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"SCENARIO SISMICO": A TOOL FOR REAL TIME DAMAGE SCENARIOS

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SUMMARY

"Scenario Sismico" is a GIS tool designed and implemented by the authors for the simulation and the representation of real time damage scenarios in Liguria Region. The specific aim of the tool is to support local Civil Protection departments and government officials for the emergency management, during the first hours after an earthquake event. "Scenario Sismico" can be as well regarded as an useful tool to help formulating general strategies for earthquake mitigation and disaster response planning. Thanks to its user-friendly framework, implemented within ALOV Map/TMJava application, its use does not require any specific GIS expertise.
Once the earthquake scenario is set (by specifying the epicentre position, the magnitude and the hypocentral depth) the expected hazard, the physical damage to buildings and the consequences to people, expressed in terms of possible range, are automatically obtained and displayed in terms of thematic maps and databases. The results of the vulnerability and of the exposure analyses for all the Liguria Region are as well provided in terms of maps and databases. This paper is addressed to the presentation and to the description of the software and of the methodological framework at the basis of the "Scenario Sismico" tool. The simulation of an earthquake event is moreover presented, in order to show the effectiveness of the real time damage assessment resulting from "Scenario Sismico" in supporting the emergency management.

1. INTRODUCTION

The extreme consequences of the recent seismic events have raised the consciousness among private and public on the need for an efficiency risk management. In order to avoid, or at least to limit, mistakes and delays that could increase the negative effects of an earthquake event, the identification of areas potentially effected and quantitative information about the possible effects, are immediately needed by the rescue agencies and by the civil protection departments. Moreover, a preventive estimation of the potential impact of a future earthquake is necessary in order to quantify the resources, in terms of people and facilities, and to verify their effective availability.
Aiming to reach both these two goals the "Scenario Sismico" tool have been conceived and implemented within a collaboration between the Civil Protection Department of the Liguria Region and the University of Genoa. The tool allows the representation and the simulation of seismic event within Liguria Region. Inside the tool information and procedures are properly organized to be useful for Civil Protection specific requirements; useful informative layers identifying the type and the location of the roadway system and of the strategic buildings can be overlaid to the damage and consequence scenario maps.
A very user-friendly framework allows running the program and examine the results (in terms of databases and maps) without the need for any GIS (Geographycal Information System) expertise. Three main applications can be identified: 1) "Scenario Sismico - Elaboration" a Microsoft Visual Basic® application that allows running the program after the definition by the user of the earthquake event, 2) "Scenario Sismico - Visualisation" the ALOV Map/TMJava GIS tool that allows the visualisation and the querying of the maps, 3) "Report Sismico" a

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post-processor software developed as a Visual Basic® application that allows the visualisation of the results in terms of databases. The first part of this paper is devoted to the presentation and to the description of these software features.

In the second part of the paper the methodological framework at the basis of the "Scenario Sismico" analyses is presented. "Scenario Sismico" implements deterministic damage scenarios convoluting the results from deterministic hazard analysis, exposure and vulnerability assessment in order to achieve the estimation of the expected damages and consequences to buildings and people.

Hazard scenarios are directly evaluated by the tool once the position, the magnitude and, when known, the hypocentre depth are provided. EMS-98 macroseimic intensity (Grunthal 1998) is employed to describe the resulting shaking. Intensity increments are applied to account for particular morphological conditions assessed from the Digital Elevation Model (DEM). The characterization of the exposed building-stock is obtained by processing the available census data according to a GIS automatic procedure allowing the immediate updating in the case of new data availability. The seismic vulnerability assessment is therefore obtained applying a macroseimic approach properly specified for the building typologies recognized in the territory. All the meaningful information available on the building-stock and on the soil conditions are accounted for within the vulnerability evaluation. Once the earthquake scenario is set, physical damages, losses and consequences to people are automatically obtained and displayed in terms of thematic maps or databases, available at different scale and level of detail.

The program allows the simulation and the representation of real time damage scenarios in Liguria Region, anyhow the same procedures and software framework could be implemented for any other geographical area with the same availability in terms of digital maps and data.

2. THE "SCENARIO SISMICO" TOOL

"Scenario Sismico" is a computer tool for the simulation and the representation of real time damage scenarios in the Liguria Region. The "Scenario Sismico - Elaboration" and the "Scenario Sismico - Visualisation" can be both activated starting from the home page of the computer program (Figure 1).

Figure 1: "Scenario Sismico" home page

When the "Scenario Sismico - Elaboration" is selected, a Microsoft Visual Basic® application allows running the program.

