ON THE DEFINITION OF SEISMIC VULNERABILITY MAPS IN CROSS-BORDER MEDITERRANEAN AREAS

Cavaleri, L., Di Trapani, F., Macaluso, G., Bilello, C.
Department of Civil, Environmental, Aerospace and Materials Engineering,University of Palermo,ViakedelleScienze, 90128, Palermo, Italy, liborio.cavaler@unipa.it

Introduction

The chance to locate and quantify the major risks associated to natural catastrophic events on a territory allows the planning of adequate strategies and interventions by civil protection bodies involved in local and international emergencies. The seismic risk depends most of all by the vulnerability of buildings belonging to the urban areas. For this reason the definition, by a deep analysis of the territory, of instruments identifying and locating vulnerability, largely favours the activities of institutions appointed to safeguard the safety of citizens.

Seismic and hydro-geological risks constitute the major component of the activities involving assistance actions carried out by civil protection bodies because of their repetitiveness and the amount of human resources needed to face the emergencies. The possible coordinate action and cooperation between different countries is of fundamental importance, especially if the procedures are based on standardized rules and civil protection plans are characterized by consciousness of the territory and the associated risks. The promptness of the response is basic for the success of the operations. This feature is however not only achievable by practice exercises aimed to implement a responsiveness system to emergencies, but also through a deep understanding of the existing risks and the major exposure recognized for the urbanized contexts.

The challenge for the assessment of seismic vulnerability of buildings is not easy because it involves a large amount on constructions to investigate in a reasonable time. Several researchers, based on the post processing of data coming from the observation of damaged buildings, proposed simplified relationship linking a vulnerability index with the intensity of a seismic event (Benedettini and Petrini (1984), Braga et al. (1984), Angeletti et al. (1988), Casolo et al. (1993)). In other studies the interest has been addressed to the definition of fast assessment methods for the vulnerability index and the relative large scale application (Martinelli et al. (1999), Dolce et al. (2004), Dolce and Moroni (2005), Dolce and Martinelli (2005)).

In this summarythe outputs of the activity carried out within the research project “SIMIT-Development of an integrated cross-border Italian-Maltese civil protection network” are presented with specific reference to the assessment of the seismic vulnerability of buildings and definition of vulnerability maps in terms of vulnerability index and peak ground acceleration limit values. In agreement with the scope of the paper, the criteria adopted for the assessment of vulnerability and definition of the vulnerability maps were calibrated to provide reliable predictions for typically small urban contexts, which are largely widespread in the Mediterranean area. The representative test site selected for the activities was the city centre of the island of Lampedusa. The choice was particularly suitable for the prefixed purposes because of the opportunity to operate on a large quantity of buildings concentrated in a small area with and characterized by a repetitiveness of the constructive typology. The final goal was to develop a standard procedure for the assessment of seismic vulnerability of small urban contexts widespread in the Mediterranean.

The specific research activity carried out on the island has been divided in 4 phases, characterized by a progressive level of depth of the analysis, listed below:

- Historical, critical, and typological analysis of the urban centre and typical buildings;
- Simplified assessment of seismic vulnerability of buildings by standard vulnerability forms;
- Choice and validation of a vulnerability model;
- Definition of fragility functions and vulnerability maps.

The historical-critical study was aimed at the recognition of the urban evolution of the city centre of Lampedusa over the time and of the regulations succeeded which have changed the constructive and typological framework of buildings. The subsequent typological analysis of the buildings, performed through several surveys, made it possible to categorize the recurring structural types within the city centre of the island and their similarities and differences in relation to periods of construction. Such preliminary activities permitted to collect fundamental information, necessary for a fast and effective assessment of the buildings vulnerability, carried out by the use of evaluation forms already known in the literature and commonly used in Italy (GNDT (1994))for the fast assessment of the vulnerabilitysingle buildings and building aggregates. The major output coming from the use of such kinds of vulnerability evaluation forms is constituted by possibility to determine a numerical vulnerability index, suitable to be adopted for the definition of the vulnerability maps.

The definition of the fragility curves, which provide a relationship between the intensity of the seismic event (synthetically represented by the Peak Ground Acceleration) and the structural damage, passes through a preliminary calibration, necessary to adapt the vulnerability model (index of vulnerability vs. PGA) to the characteristic building context. In the current study, the calibration operations were performed by an experimental dynamic monitoring campaign on two prototype buildings, followed by the realization of the numerical structural models consistent with the experimental results. The seismic assessment of the prototype buildings by static pushover analysis made possible the determination of the critical PGA values to be linked with indexes of vulnerability previously evaluated, in order to adapt the vulnerability model to the urban context of the island of Lampedusa. The final outputs are the fragility curves and the associated vulnerability maps for the urban area of Lampedusa, presented in terms of index of vulnerability and critical peak ground accelerations.

