Earthquake-triggered landslide hazards in the Catania area

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Abstract

Earthquake-triggered landslides represent one of the most important effects of large earthquakes. Then, the evaluation of seismic stability conditions of slopes, embankments and other earth-structures involved in road and railway networks represents an important topic interest in the assessment of regional seismic hazards. In this paper a GIS-based model for prediction of earthquake-triggered landslide hazards for the Catania district (Sicily) is presented. Geological, topographical and geotechnical data were selected and stored in a database; then, using a reliable ground motion scenario, the stability condition of slopes was evaluated in terms of earthquake-induced permanent displacements. The resulting GIS model allowed us to map the potentially instable areas, the spatial distribution of displacements and the damage induced on the main road and railway networks of the area.
Keywords: landslides seismic hazard, displacement analysis, GIS, Catania project.

1 Introduction

The experience of last decades has shown that seismic induced landslides represent one of the most damaging collateral hazards associated with large earthquakes. Frequently, damages induced from earthquake-triggered landslides exceed damages directly related to the ground shaking. Post-earthquake reports have given evidence of the severe social and economical consequences of earthquake-triggered landslides consisting of loss of human life and damages to structures and infrastructures. Moreover, serious consequences are frequently related to the landslides effects on lifelines serviceability and to the damages

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induced on road and railway networks. These last aspects play an important role in the post-seismic scenario since are related to the emergency management of the stricken area.

For all these reasons, the analysis of seismic response of natural slopes and the evaluation of post-seismic serviceability of earth-structures involved in road and railway networks have received great impulse in the last decades. Concerning the evaluation of regional seismic hazard, it is generally recognised that a deterministic approach represents a valid support; this approach improves the ability to predict the amount and the spatial distribution of damage and provides useful tools in the emergency management phase.

For the evaluation of seismic stability conditions of slopes and earth-structures different methods are available. For the assessment of landslides hazard in regional scale, the use of a Newmark-type analysis [1] represents a convenient compromise between the required degree of accuracy and the level of knowledge of topographical, geotechnical and seismic characteristics. To this purposes, empirical models, based on Newmark analyses results, are usually adopted together with attenuation relationships of seismic parameters. Several studies have shown that this approach becomes a powerful tool for the seismic hazard mitigation procedure if implemented in a geographical information system [2,3]. The goal of this kind of analysis is the evaluation of the earthquake-induced permanent displacement of slopes and its spatial distribution on the selected area. For each slope the obtained permanent displacement could be adopted as an index of the seismic stability condition; then the spatial distribution of permanent displacements allows estimating post-seismic scenarios useful for the emergency management phase. This kind of analysis has been usually carried out locally on small areas, due to the difficulties of collecting and managing a great amount of heterogeneous data. In order to apply these methods to widely areas, the use of advanced instruments able to manage and to elaborate a large number of spatial data is necessary and a GIS software is the ideal working environment.

In the framework of the research project "*Detailed scenarios and actions for seismic prevention of damage in the urban area of Catania*" (Catania Project), [4], a study of the post-seismic scenarios of the rail and road networks is actually in progress. A GIS-based model for the urban and extra-urban area of Catania was developed using available dataset of topographical, geological and geotechnical characteristics. Different ground motion scenarios was analysed for a selected design earthquake and the spatial distribution of the potential earthquake-triggered landslides was computed and described herein.

2 Data sources for GIS implementation of the area

The area of interest has an extension of about 3415 km^2, lies on the south-eastern part of Sicily, and represents an example of high-risk damage scenario in the Mediterranean area. The topography of the area range from flat areas, in the Catania Plain, to very steep slopes (>65°) near to mount Etna.

The first part of the study was devoted to the collection of data on historical earthquakes and the geological, geotechnical and topographic conditions of each

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site; this stage represents a fundamental step since all these aspects are strictly related to the magnitude of ground motion and to the spatial distribution of earthquake-induced damages.

Analysing the past seismic history, the most probable source of earthquakes for the area is the Malta Escarpment, located at about 13 km kilometres offshore, and representing one of the master fault in the central Mediterranean.

Geological data were collected using the database of the main geological characteristics of the municipal area of Catania developed during the first stage of the Catania Project. Surface lythology of the area was obtained through datasets and documents available in the literature and thematic maps. The data were reclassified using a single criterion based on the physical and mechanical properties of each unit.

Concerning the susceptibility to earthquake-triggered landslides, information were collected using published papers related to the first stage of the Catania Project and to the studies in progress [5,6]. Moreover, data were obtained from the landslide hazard zonation proposed by Grasso & Maugeri [7] using a GIS model; finally the spatial distribution of landslides triggered by the 13 December, 1990 earthquake was also analysed.

The review of all the above-mentioned documents and datas*et al*lowed us to construct a reliable model of the study area concerning both the topographical and geological aspects. In particular all the collected data sets have been digitalised at a 40m-grid spacing in the GIS platform. In figure 1 the 1:25.000-map of the high-resolution digital elevation model of the area is shown.