The parameters defining the earthquake event, that has to be simulated, can be specified by the operator via a user-friendly form (Figure 2). Two different options are available on the left side of the form: 1) the earthquake event can be specified providing the epicentre coordinates (either in terms of Gauss-Boaga coordinates or in terms of Latitude and Longitude), the earthquake magnitude and the hypocentre depth (km); 2) the epicentre can be located by selecting an urban centre among a list, while the earthquake size is specified providing the epicentre macroseismic intensity (in terms of EMS-98 macroseismic scale) and the hypocentre depth (km).

The scenario can be run for all the Liguria Region or only for some specific areas by selecting, respectively, all the administrative units ("province") or only some of them, on the right side of the form.

It is moreover possible to choose which kind of output is expected: a "complete scenario" or either only an "hazard scenario". The option "complete scenario" provides, as a results, the macroseimic intensity hazard, the mean damage and the consequences expected for buildings and people, all evaluated at the level of census tracts, urban centres and municipalities. The option "hazard scenario" provides only the macroseimic intensity hazard at the level of census tracts. This second option, that can be selected for a preliminary analysis, allows the reduction of the required computational time, that anyhow is very limited, also for the complete scenario. As a matter of fact, running the program, the databases are modified in a few minutes depending on the selected type of analysis and on the available hardware architecture.

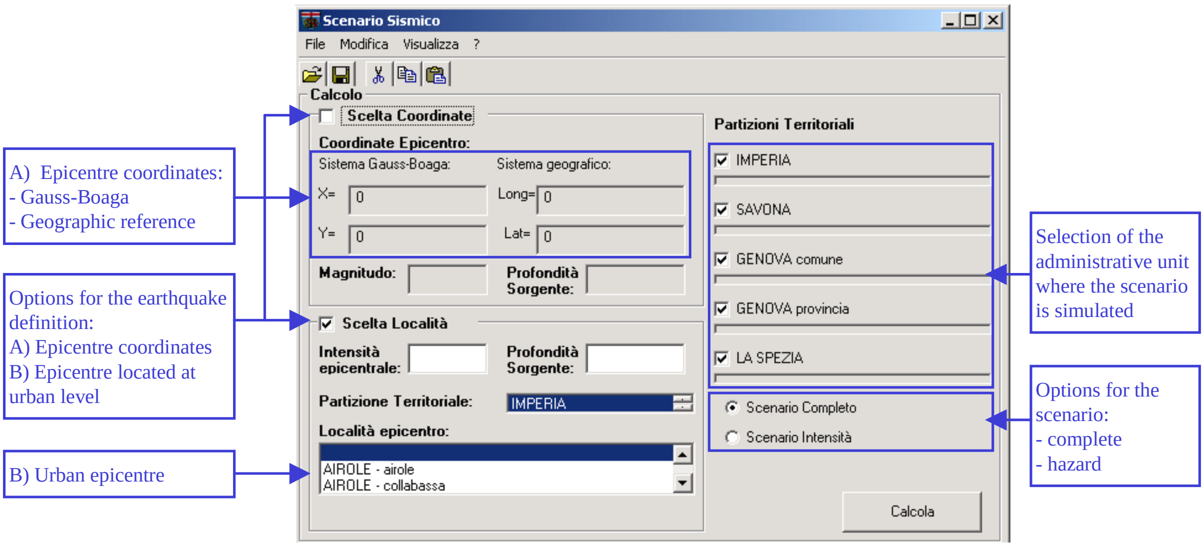

Figure 2: “Scenario Sismico Elaboration” form for the definition of the earthquake event (right side) and of the type of analysis (left side)

When the scenario elaboration is completed, the results can be visualised in terms of maps by selecting the “Scenario Sismico Visualisation” on the home page. The “Scenario Sismico” GIS (Geographical Information System) tool looks like a web page where, on the main frame, maps are displayed. On the left side typical GIS controls allows to zoom and to move on the maps.

On the left side of the visualisation frame it is moreover possible to select:

- the visualisation scale among: 1) the whole Liguria Region, 2) a specific area corresponding to an administrative unit (“provincia”), 3) specific municipality;
- the thematic output to be visualised among the ones presented in Table 1;
- the administrative level where the data have to be displayed (census tracts, inhabited centres or municipalities);
- the further layers to be visualised among the ones presented in Table 2.

