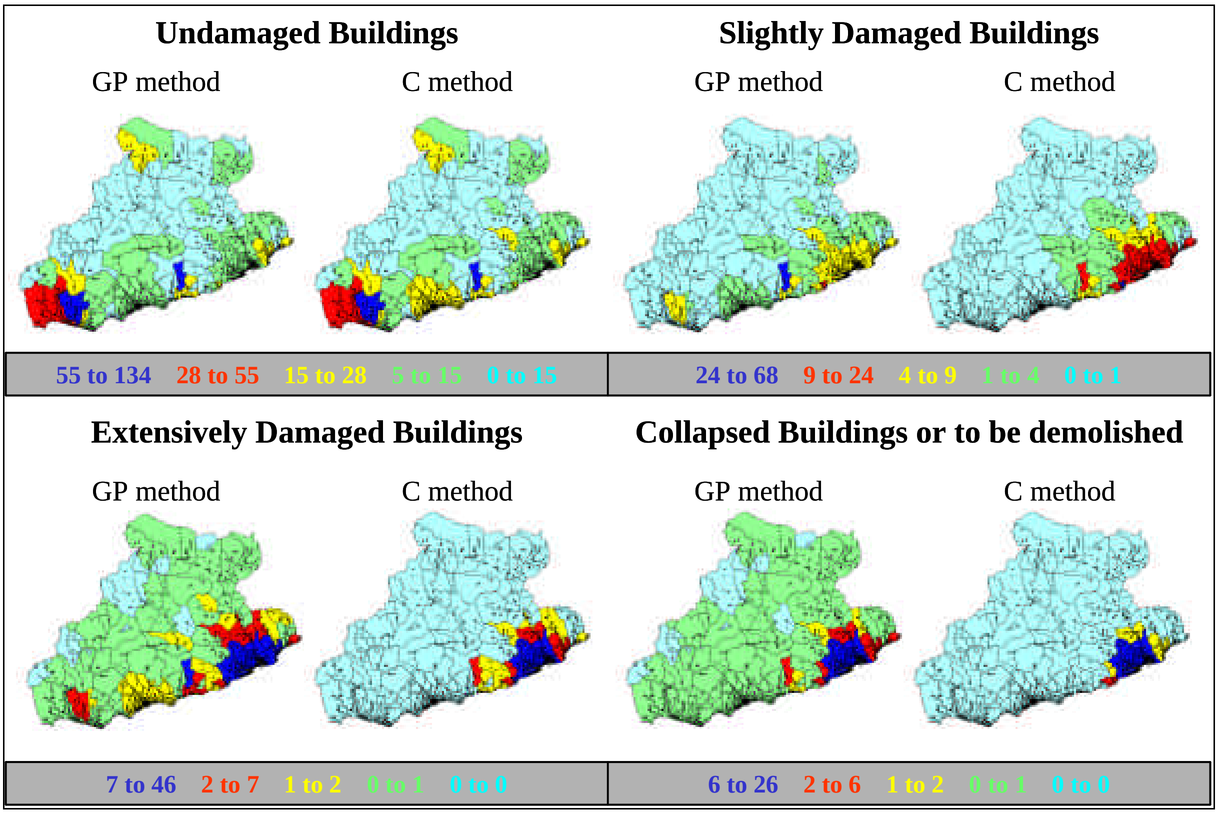

Fig. 5.1 – Comparison between the Calvi method and the proposed probabilistic methodology for r.c. buildings under a given scenario earthquake.

Innovative contributions

The development and application of a new mechanics-based, probabilistic procedure for the seismic risk evaluation of classes of r.c. buildings constitutes a meaningful step forward towards rational and flexible approaches which appropriately take into account the seismic input characteristics affecting structural response. Such methodology represents the seismic input by mean of variable damping response spectra, which are a more complete representation with respect to single-parameter representations such as those based on PGA or macroseismic intensity.

Although, the new mechanics-based procedures need further calibration and comparison with surveyed damage data and other methodologies, the results obtained appear to be promising and of practical relevance.

6. Traditional and innovative interventions for the damage mitigation

Responsible: Carlo Baggio, III University of Rome

This task addresses, in particular, to the vernacular popular buildings.

Obviously, the first step of the research was a thoroughly knowledge of the chosen sites (Taggia in particular): historic urban development, the system of urban connections represented by main roads oriented roughly along contour lines of the hill cut by minor alleys following the maximum slope, the general layout of the buildings from a geometrical point of view. A great amount of work was spent during first year activity in collecting data (bibliographic, archive, historical and modern graphic documents) on historic centres of Western Liguria, in particular Taggia. Typological analysis was also started, to be completed during the second year.

