A procedure for the evaluation of geotechnical risk in urban areas: the case of Centuripe town

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Abstract

In Italy, many urban areas suffer geotechnical hazard problems. However the Municipalities are not yet organised either to deal with the consequences of the possible phenomena, or to plan risk factor mitigation actions, by vulnerability reduction of the exposed elements. Before acting, a deep knowledge of the studied area and of the most important element at risk is needed. For this aim, one of the most widely used procedures is microzonation. This follows the recommendations of the "Manual for zonation on areas susceptible to Rain-Induced Slope failure" (ATCGNH – ISSMFE (Asian Technical Committee on Geotechnology for Natural Hazards in ISSMFE) The Japanese Geotechnical Society, July, 1997), for example, compiling expressly designed penalty forms. In this work, an approach to detect the vulnerability factors of Centuripe town's (EN – central-eastern Sicily) historical centre buildings is shown. A model of the penalty form based on the one proposed by Massimino et al. (The Grade 2 microzonation of Sellano. Italian Geotechnical Journal, XXXV, n.4, pp. 79-89, 2001) and conveniently modified to point out hydrogeological risk (Raciti et al. "GIS Techniques Application in Geological Hazard of Slope Instability Map Editing". Mining and Environmental GeoEngineering, XLV, n. 1, April 2008) is proposed. The proposed forms will be compiled for 101 buildings and 3 roads.

Keywords: geotechnical hazard, urban vulnerability, penalty form, hydrogeological microzonation.

1 Introduction

Natural hazards are severe and extreme events, such as earthquakes, landslides and floods, which occur naturally in all parts of the world, in different time and area scales. An extreme weather event can involve multiple hazards at the same

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time or in quick succession. In addition to high winds and heavy rain, floods and mudslides can happen, and later landslides can occur. Winter storms with high winds and heavy snow or freezing rain can also contribute to avalanches on some mountain slopes and to high runoff or flooding later on in the melt season.

Natural hazards become natural disasters when people's lives and livelihoods are destroyed. In recent years, a number of major disasters have made the global community aware of the immense losses of human lives and properties.

By issuing accurate forecasts and warnings in a form that is readily understood and by educating people how to prepare against such hazards, before they become disasters, lives and property can be protected.

It can be argued that a well defined and clear model is highly beneficial in the management of disasters because it facilitates the securing of support for disaster management efforts. Hence, disaster management needs a formal system, or a model, to manage and possibly reduce the negative consequences of a disaster.

Being slope failures, in general, not so spectacular or devastating as an earthquake, a volcanic eruption or a flood, they are quite neglected. Yet, being much more frequent and widespread over the years, landslides have caused considerable loss of property and life. In many countries, economic losses due to landslides are great and apparently are growing as development expands into unstable hill areas under the pressure of expanding populations.

Italy is widely exposed to landslides hazard phenomena. It has been observed that some regions are more vulnerable than others: a deep knowledge of the studied area and of its own features is needed to design mitigation actions that could be applied during territorial planning and during ordinary life.

Landslide hazard, in general cannot be completely prevented. However, the intensity and severity of landslides impacts can be minimized if the problem is recognized as far as possible, or even before the development a specific activity that could influence the sliding aptitude. Hence, there is a dire need for identification of unstable slopes, which can be fulfilled by hazard microzonation and mapping (Raciti et al. [3]).

Landslide hazard zonation of an area has the aim of identifying the landslide potential zones and ranking them in order of landslides hazard degree.

Landslide hazard zonation can be made following the recommendations of "Manual for zonation on areas susceptible to Rain-Induced Slope failure" (ATCGNH – ISSMFE [1]), where many methods are proposed, or following other methods proposed in technical literature. In most of the techniques though input parameters are mostly the same, they differ in ranking the factors. In general, methods are either based on qualitative approaches that dictate the weight assignment to the factors based on the experience and expert knowledge or on statistical approaches which involve relationship between existing damages caused by landslides and the factors. In every case all available data must be collected and used as input: this can be made, for example, compiling, expressly designed Geotechnical Hazard Forms (GHF).

It cannot be neglected that most of the information required for disaster management has spatial component or location. Current studies show that there are different problems with collection, dissemination, access and usage of spatial data/information for disaster management.