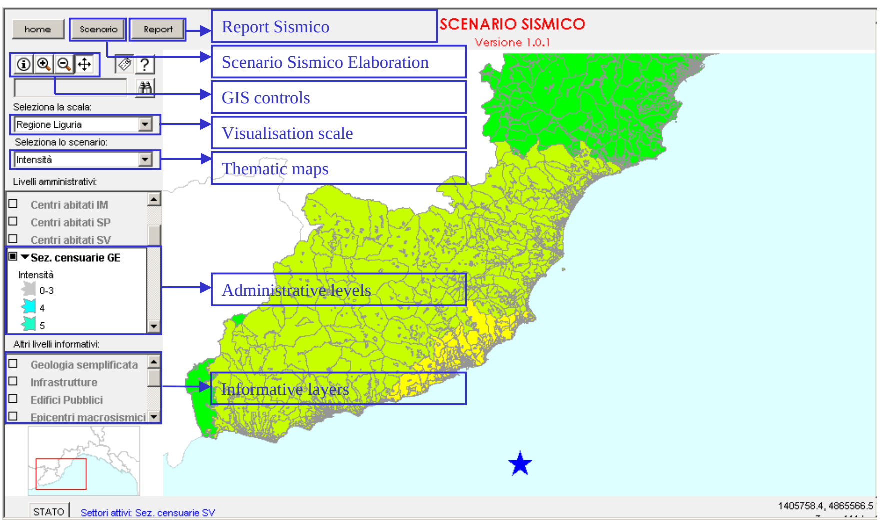

Figure 3: “Scenario Sismico – Visualisation” frame

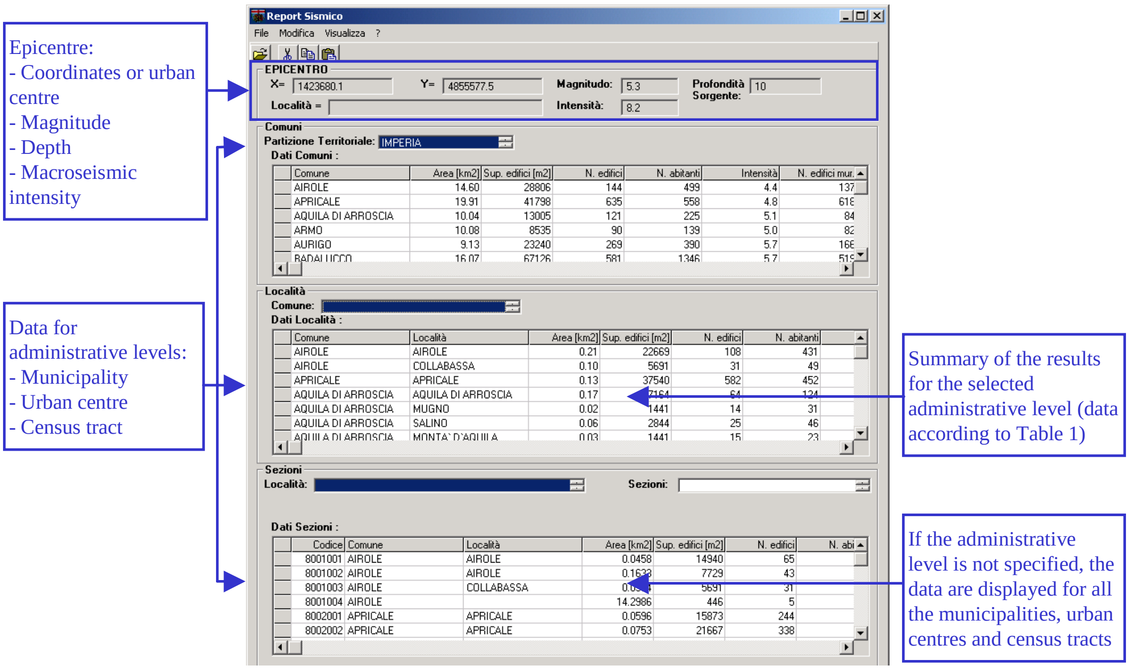

Figure 4: "Report Sismico" form for the exposure, vulnerability and damage data visualisation

For each selected administrative level, maps can be queried using the control . Data about the exposure, the vulnerability, the damage and the expected consequences (Table 1) are in this way provided for each selected geographical unit. The same data can be visualised and consulted for the whole region by the use of "Report Sismico" a post-processor software developed as a Visual Basic® application (Figure 4) that allows the visualisation of the outcomes for a simulated earthquake event in terms of databases. Restrictive selection in order to obtain the data only for specific territorial areas at different scale (provincial area, municipality area, urban centre) might be optioned.