During second year, typological analysis on the settlement of Taggia was carried out in view of vulnerability assessment and consequent mitigation of damage; cadastral maps but even more plan of ground walls (supported by direct observation and direct survey) let individuate the arrangement of building units, the specific types of masonry connections between units and specific types of relation with second phase construction, reconstruction, alteration of streets and so on.

Some innovation from the methodological point of view consists in the consideration of a complex arrangement of building units resting on the hill slope in its full 3D reality, focusing on wall connections and on height of facades. Numerical analyses via ANSYS package were performed on masonry assemblages, using “gap elements”, which are able to model a 3D texture of blocks. Results are not obvious and show that collapse depends mainly on force orientation; angle interlocking of the two intersecting walls plays a minor role.

Moreover, the research in the historical archives has put forward the finding of a technical code, issued with a Royal Decree on November 13, 1887, containing rules for rebuilt and repair of the damaged buildings; among the many recommendations, we mention: new buildings must be built on stable sites; public buildings (schools, hospitals, town halls) should be lower then 4 storey; in the churches, the basilica plan has to be preferred (vaults in the nave are forbidden); masonry vaults are allowed only in the basements; doors and windows should be far from the corners for, at least, 1.5 meters; the cuts in the masonry bearing walls (pipes, chimneys, etc.) should be made in such a way that doesn’t compromise the stability. (RU2)

Final products

Collections and elaboration of information and documents in view of the development of the Code of Practice:

Table no. 1

Historic routing in Western Liguria from the roman empire to the medieval network of roads connecting Taggia to the passes of the Ligurian Alps along the Argentina valley. Ways entering and going out from the centre of Taggia as reported in historic documents dating back to the eighteen century.

Table no. 2

Comparison of historic maps of the centre of Taggia (in scale 1:3000): Vinzoni's survey of 1759, cadastral map (1894), modern cadastral map, aerial photography. The comparison shows a quite good according of the four maps except that the orientation of the historical cadastral map seems wrong.

Table no. 3

A map resulting from the comparison of documents described in table 2; defensive wall position during different periods are individuated; water streams entering Taggia in the eighteen century and today covered or disappeared are positioned in the map. Urban expansion along the Argentina river during nineteen century as well as buildings ruined or reconstructed are pointed out.

Table no. 4

Individuation of different typologies in the historic centre of Taggia: wall plans at ground floor as well as front view along some streets are reported. The study refers to the minor buildings and is constructed using survey documents dating back to the seventies. Plan and front view for "via Tages" were elaborated by a street survey performed by the research unit. The study covers different areas in the urban centre: via Tages, via S. Dalmazzo, via Soleri, via Lercari, via S. Lucia.

Table nos. 5-10

A completely new survey was performed for a little block in the older upper part of the Taggia centre bordered by via Tages, via Segneri, salita alla torre, vicolo N. Calvi. From the street survey were elaborated front views and sections of the block; this area has some relevant features and is bordered to the south-est by some ruined buildings only partially reconstructed and the urban big empty area of Piazza Grande resulting from the whole demolition of two blocks after the 1887 earthquake.

Table no. 11

Survey of traditional roofing techniques in Taggia

Table no. 12

Survey of traditional vaulting techniques in Taggia

Table no. 13

Mechanical models for the check of vulnerability of traditional masonry building techniques; in particular were analysed the arrangement of building units, the specific types of masonry connections between units and specific types of relation with second phase construction, reconstruction, alteration of streets and so on. Numerical analyses via ANSYS package were performed on masonry assemblages, using “gap elements”, which are able to model a 3D texture of blocks.

Table no. 14
Catalogue of techniques for interventions for seismic improvements of minor vernacular buildings (Documents in view of the development of the Code of Practice).