In this work, a model of geotechnical hazard form, based on the one proposed by Massimino et al. [2], conveniently modified to point out hydrogeological risk, is proposed.

An application is shown about the detection of the vulnerability factors of Centuripe town (EN – central-eastern Sicily) historical centre buildings. For this case history, the proposed form has been compiled for 101 buildings and 3 roads.

2 The importance of data collection

Disaster management have different role during different stages of the disaster, like planning, mitigation, preparedness, response, and recovery, but in every case it could help to obtain a more sustainable development, reducing human and material losses caused by natural disasters.

To obtain a proper disaster management a great amount of information should be collected and managed. The ability of a disaster victim to prepare for, respond to, and recover from a disaster depends on a variety of factors like the severity and longevity of the event, the efficiency of the warning systems, the victim's health status, and his or her access to resources and information. An ideal Disaster Management System can support the activities related to preparedness, prediction, damage assessment and rehabilitation.

Several critical inputs like building, lifeline system, road and hospital location etc. are required in order to take preventive measures through vulnerability analysis, hazard zonation, prior risk assessment, timely and reliable weather forecasts, and advance warnings to minimize loss of life and damage and facilitate timely and effective rescue, relief and rehabilitation of the affected population. Many organizations, which involve in disaster management, require to access to the right data in the right time to make the right decisions.

In more details, while most of the information required for disaster management has spatial component or location, current studies show that there are different problems with collection, dissemination, access and usage of spatial data/information for disaster management.

Disaster risk reduction activities should be integrated and coordinated among international, national and regional organizations, to mitigate human and property losses through improved forecast services and early warnings, as well as risk assessments, and to raise public awareness. National specialized centres, like Meteorological and Hydrological Services and National Institute of Geophysics and Volcanology have responsibility for investigating geophysical hazards, including earthquakes, volcanic explosions, floods and so on.

It can be argued that a well defined and clear model is highly beneficial in the management of disasters because it facilitates the securing of support for disaster management efforts. Hence, disaster management needs a formal system, or a model, to manage and possibly reduce the negative consequences of a disaster.

A disaster model is useful to simplify complex events and to help in distinguishing between critical elements, especially when responding to disasters with severe time constraints. Comparing actual conditions with a theoretical model lead to understand better the current situation and facilitate the planning process and the comprehensive completion of disaster management plans.

Moreover, a disaster management model is essential in quantifying disaster events and allows for better integration of the relief and recovery efforts.

A well defined and clear model is highly beneficial in the management of disasters because it facilitates the securing of support for disaster management efforts.

Majority of the data required for the disaster management are spatial and hence a geographic information system (GIS) can provide that sort of information.

It would be a great success in the disaster management if police, fire, public health, civil defence and other organizations would implement a disaster management application in a coordinated manner at both intra and inter-organization at several hierarchy levels.

3 The data base conceptual model

The main topic of the entity relationship model is the "studied area", which obviously can be located in a precise region and can be included in one or more hydrogeological basins.

"Hydrogeological basins" can be identified by an Identification code (Id), its name, an administrative identification code and some notes.

The studied area is characterized by an Id, that is a primary key, its name, an administrative code, some notes. Moreover it must be geographically located: a "Localization" entity has been created, where a *.doc file, describing of the main features and of morphology, is hyperlinked.

One entity called "topography" will contain all raster topographic maps, at different scales, that will be collected.

One entity called "lithology" will contain all lithological units, a second entity called "geology" will contain all geological formations, while geomorphologic information will be stored in another entity called "geomorphology", which will store slope, exposition and other morphological information.

One entity will represent "Land use": that information will be acquired from Corine Land Cover or more detailed thematic maps.

One entity called "buildings" will store information about buildings: attributes will be Id, Name, Address, Civic Number, Type, Function, Foundation type, Structural type, number of underground floors, suffered damage, fonts of information and some notes.

Other entities will be devoted to lifeline networks, like roads, railways, water, sewer or gas pipes, electric power, and other technological networks: for each network arc, an Id, a name, a classification, a structural type, information about the bed location (road-bed, railway-bed, pipe-bed), information about the suffered damages, and some notes will be stored.