Table 1: Exposure, vulnerability, hazard, damage and consequences on building and people for all the administrative levels (municipalities, urban centres, census tracts)

	Visualised Data	Description
Exposure	Number of inhabitants	Total number
	Number of buildings	Total number
	Building surface	km^2
Vulnerability	Vulnerability of all building types	EMS-98 vulnerability class
	Vulnerability of masonry buildings	
	Vulnerability of r.c. buildings	
Hazard	Macroseismic Intensity	EMS-98 Macroseismic Intensity
Damage	Mean damage for all the building types	Mean value of the probability distribution of the damage (EMS-98 discrete damage scale D_k k=0÷5)
	Mean damage for masonry buildings	
	Mean damage for r.c. buildings	
Consequences	Unfit for use buildings	Number/km^2 for census tract Absolute value for town centres and municipalities
	People needing temporary shelter	
	Collapsed buildings	
	Dead and severely injured people	

Table 2: List and description of the available informative layers

Informative Layer	Description
Geotechnical zonation	Geology-based geotechnical zonation arranged in terms of EC8 soil classes
Infrastructures	Road and railway system
Strategic buildings	Strategic buildings, schools, hospitals, town halls
Macroseimic epicentres	Epicentres of historical earthquakes in Liguria Region
Historical events	Observed damage from historical events in Liguria Region (e.g. 1831, 1887, etc.)

2.1 Further considerations on the software framework

At the beginning of the research project, the GIS data management has been performed by the use of MapInfo® GIS program, available and in use both at the University of Genoa and at the Civil Protection department headquarters.
Adequate procedures have been developed and implemented within the MapBasic® programming language in order to assess the vulnerability indexes for each census tract starting from the available exposure data. Subsequently the system has been implemented by aggregating these data to different administrative levels: urban centre and municipality area. Finally, specific procedures have been defined in order to obtain damage scenario and losses evaluation for a specific hazard and for every analysed territorial level. So a complete and functional GIS tool for damage scenario analysis was set, but its use was not immediate and easily manageable for a non-expert MapInfo® user.
For this reason, an alternative solution has been looked for, in order to achieve the relevant requirements of the simplicity and the effectiveness of use when displaying maps, inquiring and updating databases. After analyzing several options, the ALOV Map/TMJava software has been chosen. ALOV Map/TMJava is a Java® application that allows the publication of vector and raster maps for internet or standalone workstations. It supports the complex rendering architecture, the unlimited navigation and allows working with multiple layers, thematic maps, hyperlinked features and attribute data.
ALOV Map/TMJava allows creating useful GIS tool with an appearance of web page ("web-GIS"); databases files are linked to the maps in the format of ArcView® "shapefile" or MapInfo® "mif" file. Some of the most important features are the powerful rendering and the user-friendly management; moreover, it is available for free for personal, educational and, generally speaking, for non-commercial purposes.
It is worth noticing that this software has already been successfully used within the project "Earthquake scenario in Western Liguria, Italy, and strategies for the preservation of historic centres" (Lagomarsino 2005, Pessina and Balbi 2005).

3. STEPS FOR THE IMPLEMENTATION OF DAMAGE SCENARIO ANALYSIS

"Scenario Sismico" allows the evaluation of deterministic damage scenarios convoluting the results from deterministic hazard analysis, exposure and vulnerability assessment in order to achieve the estimation of the expected damages and consequences to buildings and people. In the following the methodological framework assumed at the basis of each one of these steps is shortly presented making reference to other works for more extensive explanations.

3.1 Exposure Analysis

For the exposure analysis a classification criterion has been assumed where different buildings types are considered, recognized as the ones mostly representative of the built environment for Liguria Region. Depending on the types of vertical structures six types of unreinforced masonry building have been identified: rubble stone (M1), simple stone (M3), massive stone (M4), unreinforced masonry made of old bricks (M5) and unreinforced masonry made of modern bricks (M6). For each unreinforced masonry typology the considered horizontal structure are: wooden slabs (_w), masonry vaults (_v), composite steel and masonry slabs (_sm), reinforced concrete slabs (_rc).
Reinforced concrete structures have been classified depending on the adopted seismo-resistant system as: concrete moment frame (RC1), concrete shear walls (RC2) and dual system (RC3). The presence of effective infill-walls is moreover considered for reinforced concrete frame typology (_i). Buildings non designed according to a seismic code (–NC) and buildings designed according to low (-DCL) and moderate (-DCM) ductility prescriptions are distinguished for reinforced concrete buildings.
Census statistical data (ISTAT 1991) have been employed for the inventorying of the population and of the buildings stock, including number and characteristics. The processing of ISTAT data has allowed identifying the distribution of buildings on the territory for constructive material (masonry or reinforced concrete) and age of construction. In particular seven categories have been identified when distinguishing four classes of age for masonry buildings and three for reinforced concrete buildings. The distribution of the buildings for the typologies considered by the assumed classification criterion has been obtained assuming inferences between building typologies and building categories as shown in Table 3.
For example, inferences take the form of "masonry buildings built before 1919, belong for 40% to rubble stone typology and for 10% to old brick masonry building with wooden slabs, etc".