7. Information data management

Responsible: Vera Pessina, INGV - Milan

Available data have been collected from administrative offices, universities and researcher centres, ISTAT, etc. and they were organized in a GIS structure, mainly during the first and second year of the Project. An important effort was dedicated to the correction of the PTCP (Piano Territoriale di Coordinamento Provinciale) data: morphology and lithology maps, at scale 1:10.000, for all the Imperia province, have been corrected and delivered to the Provincia Office (RU2 and RU3).
During the second year, the collected GIS data were integrated with the results produced within the Urs, that is (i) ground shaking scenarios in terms of intensity, PGA, acceleration spectral values, (ii) classification and characterization of existing buildings, historical centres, etc. This activity was carried out mainly by the RU 1, 2, 3 and 7. In order to share the data and to assure the same level of knowledge within the different RUs, data were disseminated by a CD.
The preliminary structure of the GIS was modified in the last year, because of the availability of new results (new versions of shaking ground scenarios, upgraded classification on historical centres and monumental structures). The GIS was steadily upgraded and it was as well published on Web. Even if differently specified in the project proposal, it was not be possible to use the ArcIMS software for the Web publication because it was available late and, on the other hand, its license was bound on Polimi while the task 5 responsible moved to another Institute. After an accurate analysis of alternative solutions (SVG,GML, etc.), and in consideration of the features of the GIS’s structure already elaborated, it was decided to adopt an “applet” developed from the Sydney University, within the “Time-Map” project, freeware in case of scientific Web publication.

In conclusion, all the proposed activity has been done: indeed, the collection of the results from the RUs has been completed; data have been organised in the GIS structure and they have been published on Web. The latter is the more innovative aspect because the WebGIS is done by a technology based on the freeware software Alov, generated in Java technology (and therefore not hardware or software depending), which development is assured (being part of a great researching project) and with excellent capabilities.

Considering the last referees opinions, we should recall that, differently from other GNDT projects, the analysis of this projects have been carried out at two different scales (provincial and local ones). If, on one hand, this choice has shown a lot of potentialities inherent the process of risk analysis at different scales, on the other hand it has not assured a strong collaboration with the involved administrative offices. For instance, the choice of examining closely some local centres has not be

suggested by the availability of data or by the level of collaboration of the municipalities
Anyway, the GIS will be transferred to the interested administrations and it will be public presented during the itinerary exhibition organised by RU8.

Deliverables

The GIS of the Liguria Project will be available on:

- http://www.stru.polimi.it/new/Progetto_Liguria.htm

and now it is provisionally available on http://www.era.cc/scenari/

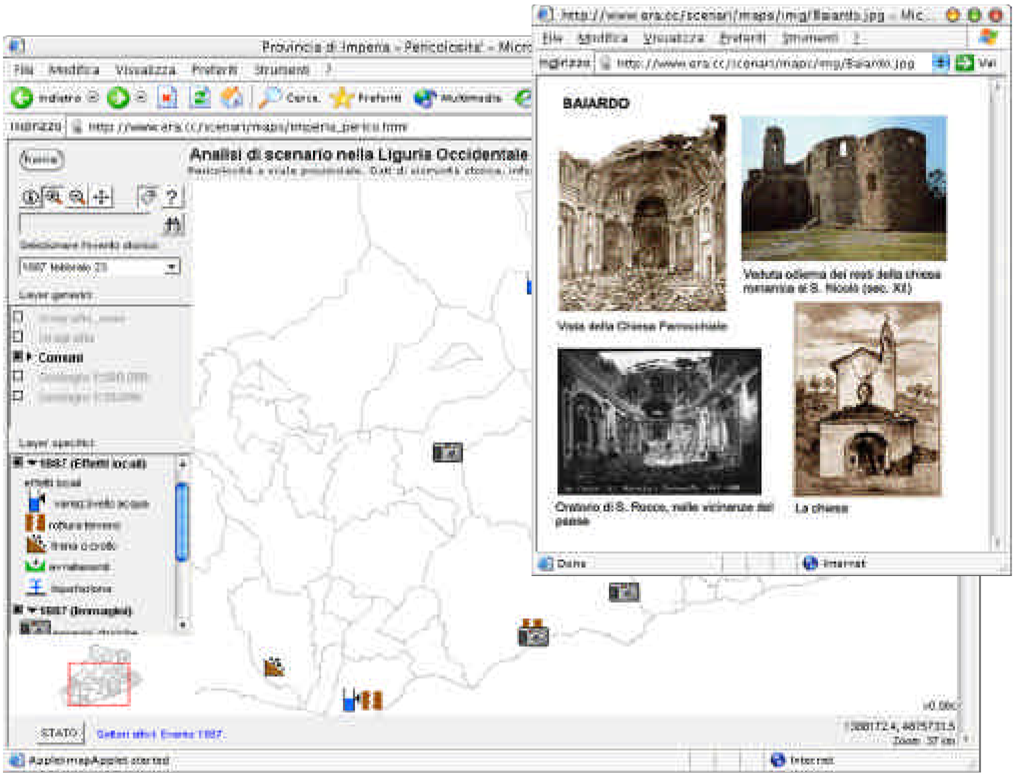

Fig. 7.1 – Some data associated to the hazard analysis at provincial scale (zoom on municipalities around Sanremo): mapping of the local effects of the 1887 earthquake and consulting of the historical pictures of the Baiardo village, in case of the same event.