Information about surface hydrology will be divided in two groups, to distinguish areas and polyline entities. For each element, an Id, a name and information about maintenance and the origin of information will be stored.

For as regards geotechnical information, a point entity called "survey" will store an Id, East and North coordinates, survey type, the origin of information and some notes. For each survey, in situ and/or laboratory tests information will be stored in two other entities. For laboratory tests, the attributes will be Id, E and N coordinates, Date, Font and some notes. For in situ tests Id, stratigraphy, water table depth, test type, number of samples (undisturbed, disturbed, remoulded), photos and some notes are the required information.

Finally, one entity called "monitoring point" will store information about inclinometric and piezometric monitoring, with an Id, a name or an identificative code, UTM E and N coordinates, the date of start and stop of monitoring, some photos and information about the test results. In a municipal area, one or more monitoring points could be found.

In Figure 1 a simplified scheme of the data base conceptual model is drawn.

4 A form for the data collection

Once a good conceptual model has been designed and implemented in a logical and in a physical model, data should be collected to populate tables and relationships.

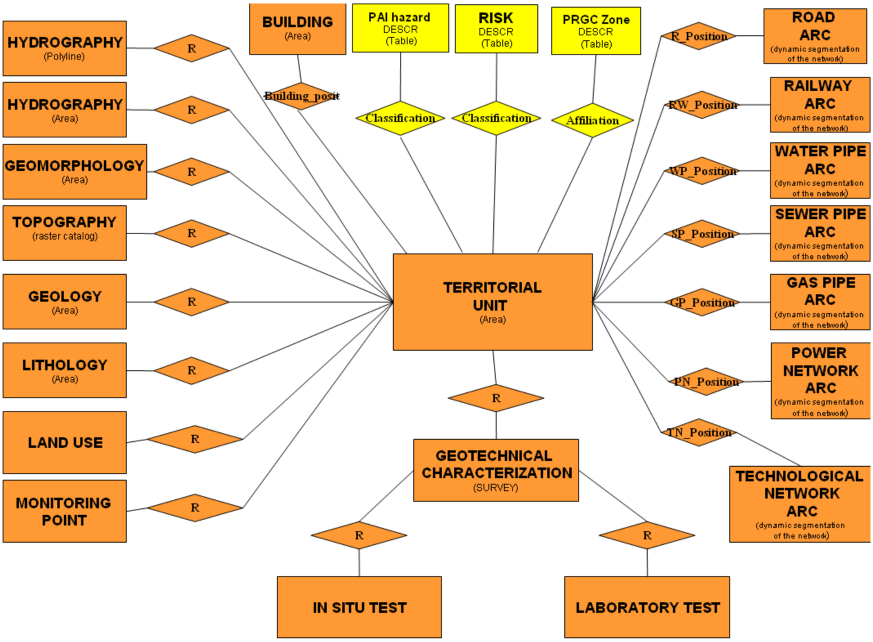

Figure 1: A schematic plot of the data base conceptual model.

In Italy, in recent years, many surveys on the existing buildings vulnerability have been brought about using “vulnerability forms”. With the aim of quantifying the part of risk due to site and soil features, the use of a "*Geotechnical hazard form*" has been proposed by Augusti et al. [4–6]. Augusti et al. [7] introduce a semi-quantitative procedure given by ISSMGE - TC4 [8] general criteria for a Grade 2 microzonation.

The first model of "*Geotechnical hazard form*" proposed by Augusti et al. [4, 5] have been improved by other authors, basing on experimental observations on occurred damages and on geological and geotechnical conditions of the investigated areas. A procedure, based on compiling a "*Geotechnical hazard form*", adapted to geomorphologic and geologic features of the Umbria zones, was successfully used by Crespellani and Garzonio [9, 10] for Gubbio town (Umbria-Italy), by Cascone et al. [11, 12] for the city of Catania (Sicily - Italy) and by Massimino et al. [2] for Sellano town (Umbria-Italy).

In this paper a new version of "*Geotechnical hazard form*", based on that proposed by Cascone et al. [11, 12] and by Massimino et al. [2], but conveniently modified to point out hydrogeological risk, is proposed. Two form types are proposed: the first deals with buildings and consist of six sections; the second with transportation “*lifelines*” (road, railway, bridge, tunnel), consists of four sections.