Table 3: Inferences between the building categories and building typologies

	Building typologies							
Masonry building categories	M1	M3-w	M3-v	M3-sm	M3-rc	M4	M5-sm	M6
I (M<1919)	40	10	15	15	15	5	-	-
II (M=1919 ÷ 1945)	15	30	-	40	15	-	-	-
III (M =1945 1971)	10	10	-	10	-	-	30	40
IV (M> 1971)	-	-	-	10	-	-	10	80
R.C. building categories	RC1-NC	RC1-DCL	RC1-DCM	RC1- i DCL	RC2-DCL	RC2-DCM	RC3-DCL	RC3-DCM
V (RC<1971)	80	-	-	10	-	-	10	-
VI (RC=1971 ÷ 1981)	-	70	-	-	20	-	10	-
VII (RC >1981)	-	-	70	-	0	20	-	10

The processing of ISTAT data has moreover allowed the evaluation for each category of the percentage of buildings for each class of height (low-rise, medium-rise high-rise building) and the percentage of isolated buildings or buildings in an aggregate context, the percentage of buildings designed according to an earthquake resistant design (ERD), the percentage of buildings with a pilotis configuration.
The characterization of the exposed building-stock has been obtained processing the available census data according to GIS automatic procedures allowing the updating in the case of new data availability.

3.2 Hazard Analysis

A deterministic hazard analysis has been developed including soil and morphological amplification effects. A geology-based approach has been adopted allowing to derive a simplified geotechnical zonation in terms of EC8 soil classes (CEN 2003). To this aim reference has been made to 1:10.000 geological maps. Particular morphological conditions, have been identified making reference to a DEM. Both the geological maps and the DEM have been provided by Liguria Region administration. No intensity increments have been considered to account for site effect amplifications, as they are computed within the vulnerability analysis (§ 3.3), while for markedly irregular topography (i.e. hilltop, crests and severely sloping ground) intensity increments have been computed according to Faccioli et al. (2002).
Deterministic hazard scenarios are evaluated by the program, making reference to the grid-points identified with the centroids of the census tract portions, split into the different soil classes therein identified. Grandori (1991) attenuation relationship has been adopted for attenuating the intensity as a function of the epicentre distance and of the intensity. The parameters of the attenuation law have been defined as a function of the magnitude and of the hypocentre depth (1). The correlations have been derived considering the shape of the isoseismal lines of historical earthquake events (occurred in Liguria Region) with different magnitudes and hypocentre depths.

$$
\begin{aligned}
D_0 &= 0.16(M \cdot z^{1/2}) + 0.6 \\
\psi_0 &= 1.4 - 0.5\tanh\left(\frac{M \cdot z^{1/2} - 12}{10}\right) \\
\psi &= 2 + \tanh\left(\frac{M \cdot z^{1/2} - 20}{12}\right)
\end{aligned}
\tag{1}
$$

3.3 Vulnerability Analysis

The observational-based vulnerability approach, referred to as "macroseismic method" (Giovinazzi and Lagomarsino 2004, Giovinazzi 2005), has been adopted for the vulnerability assessment. According to this approach, the relationship between the mean damage grade μ_D and the macroseismic intensity, I_{EMS-98}, as a function of the vulnerability, is set as a closed analytical expression. The vulnerability is measured by two indexes: 1) a ductility-based index Q, 2) a vulnerability index V. The vulnerability index V accounts for the building category, V^* the presence of behaviour modifiers, ΔV_m, and the particular soil conditions, ΔV_s.
For the vulnerability analysis implementation within the "Scenario Sismico" tool, the vulnerability index V^* has been attributed to each category (Table 4) combining the vulnerability indexes associated to the building types, on the basis of the inferences established in Table 3.