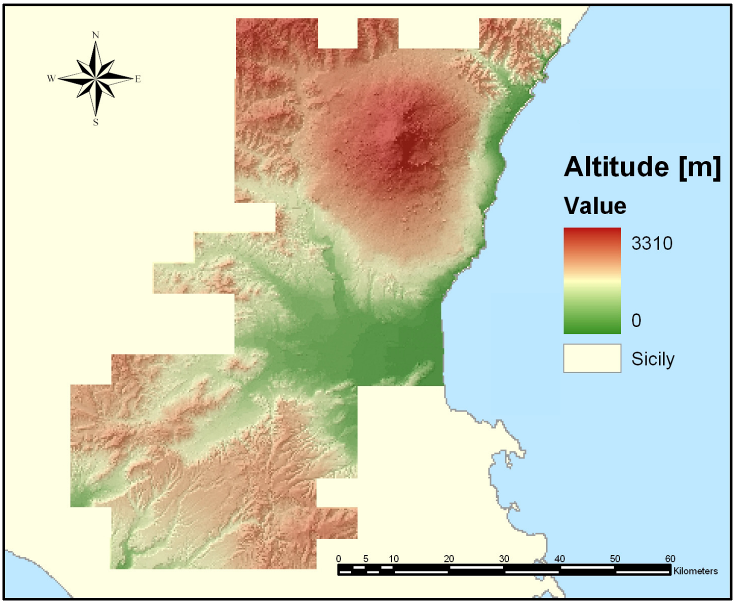

Figure 1: Topography of the study area.

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Concerning the geotechnical properties of soils, a characterization based exclusively on extensive laboratory and in situ test results is obviously impracticable for a regional seismic hazard study. Then average values or range of values for soil properties were estimated for each geological unit. Among site conditions, strength parameters of soils and water table level are those directly involved in the stability analysis procedure adopted in this study. For these parameters, a great amount of data was collected and available database [8,9] were analysed. In case of lack of data, different approaches were applied to evaluate average values of strength parameters. If available, results of in situ and laboratory test results were assumed as representative values for an entire geological unit. Otherwise, data available in the literature for similar materials or soils in the nearest area were employed. Based on all the collected data, representative values of geotechnical parameters were selected for each geological unit using a judgment-based approach. All the selected values were assigned to each unit of the study area and were stored in the GIS model. As described in the following sections, some adjustments to the selected values of strength parameters have been performed based on the results of the performed static stability analyses. Concerning the hydraulic condition of slopes, data were collected using information available in the literature. The data are not sufficient to build a reliable model and significant differences in the water table level were obviously observed depending on season. Then, slope hydraulic conditions will be modeled referring to two extreme scenarios: water table at the ground level and water table lowed than the potential failure surface.

3 Evaluation of ground motion scenario

The first level scenario event for the Catania area may be reasonably assumed the catastrophic event that hit western Sicily in 1693. This earthquake was characterised by an intensity XI MCS and estimated magnitude of 7.3; the most probable source is located along the northern part of the Ibleo-Maltese fault and is commonly associated to rupture with a pure normal mechanism along the escarpment. For the present work, the reference source is assumed an event localized along the northern part of the Ibleo-Maltese system, which is simplified in a segment about 25 km long. The considered fault line (*s.IBM*) and source location (along the transect t01) are showed in figure 2 together with the location of the December 13, 1990 earthquake epicentre [10].

In order to describe a ground-shaking scenario for the selected earthquake, attenuation relationships of peak ground acceleration *PGA* and velocity *PGV* were selected among those available in the literature. The main characteristics of the selected relationships are listed in Table 1.

The Sabetta & Pugliese [11] relationships was selected since it was developed using exclusively Italian earthquakes. The proposed models is:

$$\log PGA = -1.562 + 0.306 \cdot M - \log\sqrt{R^2 + 5.8^2} + 0.169 \cdot S \quad (1)$$

$$\log PGV = 0.710 + 0.455 \cdot M - \log\sqrt{R^2 + 3.6^2} + 0.133 \cdot S \quad (2)$$

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were *PGA* is in *g* and *PGV* is in cm/s. *R* (km) represents the shortest distance to fault rupture and magnitude *M* is assumed as surface-wave magnitude for *M*>5 and local magnitude otherwise. The site dependency is accounted for through the parameter *S*: *S*=0 for stiff and deep soil; *S*=1 for shallow soil. Stiff and deep soil are limestone, sandstone, siltstone, marl, shale and conglomerates characterised by shear wave velocity greater than 800 m/s or soils with depth > 20m; shallow soils are characterised by depth ranging form 5 to 20 m. The standard deviation of the models are σ=0.173 and σ =0.215 for *PGA* and *PGV* respectively.

Table 1: Characteristics of the selected attenuation relationships.

Model	Characteristics of the adopted database						
	Area	*E*	*C*	*M*	*R* (kM)	*S*	*SM*
Sabetta & Pugliese (1987)	Italy	17	190	4.6-6.8	1.5-180	Rock, soil	Not specified
Ambraseys *et al*. (1996)	Europe, Middle East	157	422	4.0-7.9	0-260	Rock, stiff soil, soft soil	Not specified
Spudich *et al*. (1999)	Worldwide	39	142	5.1-7.2	0-99.4	Rock , soil	Normal, Reverse
Tromans & Bommer (2000)	Europe	51	249	5.5-7.9	1-359	Rock, stiff soil, soft soil	Not specified
Bommer *et al*. (2000)	Europe, Middle East	157	422	5.6-7.9	1-359	Rock, stiff soil, soft soil	Not specified

E: number of earthquakes; *C*: number of components; *M*: earthquake magnitude; *R*: site-source distance; *S*: site categories; *SM*: source mechanism