The assessment of the seismic vulnerability of buildings

The assessment of seismic vulnerability has been carried out for masonry and reinforced concrete buildings belonging to the city centre of Lampedusa. For the sake of brevitythe procedure for the assessment described in the following regards only masonry buildings.

The recognition of vulnerability of masonry structures has been carried out by the evaluation forms developed by GNDT (1994). The need to correlate scientific information with on-site surveys has requested the use of so called "second level forms", since their compilation is not direct but requires a deeper investigation of the geometrical and mechanical characteristics, followed by the evaluation of specific parameters by a numerical calculation.

The assessment of the vulnerability by the 2nd level GNDT forms is based on the determination of a vulnerability index which is a conventional measure of the propensity of a building to undergo seismic damage. The index is numerically calculated as sum of vulnerability scores obtained by the analysis of 11 parameters considered fundamental for the identification of the seismic behavior of masonry buildings. The vulnerability index that is obtained allows to compare buildings and to establish graded lists or a map of vulnerability (as in the case of the present study).

Table 1.Parameters for the identification of vulnerability of masonry buildings in GNDT forms and related scores and weights.

		Class C_{vi}				Weight
PARAMETER		**A**	**B**	**C**	**D**	p_i
1	Type and organization of the resisting system	0	5	20	45	**1.00**
2	Quality of the resisting system	0	5	25	45	**0.25**
3	Conventional resistance	0	5	25	45	**1.50**
4	Position of the building and foundations	0	5	15	45	**0.75**
5	Floors	0	5	25	45	**0.75**
6	Configuration in plan	0	5	25	45	**0.50**
7	Configuration in elevation	0	5	25	45	**1.75**
8	Walls maximum interaxis	0	5	25	45	**0.25**
9	Roof	0	15	25	45	**0.50**
10	Non-structural elements	0	0	25	45	**0.25**
11	Current conditions	0	5	25	45	**1.00**

The choice of GNDT forms has been determined on the following base requirements:

• Possibility of detecting pre-earthquake vulnerability

• Adequate amount of information about the parameters that affect the vulnerability;

•Compilation without specific investigations or detailed surveys on buildings;

- Consolidated use of the forms on the national territory;
- Possible adaptation of the forms to particular needs found in the area;
- Availability of the same type of forms masonry and RC structures.

The GNDT vulnerability assessment form for masonry buildings requires the determination of the 11 parameters reported in Table 1. Each parameter is associated with a class of vulnerability between A and D, where A represents the best condition detected and D the worst. At the same time a class of quality of the information used to establish the class of vulnerability, is assigned. The vulnerability classes are characterized by increasing scores and identified by the symbol cvi. The single parameters are moreover weighted by the weight pi, which establishes their influence on the overall assessment of the vulnerability.

The vulnerability index V is defined as:

$$V = \sum_i c_{vi} p_i$$

taking values between 0 and 328.5. The vulnerability index can be also normalized by its maximum value and assume values between 0 and 100.

The vulnerability model and its calibration

The definition of a relationship between the severity of the earthquake and the damage, through the vulnerability index *V*, is based on the observation that a building, subject to seismic actions of increasing severity, is typically characterized by a beginning stage of damaging, a phase of increase and a rapid decay up to the collapse. If one assumes the parameter *y=a/g*, which identifies the normalized ground acceleration, as index of the severity and the parameter *D* as index of the damage (between 0 and 1), identifying the loss of the economic value, the relationship may be represented by a fragility function.On this curve one can identify the accelerations corresponding to damage beginning $y_i$and collapse y_c. As proposed in Guagenti and Petrini (1989), a linearized fragility function has been used to reduce the problem of establishing the fragility function to the simple calculation of the values of $y_i$andy_c.

$$D(y,V) = \begin{cases} D = (y - y_i)/(y_c - y_i) \\ D = 0 \quad per\ y < y_i \\ D = 1 \quad per\ y > y_c \end{cases}$$

In particular the following functional relationship linking the early damage acceleration $y_i$and the collapse acceleration y_c to the vulnerability index according to Guagenti and Petrini (1989) was assumed:

$$y_i(V) = \alpha_i \, exp[-\beta_i(V)]$$

$$y_c(V) = \alpha_c + \beta_c(V)^{\gamma}$$

The equations reported above depend on 5 parameters whose calibration is of great importance for the reliability of the results and has to be performed by major investigations on typical buildings.