With regard to the behaviour modifiers, the scores ΔV_m proposed in the framework of the macroseimic method have been assumed (Table 5). These values have been calibrated on the basis of observed damage data and expert judgment. In Tables 6 and 7 the adopted soil amplification factors ΔV_s are shown, evaluated for masonry and reinforced concrete buildings of different class of height and for different soil classes (EC8 soil classes). Reference has been made to EC8 Type 1 and Type 2 response spectra (CEN 2003), respectively defined for Ms>5.5 and Ms<5.5 surface-wave magnitude Ms

Table 4: Vulnerability index V^* for building categories

Masonry Categories		V^*	R.C. Categories		V^*
I	M<1919	0.79	V	RC<1971	0.59
II	M=1919 ÷ 1945	0.73	VI	RC=1971 ÷ 1981	0.55
III	M =1945 1971	0.69	VII	RC >1981	0.42
IV	M> 1971	0.65			

Table 5: Vulnerability increments ΔV_m for the behaviour modifiers

Categories	State of preservation		Number of floors			Aggregate Building		ERD	Piloty
	good	bad	low	medium	high	isolated	aggregate		
I	0	0.08	-0.08	0	0.08	-0.04	0.04	0	0
II	0	0.06	-0.08	0	0.08	-0.04	0.04	0	0
III	0	0.04	-0.08	0	0.08	-0.04	0.04	0	0
IV	0	0.04	-0.08	0	0.08	-0.04	0.04	-0.08	0
V	0	0.04	-0.03	0	0.03	0	0.04	0	0.12
VI	0	0.04	-0.03	0	0.03	0	0.04	0	0.12
VII	0	0.04	-0.03	0	0.03	0	0	0	0.06

Table 6: Vulnerability increments ΔV_s for EC8 Type 1 Spectrum (M_s>5.5)

Masonry Categories	ΔV_s				R.C. Categories	ΔV_s			
	B	C	D	E		B	C	D	E
M_low	0.04	0.03	0.07	0.08	RC_low	0.04	0.03	0.07	0.08
M_medium	0.04	0.03	0.07	0.08	RC_medium	0.09	0.12	0.21	0.13
M_high	0.06	0.05	0.09	0.10	RC_high	0.09	0.12	0.22	0.13

Table 7: Vulnerability increments ΔV_s for EC8 Type 2 Spectrum (M_s<5.5)

Masonry Categories	ΔV_s				R.C. Categories	ΔV_s			
	B	C	D	E		B	C	D	E
M_low	0.07	0.09	0.13	0.11	RC_low	0.07	0.09	0.17	0.11
M_medium	0.07	0.09	0.17	0.11	RC_medium	0.07	0.09	0.17	0.11
M_high	0.07	0.09	0.17	0.11	RC_high	0.07	0.09	0.17	0.11

The vulnerability index V, for each census tract, has been evaluated combing V^*, ΔV_m and ΔV_s according to: the different categories and the percentages of buildings affected by behaviour modifiers, as they result from the exposure analysis (Giovinazzi et al. 2004). With regard to the ductility index, a value Q = 2.3 has been assumed corresponding to the one proposed by the macroseimic approach for buildings designed prior to the introduction of adequate seismic code previsions.

3.4 Damage and losses assessment

The expected mean damage grade μ_D has been evaluated, for each census tract portion, as a function of the macroseismic intensity I_{EMS-98} resulting from the hazard analysis and as a function of the vulnerability index V from the vulnerability analysis. A binomial function has been assumed to obtained the damage distribution, intended as the probability of reaching each damage grade (D_k k = 0÷5) for the assessed mean damage μ_D.
For the losses and consequences estimation, damage to buildings have been converted into percentage of losses through empirical correlations, proposed for the Italian territory (Bramerini et al. 1995) on the basis of observed damage data. In particular, unfit for use buildings have been assumed as the ones suffering damage levels $D_k = 4$ and $D_k = 5$, and as 40% of the ones suffering a damage level $D_k = 3$. People living there inside have been classified as people needing temporary shelter. Dead and severely injured people have been evaluated as 30% of the ones living in collapsed buildings $D_k = 5$.

4. REAL TIME SIMULATION OF AN EARTHQUAKE EVENT

A simulation of the expected effects due to an earthquake event is presented in the following in order to show which kind of information the “Scenario Sismico” tool could provide to the civil defence managers immediately after a seismic event. The simulation has been run in the hypothesis that information about the epicentre position, the earthquake magnitude and depth are available to the civil protection agency.
An offshore event has been considered, located ahead Imperia municipality (Lat = 43.846, Long = 8.048). A magnitude M = 5.3 and an hypocentre depth z = 10 km have been considered for the event.
After running the program, emergency managers can obtain a first insight about the gravity and the extension of the possibly affected area, within the Liguria Region, by visualising the macroseimic intensity hazard scenario at municipality level (Figure 5-a). A clearer understanding with regard to the most affected area, is obtained making reference to the visualisation at census tract level.