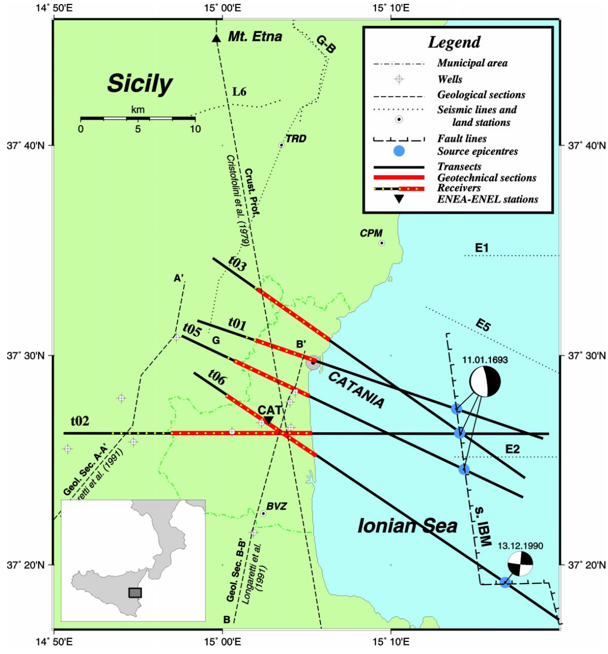

Figure 2: Fault system and source location considered in the analysis (after Priolo [5]).

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The *PGA* attenuation relationship by Ambraseys *et al.* [12] was considered because more than one third of the considered records are related to earthquakes occurred in Europe or adjacent regions. The model (*PGA* in *g*, $\sigma = 0.250$) is:

$$\log PGA = 1.512 + 0.266 \cdot M + 0.922 \cdot \log\sqrt{R^2 + 3.5^2} + 0.117 \cdot S_A + 0.124 \cdot S_S \quad (3)$$

The model takes into account local site condition through the average shear wave velocity $V_{s,30}$ in the upper 30 m: S_A=0 and S_S=0 for $V_{s,30}$>750m/s; S_A=1 and S_S=0 for 360<$V_{s,30}$ ≤750m/s; S_A=0 and S_S=1 for $V_{s,30}$<360m/s.

The *PVG* attenuation relationship proposed by Bommer *et al.* [13] was developed using the same set of data employed by Ambraseys *et al.* [12], with the exception that all data from earthquakes of small magnitude (M_s<5.5) were removed and two records, from the 1976 Friuli and 1995 Aegion earthquakes, were added. The proposed model (*PGV* in cm/s, σ=0.27) is:

$$\log PGV = -0.195 + 0.390 \cdot M - 1.074 \cdot \log\sqrt{R^2 + 4.5^2} + 0.142 \cdot S_A + 0.185 \cdot S_S \quad (4)$$

The *PGA* attenuation model proposed by Tromans & Bommer [14] was developed using a database 51 shallow European earthquakes with surface magnitude ranging from 5.5 to 7.9. The recording site geology is classified according to $V_{s,30}$: soft soil for $V_{s,30}$<360m/s, rock for $V_{s,30}$≥750m/s and stiff soil for $V_{s,30}$ between these levels. The proposed model (*PGA* in cm/s^2, σ=0.27) is:

$$\log PGA = 2.080 + 0.214 \cdot M + 1.049 \log\sqrt{R^2 + 7.2^2} + 0.058 \cdot S_A + 0.085 \cdot S_S \quad (5)$$

where *PGA* is in cm/s^2. S_A and S_S assumes the following values: S_A=1 for stiff soil sites otherwise S_A=0; S_S=0 for soft soil sites otherwise S_S=1.

Spudich *et al.* [15] developed a model using records of 39 worldwide earthquakes. Only 26 of the selected records are related to Italian earthquakes; however all the considered events are related to extensional regimes area such as that predominating in south-eastern Sicily. The proposed model (*PGA* in *g*) is:

$$\log PGA = 0.299 + 0.229 \cdot (M_w - 6) - 1.052 \cdot \log\sqrt{R^2 + 7.27^2} + 0.112 \cdot S \quad (6)$$

The parameter *S* refers to the site condition considered in the model. *S*=0 for rock class which includes hard rock, soft rock and unknown rock; *S*=1 for soil class which include shallow soil (5 to 20 m deep), deep soil (>20 m deep) and unknown soil. The standard deviation of the model σ is equal to 0.203 and to 0.223 for randomly oriented and for larger horizontal component respectively.

4 Modelling of seismic slopes response

Different approaches are available to predict the seismic response of slopes and earth-structures. The methods differ in the assumptions adopted to describe the ground motion effects, for the hypothesis concerning the cyclic soil behaviour and, finally, for the technique adopted to estimate the seismic stability condition and the post-seismic serviceability.

In this paper the seismic response of slopes was analysed using statistically based models developed starting from the Newmark sliding block analysis. In

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this analysis, the potentially unstable soil mass is treated as a rigid block lying on a fixed base subjected to an acceleration time-history. The block is subjected to driving actions, due to the soil weight and inertia forces imposed by the base acceleration, and resisting actions related to the soil shear resistance. In the traditional approach the infinite slope scheme is considered and resisting forces are assumed to be constant neglecting any cyclic degradation of soil shear strength. Based on this scheme, permanent displacements of the slope starts when the imposed acceleration overcomes a critical value, the slope critical acceleration a_c, which is related to the mechanical and geometrical properties of the slope and to the direction of the base acceleration. Integrating the relative velocity of the block, the cumulate permanent displacement is evaluated and can be used to evaluate the seismic slope response and the post-seismic serviceability of structures and infrastructures potentially involved in the failure mechanism.