For this reason the calibration has been performed on the basis of an experimental investigation, which included the dynamic identification of 2 prototype buildings chosen to be adequately representative of the previously discussed features of the urban centre built. The final purpose was the definition of refined numerical models to be used for the determination of the critical PGA values ($y_i$and y_c) at the specific vulnerability levels characterizing the buildings.

The calibration process was performed according to the following steps

- Choice of the prototype building and assessment of the vulnerability index by GNDT forms;
- Dynamic identification of the buildings and definition of the numerical models;
- Evaluation of y_i and y_c values by static pushover analyses;
- Positioning $V – y(V)$ points and best fitting.

The buildings selected for the investigation were the City Hall of Lampedusa (BT "A") and the headquarters of the Marine Protected Area of Lampedusa (BT "B").

The numerical models

Structural models were performed using the software SAP 2000 NL. For the sake of brevity only the BT"A" model is reported here. A "frame-type" schematization of the masonry structure was adopted. Walls were modelled as beam/column elements with reference to their centroidal axis. Taking into account the presence of RC curbs at any level, it was assumed that the coupling masonry beams were flexurally resistant. The presence of concrete slabs allowed moreover to consider the rigid diaphragm constrain. The loads coming from the floors were distributed linearly on the beams at each level. Finally, the connections at the areas of overlap between the walls and the masonry beams were modelled as rigid elements. The nonlinearity was introduced by a shear – sliding hinge placed in the middle of each vertical elements. A 3D representation of the model is shown in Fig. (1).

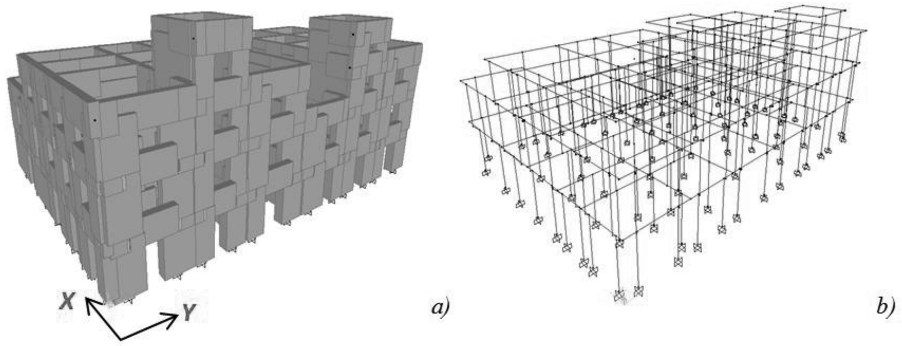


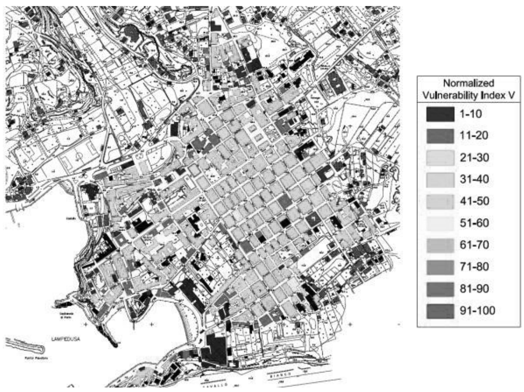
Figure 1.3D view of the structural model (BT"A"): a) solid scheme; b)unifilar scheme.

Pushover analyses were carried out in order to define the capacity of the structuresespecially in terms of early damage and collapse ground accelerations.The analyses allowed to determine the reference critical accelerations for the prototype buildings BT”A” and BT”B”. In particular, reference was made to minimum values respectively for accelerations of early damage and collapse. Joining PGA values and vulnerability indexes on a *V-y* plane, it was possible to calibrate the coefficients governing the *y(V)* relationships according to the model by Guagenti and Petrini (1989), providing suitable general expressions having validity for the buildings of the city centre of Lampedusa.

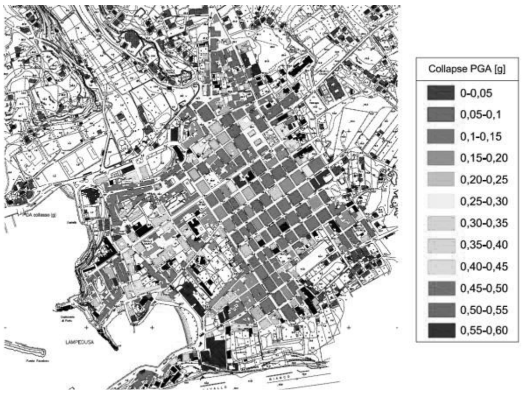
The vulnerability maps

The final output was reported in three maps. The first one (Fig. 2a) is the map of the vulnerability index, obtained by the application of the GNDT procedure to the masonry buildings investigated, which represent almost the totality within the urban centre. The map has a reference chromatic scale of the normalized vulnerability index going from cooler colours (blue - green), associated to a lower vulnerability, to warm colours (red-orange) associated to increasing vulnerability values.