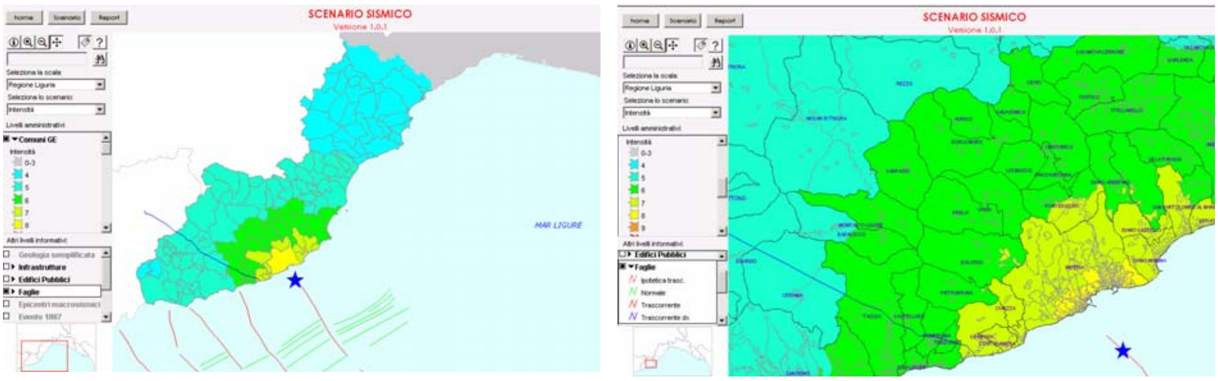

Figure 5: Macroseimic intensity hazard scenario. Visualisation at the level of: a) municipalities, b) census tracts

An overview about the expected consequences on the territory can be obtained looking at the damage suffered by the buildings because of the earthquake. To this aim, the thematic maps showing the mean damage grade can be examined at different levels of detail.
The visualisation at municipality level allows circumscribing the area where the intervention and the rescue is required (Figure 6-a). Increasing the level of detail it is possible to obtain a more precise localisation of the urban centres (Figure 6-b) and then of the census tracts (Figure 7-a) that are potentially more affected.

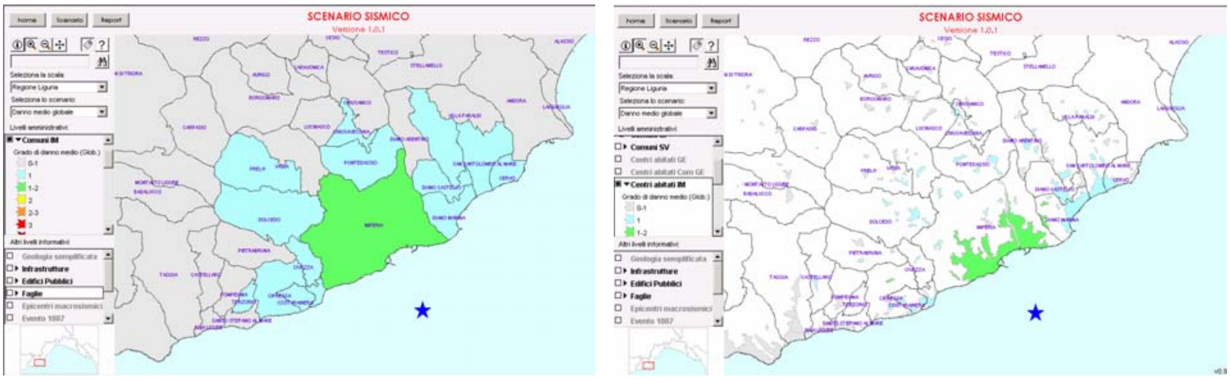

Figure 6: Damage scenario in terms of mean damage grade. Visualisation at level of: a) municipalities, b) town centres

Aiming to organise the rescue operations, some hypothesis can be advanced about the road networks that can be still travel over, starting from the information provided in terms of the mean damage grade at census tract level (Figure 7-a). Making the assumption that the routes adjacent to the buildings with damage level equal to D_k=4 or D_k=5, are obstructed, rescue teams (located in the strategic buildings identified on the map with the symbol) could, for instance, reach the most affected areas via the road system identified in Figure 7-b.