With reference to the infinite slope scheme, denoting β and H respectively the slope angle and the depth of the failure surface, and assuming a steady seepage taking place in a direction parallel to the failure surface, the static factor of safety of the slope can be expressed as follows:

$$F_s = \frac{c'}{\gamma \cdot H \cdot \sin\beta \cdot \cos\beta} + \frac{\tan\phi'}{\tan\beta} \cdot (1 - r_u) \tag{7}$$

where γ, c' and ϕ' represent the soil unit weight, the effective cohesion and the angle of shear resistance respectively and r_u denote the static pore pressure ratio:

$$r_u = \frac{\gamma_w \cdot H_w}{\gamma \cdot H} \tag{8}$$

being γ_w and H_w the unit weight of water and water table level with respect to the failure surface depth. Assuming that the inertia force is inclined of an angle ω with respect to the horizontal and neglecting any soil shear strength degradation, the slope critical acceleration expressed as a fraction of the gravity acceleration g can be computed as follows:

$$k_c = \frac{a_c}{g} = \frac{c'/(\gamma \cdot H \cdot \cos\beta \cdot \mathrm{sen}\beta)}{\cos(\beta+\omega) + \tan\phi' \cdot \mathrm{sen}(\beta+\omega)} + \frac{\cos\beta \cdot \tan\phi' \cdot (1-r_u) - \mathrm{sen}\beta}{\cos(\beta+\omega) + \tan\phi' \cdot \mathrm{sen}(\beta+\omega)} \tag{9}$$

To analyse the slope stability condition during an earthquake, k_c must be compared with the maximum values of base acceleration, i.e., the values of peak ground acceleration *PGA*. Then, denoting k_{max} the values of *PGA* expressed as a percentage of gravity acceleration g, values of k_c/k_{max} lower than unity characterise slopes that could experience permanent displacement during the earthquake.

5 Estimating permanent displacements

Starting from the results of a large number of Newmark-type analyses, empirical models were developed relating the magnitude of permanent displacements with different seismic parameters describing the acceleration time-histories imposed by the earthquake. Each model was developed through a statistically based

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approach using different databases of earthquake records. For each record, permanent displacements *d* were computed using a Newmark-type analysis; then regression analyses were performed relating *d* to k_c and to several seismic parameters. The available models differs for the sort of the of the underlying database, for the mathematical model adopted in the regression analysis and on the effectiveness of the selected seismic parameters. Then, difference in the predicted displacements are obviously and unavoidable.

For the purposes of the present research four different models (see table 2) were adopted. Then, for each set of seismic parameters, a range of displacements was computed, allowing to reduce the uncertainties in the prediction.

The model proposed by Romeo [16] was selected since it was developed using exclusively records of earthquakes occurred in Italy. In the selected database, recording sites are classified as rock or soil site for shear wave velocity higher and lower than 800 m/s respectively. The selected parameters are the earthquake magnitude *M*, the ratio k_c/k_{max} and the epicentral distance R_e:

$$\log d = -1.281 + 0.648 \cdot M - 0.934 \cdot \log\sqrt{R_e^{\,2} + 3.5^2} - 3.699 \cdot \frac{k_c}{k_{max}} + 0.225 \cdot S \qquad (10)$$

d is expressed in *cm* and *S* is a weighting factor equal to 1 for soil site and to 0 for rock site.

The model proposed by Cai & Bathurst [17] was selected since it represents a suitable middle course between the predictions of different other empirical models. In the model, *d* (cm) represents the mean permanent displacement with a 50% probability of being exceeded:

$$\log d = 9.2 \cdot \frac{PGV^2}{g \cdot k_{max}} \cdot \exp\left(-5.87 \cdot \frac{k_c}{k_{max}}\right) \cdot \left(\frac{k_c}{k_{max}}\right)^{-0.49} \qquad (11)$$

The model proposed by Ambraseys and Menu [18] and Ambraseys & Srbulov [19] were selected since were developed in the attempt to evaluate the effect of the functional relationships in the regression analysis. The models (*d* in cm) are:

$$\log d = 0.90 + \log\left(1 - \frac{k_c}{k_{max}}\right)^{2.53} \cdot \left(\frac{k_c}{k_{max}}\right)^{-1.09} \qquad (12)$$

$$\log d = -2.41 + 0.47M - 0.01 \cdot \log\sqrt{R^2 + h^2} + \log\left[\left(1 - \frac{k_c}{k_{max}}\right)^{2.91} \left(\frac{k_c}{k_{max}}\right)^{-1.02}\right] \qquad (13)$$

Table 2: Characteristics of the selected empirical models.

Model	Characteristics of database and regression model						
	E	*C*	*M*	*R* (kM)	*S*	*P*	σ
Ambraseys & Menu (1988)	11	50	5.5-7.7	9-20	None	k_c/k_{max}	0.30
Ambraseys & Srbulov (1995)	76	532	5.0-7.7	-	None	k_c/k_{max}, M_s, R	0.42
Cai & Bathurst (1996)	3	16	6.4-7.1	3-35	None	k_c/k_{max}, PGV, PGA	-
Romeo (2000)	17	190	4.6-6.8	1.5-180	Rock, soil	k_c/k_{max}, M_s, R	0.58

E: number of earthquakes; *C*: number of components; *M*: earthquake magnitude; *R*: site-source distance; *S*: site categories; *P*: adopted parameters; σ: standard deviation of log *d*.