The GIS is structured at different scales, one regards the whole province of Imperia, and the other concerns some localities of particular historical and artistic heritage (that is Taggia, Bussana and Baiardo). Data are structured according hazard, exposition, vulnerability and damage aspects: damage analysis have been carried out not only for residential buildings (according to well consolidated damage models), but also for historical centres and architectonic monuments.

Almost all the published layers could be interrogated; there are links to iconographic database of historical pictures (see Fig.1) and to geothecnic investigations (boreholes profiles, geoelectric cross-sections); simple but efficacious overlays are possible among different information, in order to realise a direct comparisons (for instance between macroseismic data and ground shaking scenarios).

A list of the available data is shown in Appendix.

Because of the stored up delay during the project, mainly due to the late assignment of funds, the final products of some RUs are not yet available in the last format, and so they will be included in a following version of the GIS, that will be presumably published before January 2005.

Conclusions

The project has gone on in accordance with the phases originally indicated, except for some unavoidable changes, which became necessary during the development of the work. The research wasn't limited to the application of well-established tools, but led, in some cases, to the statement of new methodologies and theoretical models, of scientific relevance. A list of scientific publications follows.

The data collected, the surveyed information and the obtained results have been assembled in the GIS environment, which has been used not only as a database from which it is possible to get data but also as an analysis tool. All the procedures for the damage scenarios have been implemented, making possible a real time update of the results if new information will become available (for example, it is possible to produce a real time damage scenario, in the emergency after an earthquake, or it is possible to evaluate the risk mitigation obtained with some retrofitting interventions, assuming how much they reduce the vulnerability).

The GIS will be available for the Civil Services (Municipality of Taggia, Liguria Region, Local Monuments and Fine Arts Office), while an abridged version (with not modifiable data) will be published on Internet. Moreover, a wide report of the project will be published within the end of the year. Some other deepening reports are foreseen by the RUs.

A wide conference has been organized in Sanremo (July 2-3, 2004), in which the main results of the project have been presented to the Local Authorities and the technicians (engineers, architects and geologists) that operate in Western Liguria (http://adic.diseg.unige.it/ingenium/rischiosismico.html). Many Italian researchers, not involved in the project, have been invited and appraised positively the work that has been done.

Finally, we are now organizing a travelling photographic exhibition on the relation between the seismic risk and the historic, artistic and environmental heritage of the Western Liguria. A set of photographs has been selected from those produced by the RU8 (related to the cultural heritage and its relation with the territory) and the RU4 (related to the typical Ligurian masonry, which can be seen in the ruins of the buildings damaged by the 1887 earthquake). Moreover, some ancient photographs, gathered by RU2, which show the damage after the main historical earthquakes, will be included. Last but not least, a set of artistic photographs, taken by Vittore Fossati will represent the core of the exhibition, because we feel that making use of an artist, not expert in seismic risk, is probably the most effective way to awake public opinion on this subject. The exhibition will be open in Genoa, in the last part of 2004 (year in which Genoa is the *European Capital of Culture*); then it will move to Taggia and finally to Rome.

Scientific production

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Appendix: List of GIS information (layers) published in Web-GIS

The following list is not complete and, unfortunately, is in Italian.

Sub-regional scale (Imperia Province)