Table 1: The penalty form.

SUBSOIL PARAMETERS	PENALTY		
	LOW	MEDIUM	HIGH
SLOPE STABILITY	**STABLE**	**QUIESCENT LANDSLIDE**	**ACTIVA LANDSLIDE**
	0 - 1	*2 - 3 - 4*	*4 - 5 - 6*
LOCAL SLOPE	**i < 5°**	**5° < i < 15°**	**i > 15°**
	1	*1 - 1.5 - 2*	*2 - 3 - 4*
MORPHOLOGY	**FLAT AREA**	**SLOPING AREA**	**RIGDE**
	0.5	*1 - 1.5 - 2*	*2*
WATER TABLE DEPTH	**d > 10 m**	**5 m < d < 10 m**	**d < 5 m**
	0	*1*	*2*
EXPOSURE	**S-SW**	**SE-E-W-NW**	**N-NE**
	0	*1*	*2*
Stratigraphy (*) Be considered only if evidence of Down-Hole			
TYPE OF SOIL	**HARD ROCK**	**MEDIUM SOIL**	**SOFT SOIL**
SHEAR WAVE VELOCITY	**V_S > 500 m/s**	**200 < V_S < 500 m/s**	**V_S < 200 m/s**
DEPTH (m)			
0 - 5	*0.5*	*1 - 1.5 - 2*	*2*
5 - 10	*0.5*	*0.5 - 1 - 1.5*	*2*
10 - 25	*0.5*	*1*	*2*
> 25	*0.5*	*1*	*1.5*

To restrain damages due to slow slope movements in densely populated areas, it is a main aim to individuate areas that show active, quiescent or potential instability phenomena. Landslide hazard location in a specific area has different facets. First of all a landslide in the in the area of interest or closet o it, must be identified. Then landslide susceptibility due to geological or geomorphologic structures must be evaluated. Specific factors, like local slope, aspect, and the slope foot erosion conditions must be taken into account. Moreover, where a previous slope movement has happened a landslide reactivation is likely.

A *Geotechnical hazard form* is in concept analogous to a vulnerability form, as it lists the most significant factors influencing the subsoil underlying constructions

Its compilation involves the acquisition of two major categories of data:

- the volume of soil directly underlying the building foundations (thickness and properties of the soil layers, water-table level, etc.);
- the surrounding site (local and overall morphology, slope stability, etc.);
- shear wave profile.

Buildings or *transportation lifelines* exposure to hydrogeological geotechnical hazards due to subsoil properties and to subsoil conditions can be evaluated by geotechnical hazard index which results from assigning a penalty to each scenario.

The technicians' survey team, basing on geological maps, field observations and other information, classifies each item in low, medium and high hazard.

The geotechnical hazard index can varies from zero to very high values. It is opportune that the lower and upper limits corresponding to stable and unstable sites as well as the weight factors are assigned by the operators through field experimentations.

The form can be compiled at different levels of accuracy. Data can be deduced from geological and geomorphologic maps, available geotechnical data and geophysical surveys, direct testing and mapping, field observations.

For as regards morphology slopes between 5° and 15° will be taken into account. Local slope will be classified choosing "1" for the slope foot or a valley zone, "1.5" for a zone located in the middle of a slope, 2 for a zone near the slope crest.

For as regards landslides, for a building near a stable slope a weight "0" will be considered. If the building is near an unstable or potentially unstable slope, "1" will be the weights to take into account.

Moreover, it is important to define the building position in relation to a quiescent or active landslide. A weight "2" or "4" will be taken if the building is located at the periphery of the landslide, while weight "4" or "6" will be assigned if the building is within the landslide, "3" and "5" in other cases.

For as regards exposure, a wedge "2" will be considered if the building is exposed toward north or north-east direction, "0" if towards south or south-west, "1" in all other cases.

Finally, for "Down-Hole tests", the table gives the weights in relation to the soil type and the shear wave profile (V_S) (compact, medium compact, soft or loose).

5 The case of Centuripe town

The previously mentioned procedures have been applied to Centuripe town (Figures 2 and 3) [13, 14].