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6 Mapping procedure and description of results

The use of the selected empirical models in conjunction with the previous described attenuation relationships allows to detect the spatial distribution of permanent displacements. To this purposes the developed 40m-grid GIS-model, was adopted and slope hydraulic condition will be modeled referring to two different limit scenarios. In particular due to the lack of information on sites hydraulic condition and considering that the water table level changes during time depending on the mean annual rainfall, two extreme hydraulic scenarios were considered in the analysis assuming r_u=0 and r_u=0.5 respectively.

Concerning the mapping procedure, firstly the static stability condition of the slopes in each grid cell was analysed. To this purpose the grids of geotechnical properties, slope angle and hydraulic conditions were combined using eq.(7) to evaluate the static factor of safety F_s for each grid-cell. Only slopes steeper than 5° were analysed. Through the computed values, unstable grid cells (F_s<1) were detected using a map query function incorporated in the spatial analyst. For those grid-cells, strength parameters were slightly modified using the constraint that the developed geotechnical model must be stable ($F_s \geq 1$) under static conditions. Then, for the lythological unit having unstable grid-cells, strength parameters were gradually increased with respect to the selected average values until the condition $F_s \geq 1$ was obtained. This procedure was applied for slopes less than 65° with the exception of the documented unstable area. A small number of slopes remain statically unstable even using high, but reasonable, values of strength parameters; then, since characterised by zero or negative values of slope critical acceleration, those slopes was not considered in the displacement analysis.

The grid of slope critical acceleration was computed using eq.(9) and assuming the value $\omega=\phi-\beta$ for each grid-cell of the model; in this way a minimum value of slope critical acceleration is accounted for. The obtained maps of k_c are showed in figure 3. Generally, k_c ranges from values higher than 0.05g in steep slopes in weak soils to values greater than 0.35g in flat areas characterised by higher values of strength parameters. Moreover, significant differences in the spatial distribution of k_c values can be observed depending on the adopted hydraulic condition.

Since k_c represents a measure of the slope landslide susceptibility, the seismic stability condition can be evaluate comparing the obtained k_c maps with the spatial distribution of *PGA*. To this purposes a grid of the site-source distances *R* was developed for the selected reference source and the *PGA* attenuation relationships (eqs.1,3,5,6) were applied developing four different grids. Using the cell statistic functions of the spatial analyst, grids of average and maximum values of *PGA* of each grid-cell were computed. In this procedure, the site-dependency of ground motion characteristic was taken into account through the parameters *S* involved in each of the considered attenuation relationships. The spatial distribution of the potentially unstable area was computed mapping the ratio k_c/k_{max} and looking for values lower than unity.

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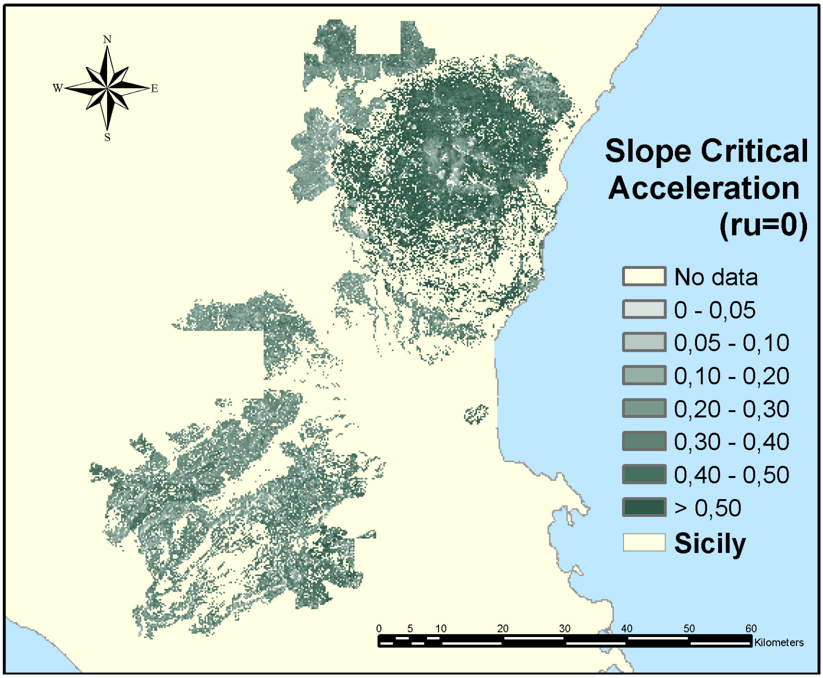