EXPOSURE	Comuni: limiti amministrativi, n. abitanti, n. edifici, tipologia edilizia, distribuzione edifici in muratura per classi di età, distribuzione edifici in c.a. per classi di età, % ed. in muratura, % ed. in c.a.) Centri abitati: limiti amministrativi, n. abitanti, n. edifici, tipologia edilizia, distribuzione edifici in muratura per classi di età, distribuzione edifici in c.a. per classi di età, % ed. in muratura, % ed. in c.a.) Rete stradale Autostrada Ferrovia Centri storici: numero di beni storico-monumentali, tipo di bene storico-monumentale, tipologia urbanistica del centro storico, morfologia terreno Beni monumentali Edifici pubblici Edifici strategici
HAZARD	Confini comunali Classificazione geotecnica 1:500.000 Classificazione geotecnica 1:10.000 dai Piani Territoriali Coordinamento Provinciale Piano quotato (PQ) evento 19 luglio 1963 PQ 23 febbraio 1887 Effetti locali evento 23 febbraio 1887 Immagini storiche evento 23 febbraio 1887 PQ 29 dicembre 1854 PQ 26 maggio 1831 Effetti locali evento 26 maggio 1831 PQ 8 gennaio 1819 PQ 23 febbraio 1818 Effetti locali evento 23 febbraio 1818 Epicentri macrosismici Localizzazione faglie Scenario 1887 in Intensità da legge di attenuazione Grandori Scenario 1887 in Intensità da modello 3D e conversione di v_{max} Scenario 1831 in intensità da legge di attenuazione *ad hoc* Scenario 1887 in PGA Scenario 1887 in PGA con effetti locali Scenario 1887 in SA (T=0.3 s) con effetti locali Scenario 1831 in PGA Scenario probabilistico T475 anni Scenario probabilistico T475 anni con effetti locali Orografia a scala nazionale Orografia di dettaglio (risoluzione 200x200m) Localizzazione strumenti installati Sismicità strumentale

VULNERABILITY	Comuni: indice vulnerabilità (Iv) edifici in muratura, Iv edifici in ca, Iv globale, % modificatore per numero di piani, % modificatore per livello manutenzione, % modificatore per pilotis. Centri abitati: Iv edifici in muratura, Iv edifici in ca, Iv globale, % modificatore per numero di piani, % modificatore per livello manutenzione, % modificatore per pilotis. Centri storici: Iv edifici in muratura, Iv edifici in ca, Iv globale, % modificatore per numero di piani, % modificatore per livello manutenzione, % modificatore per pilotis. Vulnerabilità edifici strategici Localizzazione prove per valori meccanici di tipologia muraria Localizzazione prove per valori meccanici di tipologia ca Monumenti: posizione, dimensione e rilevanza
DAMAGE	Comuni: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Sezioni di censimento: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Centri abitati: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Danno centri storici Danno beni monumentali Edifici strategici (tipologia e localizzazione)

Local scale: Taggia

EXPOSURE	Confini comunali Centri abitati: Taggia, Baiardo e Bussana Edifici a Taggia Edifici centro storico di Taggia Edifici strategici Beni monumentali (lista Soprintendenza) Beni artistici Assi viari di rilevanza storico-artistica nel centro storico di Taggia Elementi storici di arredo urbano nel centro di Taggia Rete stradale Autostrada Ferrovia

HAZARD	Confini comunali Confini centri abitati Classificazione geotecnica 1:10.000 Mappa geologica 1:2.000 Sondaggi Profilo n.2 sondaggi eseguiti durante il progetto Sezioni geoelettriche (localizzazione e visione dell'interpretazione semplificata) Registrazioni rumore (localizzazione e rapporti in frequenza e ampiezza) Tettonica Faglie Piano quotato (PQ) evento 19 luglio 1963(*) PQ 23 febbraio 1887 Effetti locali evento 23 febbraio 1887 Immagini storiche evento 23 febbraio 1887 PQ 29 dicembre 1854 PQ 26 maggio 1831 Effetti locali evento 26 maggio 1831 PQ 8 gennaio 1819 PQ 23 febbraio 1818 Effetti locali evento 23 febbraio 1818 Scenario 1887 in Intensità da legge di attenuazione Grandori Scenario 1887 in Intensità da modello 3D e conversione di v_{max} Scenario 1831 in intensità da legge di attenuazione *ad hoc* Scenario 1887 in PGA con effetti locali Scenario 1887 in SA (T=0.3 s) con effetti locali Scenario 1831 in PGA Scenario probabilistico T475 anni con effetti locali Danni terremoti storici al dettaglio
VULNERABILITY	Comuni: Sezioni di censimento: Iv edifici in muratura, Iv edifici in ca, Iv globale, % modificatore per numero di piani, % modificatore per livello manutenzione, % modificatore per pilotis. Edifici: vulnerabilità Monumenti: vulnerabilità Caratterizzazione muratura
DAMAGE	Comuni: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Sezioni di censimento: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Centri abitati: danno edif. in muratura, danno ed. in ca, danno medio o prevalente, ed. crollati, edif. Inagibili, vittime, senzatetto Danno centri storici Danno beni monumentali Edifici strategici (tipologia e localizzazione)

(*) i piani quotati sono a risoluzione di centro abitato