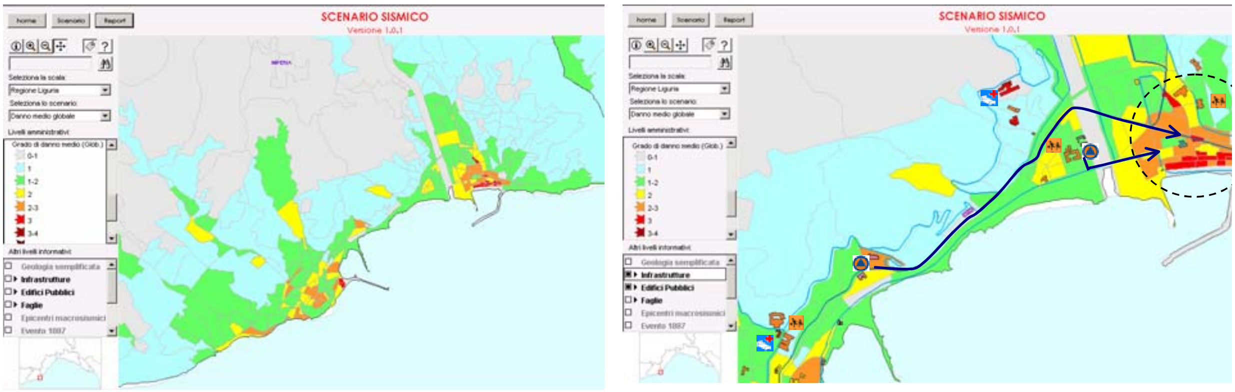

Figure 7: Damage scenario in terms of mean damage grade: a) visualisation at census tract level, b) identification of routes suitable for reaching the most affected areas

The identification of the nearest buildings suitable for recovering homeless and the recognition of the nearest health emergency facilities is, as well, possible within the program. Three school buildings have been identified as suitable for providing a first temporary shelter for the estimated 730 homeless in the analysed area (Figure 8-a). Two health facilities could provide the necessary assistance to the 20 casualties identified within the same area (Figure 8-b).

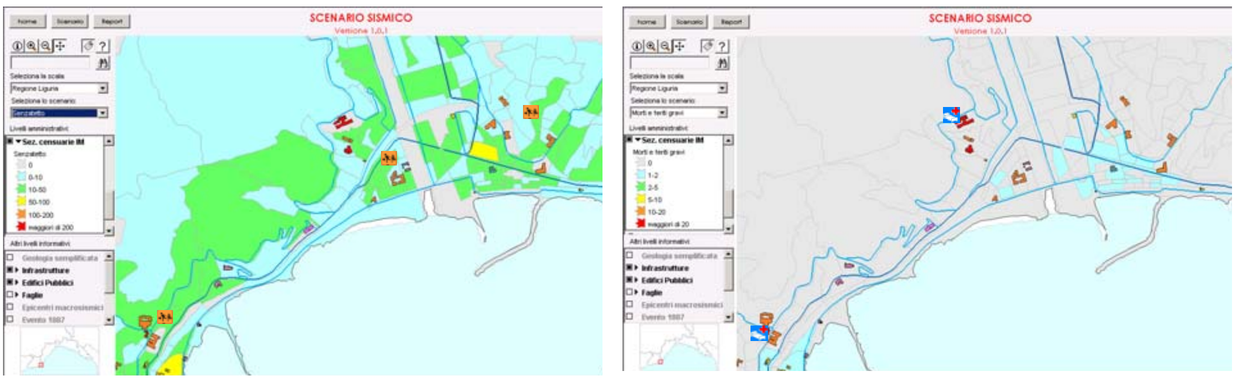

Figure 8: Consequence scenario at census tract level: a) homeless people and buildings suitable for providing a temporary shelter, b) casualties and health facilities

A first dimensioning of the people, structures and facilities that could be required for the emergency management at the level of the whole regional territory can be obtained from the results provided by the post-processor “Report Sismico”. For the simulated event the tool estimates that, for the whole Liguria Region, are expected: 31 collapsed buildings, 694 uninhabitable buildings, 4064 people needing a temporary shelter, 66 casualties (dead and severely injured people).

5. CONCLUSION

In this contribution, the structure and the methodological framework of the “Scenario Sismico” tool, a computer program for the simulation of real time damage scenarios, have been presented. This tool has been designed and implemented by the authors with the specific aim to support local Civil Protection departments and government officials for the emergency management, during the first hours after an earthquake event. The program allows the simulation and the representation of real time damage scenarios for the Liguria Region, nevertheless the same procedures and software framework could be implemented for any other geographical area with the same availability in terms of digital maps and data. Positive features of the software are its user-friendly framework, that allows running the program and examining the results (in terms of databases and maps) also by non GIS expert, and an easy implementation from a computational point of view, with the elaboration time reduced to a few minutes.

Ongoing improvements are the inclusion within the program of vulnerability and damage evaluation procedures for the strategic buildings, in order to assess their effective functionality after an earthquake event. Information about the potentiality of these strategic buildings (e.g. number of facilities available, maximum number of people that could be recovered in the school or maximum number of people that could be helped inside health centre structures) will be also included.

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