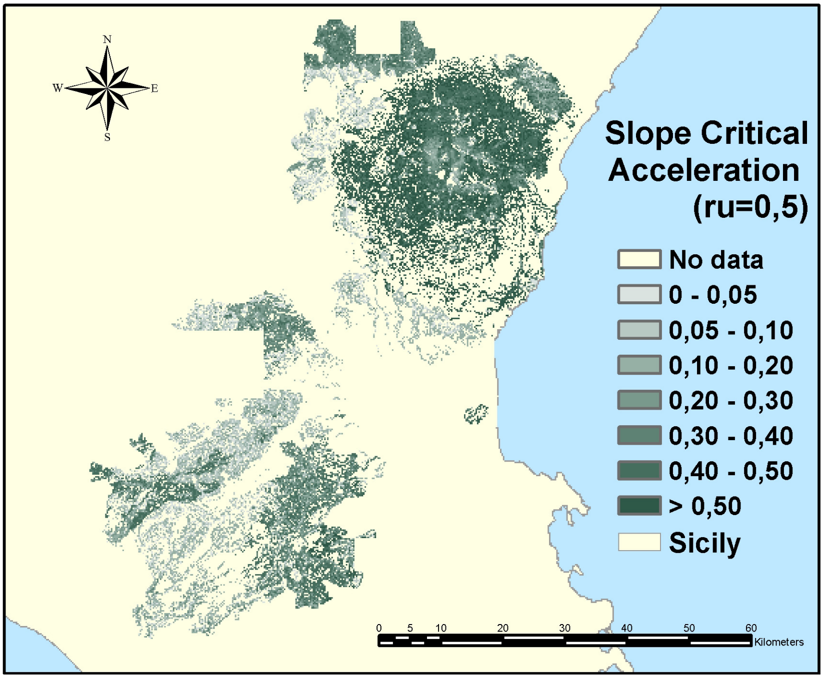

Figure 3: Map of slope critical acceleration computed for a) r_u=0 and b) r_u=0.5.

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In particular four different scenarios of potentially unstable area were computed using the two hydraulic scenarios and the average and maximum *PGA* grids. Some of the obtained maps are plotted in figure 4 showing significant differences in terms of spatial distribution of landslide susceptibility. Finally, in order to compute the spatial distribution of earthquake-induced permanent displacement, grids containing values of *PGV* were developed applying eqs.(2) and(4). Again, two grids containing the average and maximum values of *PGV* were evaluated using the raster calculation GIS function and considering only the grid-cell unstable under seismic condition (k_c/k_{max}<1). Then, using the grids containing k_c, k_c/k_{max}, *PGA* and *PGV*, permanent displacements were computed applying eqs. (10) to (13). Some of the obtained maps are showed in figure 5. In particular the results obtained using the Romeo [16] and the Ambraseys & Srbulov [19] with the maximum value of *PGA* and for the hydraulic condition characterised by r_u=0.5 are showed. From the results it is evident that the computed permanent displacement are generally lower than 2.5 cm with some localised area were values equal or higher than 10-25 cm are reached. Only in a few grid-cell of the model the computed permanent displacement achieves values equal or higher than 100 cm representing a failure of the slope.

Analysing the computed spatial distribution of computed permanent displacements it is evident that significantly differences can be observed depending on the adopted model. Moreover, significant discrepancy can be observed in terms of spatial distribution. This latter aspect is also related to the selected hydraulic condition adopted in the analysis that lead to different scenarios of potentially unstable areas.

Since an agreement was observed in the computed maps of permanent displacements, maps of average values were computed for each grid-cell using a statistic function of the spatial analyst. Then, to judge the effects displacements in terms of earthquake-induced damages, the correlation between displacement and level of damage proposed by Legg *et al* [20] was adopted. To this purposes, computed displacement were classified using the reclassify function of the spatial analist. The obtained map is plotted in figure 6 for the whole area of study and for the Catania area, together with the main road and railway network.

From the results it is evident that the spatial distribution of potentially damaged area is strictly related to the computed values of the ratio k_c/k_{max} that describe the landslide susceptibility of some area. In particular, for the selected design earthquake, the induced damages range from modest to medium in the large part of the detected unstable area were computed permanent displacements are generally lower than 5 cm. More severe damages were predicted for the sloping area near to some of the State Roads nearest to the Catania area were computed displacements achieve values equal or higher to 50 cm denoting an high level of damage in the Legg. *et al* [20] correlation. High or very high level of induced damages can be observed in a small number of areas both near and far away to the area Catania. Finally, a catastrophic level of damages was detected only in a few numbers of grid-cells of the model.