.



a)



b)

Figure 2.Vulnerability of the city centre of Lampedusa: a) Map of the vulnerability index; b) Map of the collapse PGA.

Two further maps were generated: collapse PGA map and early damage PGA map. For the sake of space only the collapse PGA map is reported in Fig. 2b. These maps were obtained after the calibration of the necessary parameters and regulating of the vulnerability model. Within these two maps the warmest colours were associated to the lowest values of ground acceleration, representative of the most critical conditions. Looking at the output expressed by the vulnerability index map, the overall condition does not present relevant criticalities. The average vulnerability is settled to mid-low values. On the contrary, the early damage and collapse PGA values are instead rather low. However, considering the expected PGA values, which are associated the low seismicity of the area, one can exclude, with good approximation, the possibility of the occurrence of catastrophic post-earthquake scenarios. It appears evident from the maps that the areas characterized by a greater vulnerability refer to the oldest urban disposition, which were also the most subject to further transformations during the time. The peripheral areas, consisting of newer buildings, resulted instead less vulnerable, consistently with the expectations coming from the initial assessments The overall framework that has emerged, for the case study of Lampedusa island, was in agreement with the predictions made by the assessment forms, in which a good general condition was recognized. The elements of major criticality detected regarded essentially the presence of aggregates building with strong irregularities in elevation. These buildings reached in fact the highest levels of vulnerability.

In accordance with the purposes, the major outputs obtained by the application of the proposed assessment procedureto the case of the island of Lampedusa gave a univocal representation of the seismic risk for its urban centre area.This procedureis suitable to bestandardizedin order to be largely forthe generation ofvulnerability mapsofsmallurbanareas in the Mediterranean.

Acknowledgements

This study was supported by PO Italy – Malta 2007-2013. SIMIT Research Project: “Development of an integrated cross-border Italian-Maltese civil protection network”

References

BenedettiniD. and PetriniV. (1984). On seismic vulnerability of masonry buildings: proposal of an evaluation procedure, L' industriadelleCostruzioni 18, 66-78.

BragaF., DolceM. and LiberatoreD. (1984). Fast and reliable damage estimations for optimal relief operations, Proceedings Int. Symp. on Earthquake Relief in Less Industrialized Areas, Zurich,145-151.

AngelettiP., BellinaA., GuagentiE., MorettiA. and PetriniV. (1988). Comparison between vulnerability assessment and damage index, some results, Proceedings of the 9th World Conference on Earthquake Engineering, Tokyo-Kyoto,181-186.

CasoloS., GrimazS. and PetriniV. (1993). Scala deiGiudizisintetici di stimadeldannosismico. Scala G.S.D.e.m. 93", Internal Report, Dipartimento di Georisorse e Territorio, Universityof Udine, Italy.

MartinelliA., CorazzaL., CherubiniA., DolceM., Di PasqualeG. and PetriniV. (1999).Censimento di vulnerabilitàdegliedificipubblici, strategici e specialinelleregioniAbruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia – RelazioneGenerale, Civil Protecion Department, Rome, Italy.

DolceM., MasiA. and Moroni C. (2004).Valutazionedellavulnerabilitàsismica di edificiscolasticidellaProvincia di Potenza, Proceedings of XI National Congress "L'ingegneriaSismica in Italia", Genoa, Italy.

DolceM., MoroniC. (2005). La valutazionedellavulnerabilità e del rischiosismicodegliedificipubblicimediante le procedure VC (vulnerabilità C.A.) e VM (vulnerabilitàmuratura), Civil Protection Department, Potenza, Italy.

DolceM. andMartinelliA. (2005).Inventario e vulnerabilitàdegliedificipubblici e strategicidell'Italiacentro-meridionale, Vol. II – Analisi di vulnerabilità e rischiosismico, INGV/GNDT".IstitutoNazionale di geofisica e Vulcanologia / GruppoNazionale per la DifesadaiTerremoti, L'Aquila, Italy.

GNDTGruppoNazionale per la DifesadaiTerremoti (1994). Schede di 1° e 2° livello di vulnerabilità e di rilevamentodeldanno (edifici in c.a. e muratura).

GuagentiE. andPetriniV. (1989).Ilcasodellevecchiecostruzioni: versounanuovaleggedanni-intensità. Proceedings of the 4th Italian National Conference on Earthquake Engineering, Milan, Italy, 1, 145-153.