Centuripe (Centorbi in Sicilian, Kentoripa in Greek, Centuripae in Latin) is located 69 km from Enna, in the hill country between the Rivers Dittaino and Salso, 730 meters above the sea-level., and is part of Enna province (Sicily, southern Italy). Its municipal area, almost entirely mountainous, is over 17,295 hectares. The municipality counts about 6500 inhabitants, with a population density of about 35 inhabitants per square kilometre.

It is a charming mountain centre that borders the municipalities of Randazzo, Bronte, Adrano, Biancavilla, Paternò, Castel di Iudica in Catania province, and Catenanuova and Regalbuto in Enna province.

The origin of the name Centuripe is uncertain: perhaps it is related to the ancient Greek colony of Kentoripa, of the IV century B.C. It was conquered by the Romans, who transformed it into a flourishing economical and cultural centre.

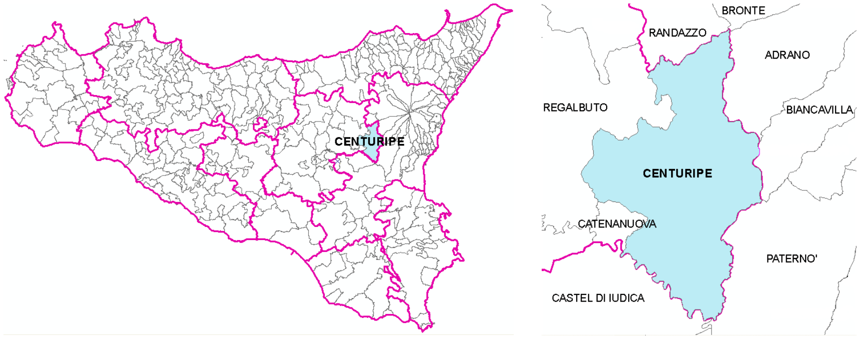

Figure 2: Centuripe town location.

Figure 3: A view of Centuripe town.

Under the Aragonese and Angevin dynasties, the suburb was destroyed and all of the inhabitants were deported. Only in 1548, the town experienced a strong renewal as it was rebuilt by will of Count Adernò Francesco Moncada. His noble family owned the town until the abolition of the feudal rights.

Considerable remains of the ancient city walls and of buildings, mostly of the Roman period, still exist, and numerous antiquities, including some fine Hellenistic terra-cottas, have been discovered in casual excavations.

Other sites include the Chiesa Madre (17th century) and the ruins of the so-called Castle of Conradin, in fact a Roman construction of the imperial age.

The territory hosts several archaeological areas, such as the Difesa area, seat of a Roman construction, the Bagni area, home of the remains of a thermal bath station of the Imperial era, and the Panneria district, home of remains from the Hellenic period.

For as regards the geological situation, its territory consists mainly of sandstone, and clayey conglomeratic rocks.

In order to assess the role played by the soil features on buildings foundations damages, and to evaluate the geotechnical hazard level of urban infrastructure and buildings the "*Geotechnical hazard form*" shown above was used to collect the required data. So, the most important features of the soil site have been taken and to the foundation by allocating adequate penalties to different situations. The "GHI" index thus defines a Hydrogeological geotechnical hazard.

The application of the "*Geotechnical hazard form*" at Centuripe, the research was carried out in three phases.

In the first phase, to obtain a reliable calibration of penalties and weight factors, as said before, a deep investigation of the geological and geotechnical properties of the subsoil was carried out. In the second phase, a map of the critical areas according to the subsoil characteristics and critical hydrogeological condition for the building and for life lines was made. The last phase regards the visit to the site and the forms compilation.

Centuripe in recent years has been affected by landslide phenomena, more or less distributed over almost the entire urban area. To make the hydrogeological risk assessment, have been selected and the areas for which they were made of visits to buildings.

In particular, data were collected for 102 buildings and three roads. Each card contains information on the type and function of the works in question, characteristics of the soil foundation and geotechnical data obtained from in situ tests and laboratory.

Based on these findings, through the allocation of weights to the geological and conditions of the land assessed, has produced a Geotechnical Hazard Index (I_{GH}) through which one can classify the level of danger of the area in question.