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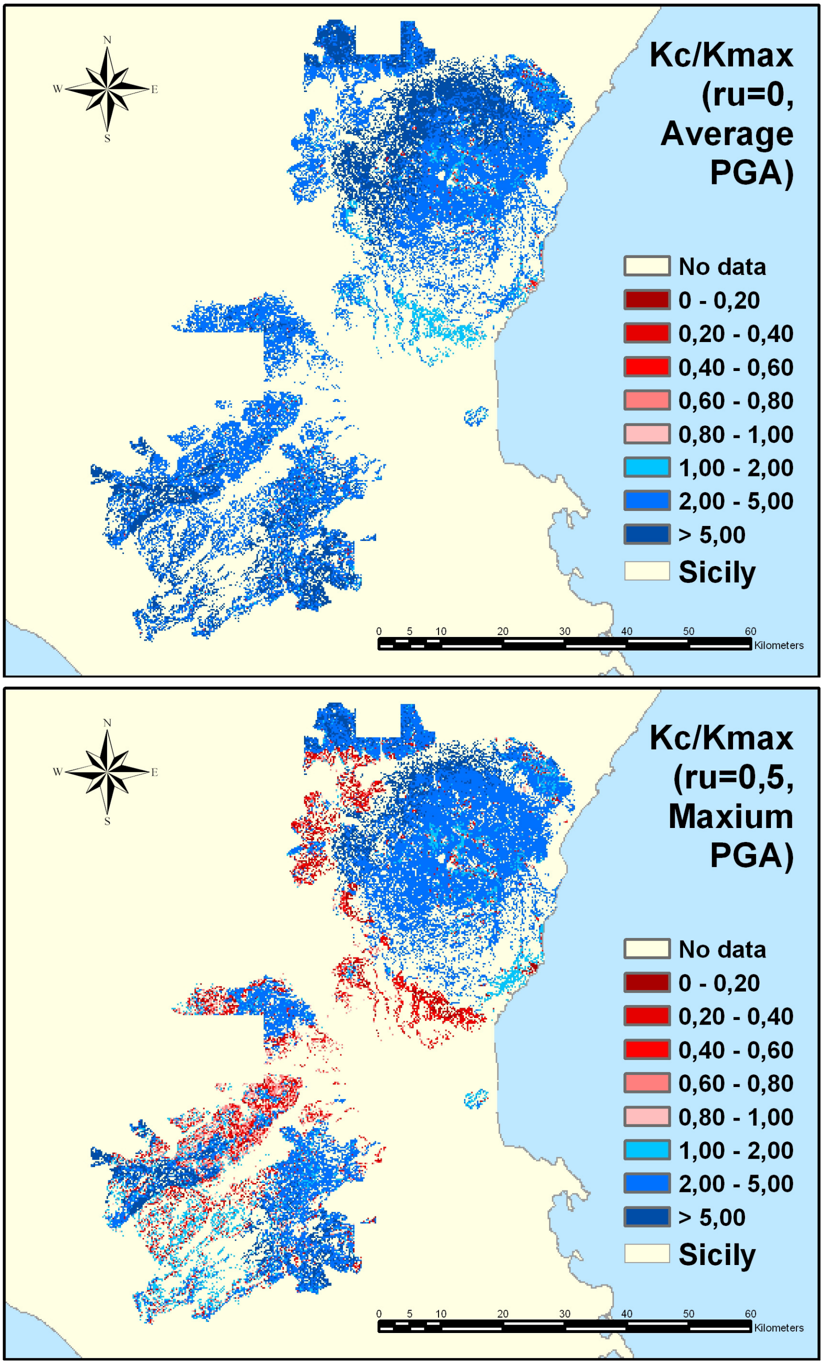

Figure 4: Maps of potentially unstable area.

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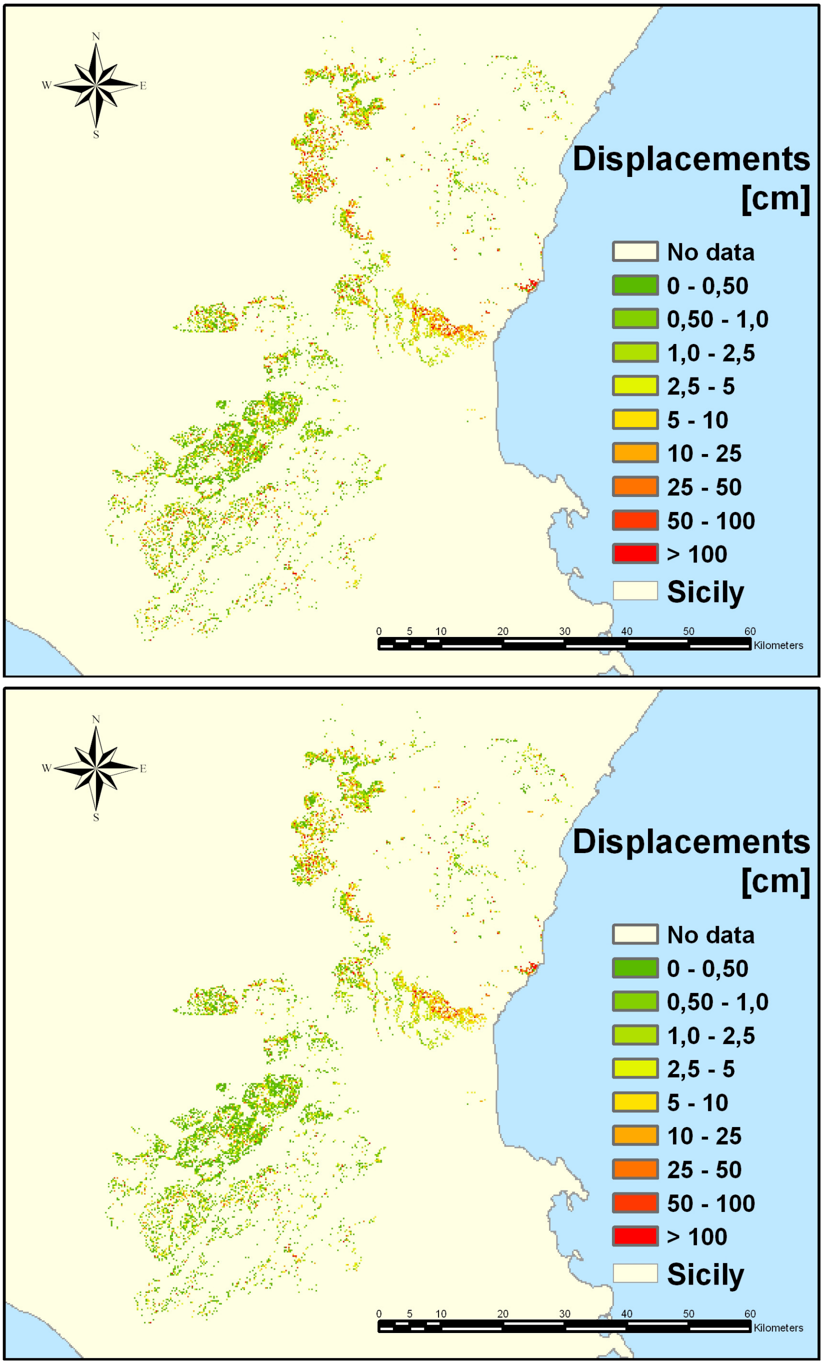

Figure 5: Permanent displacements computed with the model by Romeo [16] and Ambraseys & Srbulov [19] for r_u=0.5 and maximum *PGA*.

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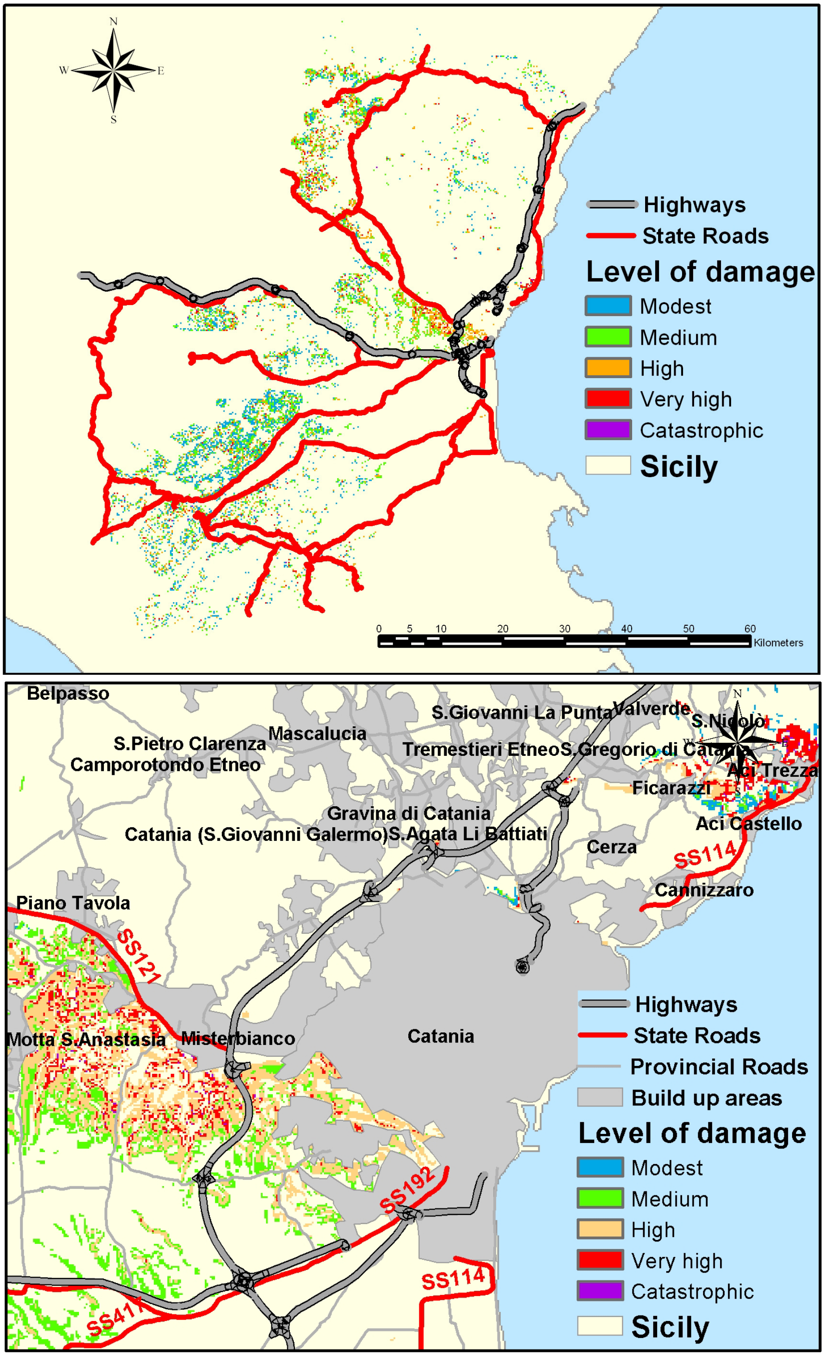

Figure 6: Map of earthquake-induced damages on slopes: a) the study area; b) detail for the Catania area.

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7 Concluding remarks

In the present paper a GIS-model for the Catania district finalised to the evaluation of earthquake-induced landslides hazard was described. The implementation of the geotechnical models in the GIS environment gives great operative advantages in spatial data management and elaboration. Furthermore, thanks to the GIS potentiality, it is possible to reiterate many times the selected models and simulation referring to different scenarios (location of epicentre, magnitude, etc.). The model was developed in order to realise an hazard predictive tool for this high seismicity area of the Mediterranean. In particular, the obtained GIS-model was used to evaluate the probability of occurrence of landslides triggered by a selected design earthquakes and the spatial distribution of potentially unstable slopes. To this purposes data concerning the topographical, geological and geotechnical characteristics of the area of study were collected using available data in the framework of the Catania Project and were stored in a database. Different ground motion attenuation relationships were selected among those available in the literature and several *PGA* and *PGV* reliable scenarios was computed with reference to a design earthquake. Starting from the computed values of slope critical acceleration maps of the potentially unstable area were obtained for different hydraulic condition of each site involved in the area. Then, using available empirical models, earthquake-induced permanent displacements of slopes was computed and its spatial distribution was mapped using the GIS functions. Finally through an empirical displacement-damage correlation, the post-seismic serviceability condition of the main road and railway network in the area was evaluated assessing the level of earthquake-induced damage.

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