A distribution of geotechnical hazard over the whole area of Centuripe town, and in particular, for the area of the Civic Museum and for that from "via Salso" to the final part of the "via G. Fiorenza", has been obtained, and basing on the hazard classes listed in Table 2, it was possible to identify areas at different hydrogeological risk.

The analysed areas falls in the old town: Three roads were also analyzed: the provincial roads SP 41 and SP 24/a and the commercial urban street via G. Marconi.

Basing on values collected compiling geotechnical hazard forms, it can be argued that for as regards the historical centre and for via Salso, not any hydrogeological hazard subsists. For the last part of “via G. Fiorenza”, a moderate hazard level has been deduced and, finally, a high hazard level has been found for the Civic Museum area.

For as regards roads, SP 41 and SP 24/a, respectively, a medium and high hazard level have been deduced, while “via G. Marconi” shows very serious damages and a very high hazard has been deduced. In fact, after the last heavy rains it has been closed to cars transit.

To better locate the hazard levels a Hydrogeological Hazard Map for the examined zones has been created, and it is plotted in Figure 4.

Table 2: Hazard levels.

I_{GH}	HAZARD	LEVEL
2.5–4.0	Low	I
4.5–6.0	Moderate	II
6.5–8.0	Medium	III
8.5–10.0	High	IV
>10.5	Very High	V

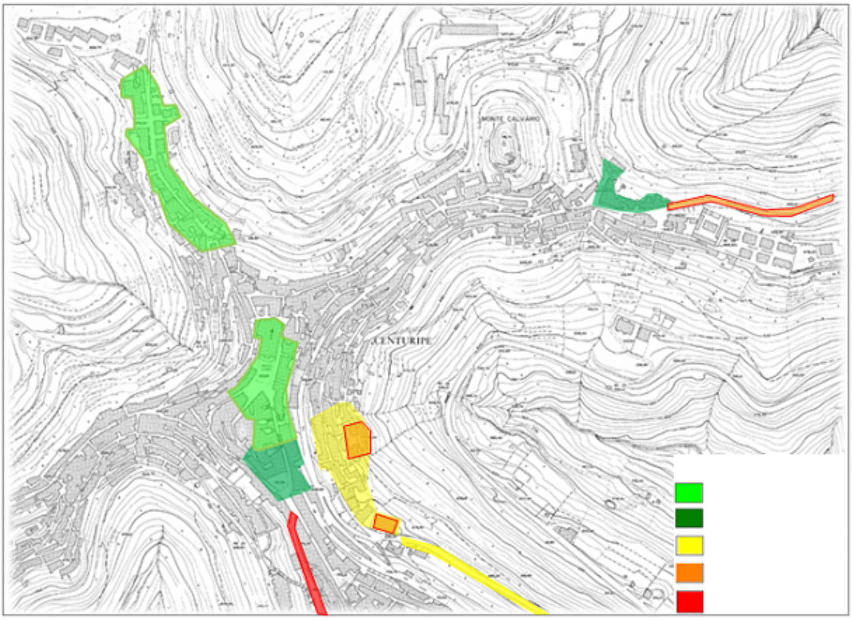

Figure 4: Map of hazard levels.

6 Results and conclusive remarks

In this work a microzonation project in terms of geotechnical hazard for the City of Centuripe has been proposed. The aim was to provide useful information in order to avoid and/or reduce the damage that may occur due to future landslide events.

To achieve this result, according to the model of "*Geotechnical hazard form*" proposed by Augusti et al. [4–6], a new model of "*Geotechnical hazard form*" has been proposed, where information are required on structures type and function, soil foundation features and on geotechnical data obtained from on-site testing and laboratory equipment. This form has been used to collect data on 101 buildings and 3 roads.

Analysing the collected data, it has been noted that no hydrogeological hazard exist for the city centre and the Via Salso. A moderate hazard has been found for the final part of the Via G. Fiorenza and a high hazard involves the museum area.

For as regards roads, SP 41 and SP 24/a respectively show medium and high hazard level, while for "Via G. Marconi" a very high hazard has been estimated.

Further developments will be brought about for this work. A more complete geo-database conceptual model will be designed and implemented in a logical and physical model, to store the collected information in a systematic manner and allow an efficient consultation and continuous update. Then new towns will be involved in the analyses to assess hydrogeological risk in other urbanised areas.

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