Available online at www.sciencedirect.com
SCIENCE DIRECT®
Engineering Structures 28 (2006) 357–371
ENGINEERING STRUCTURES
www.elsevier.com/locate/engstruct

Vulnerability assessment and earthquake damage scenarios of the building stock of Potenza (Southern Italy) using Italian and Greek methodologies

Mauro Dolce[a], Andreas Kappos[b,*], Angelo Masi[a], Gregory Penelis[b], Marco Vona[a]

[a] *Department of Structures, Geotechnics and Geology Applied to Engineering, University of Basilicata, Via dell'Ateneo Lucano, 85100 - Potenza, Italy*
[b] *Department of Civil Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*

Received 8 November 2004; received in revised form 5 August 2005; accepted 8 August 2005
Available online 5 October 2005

Abstract

The prevailing Italian and Greek methodologies for seismic risk assessment are used herein to construct loss scenarios for the building stock of a small city (Potenza, Southern Italy). The inventory of buildings of interest is obtained from a survey carried out after the 1990 earthquake that struck Potenza and its hinterland, subsequently updated in 1999. About 12,000 buildings were surveyed in Potenza, using the Italian first level survey form for damage and vulnerability evaluation. In the Italian methodology, a hybrid technique is set up to evaluate vulnerability, combining an analysis of building typologies with expert judgement. The probabilistic distribution of damage is evaluated by assigning Damage Probability Matrices (DPMs) from the literature. Besides the vulnerability classes A, B and C of the MSK-scale, the class D of the anti-seismic buildings is considered and the relevant DPM is defined. Damage and economic loss scenarios relevant to dwelling buildings are constructed for three reference earthquakes. Next, the hybrid methodology for seismic vulnerability assessment of reinforced concrete (R/C) and masonry buildings developed at the University of Thessaloniki (Greece) is applied to the same building stock. The methodology combines available statistical data of damage collected after past earthquakes with a systematic nonlinear analysis of various "model buildings", representative of several vulnerability classes. Similarities, as well as discrepancies, between the two methods are discussed in the light of the obtained results, and possible sources for the discrepancies are suggested.

Keywords: Vulnerability; Seismic risk; Assessment; Damage scenario; Nonlinear analysis; Buildings; Concrete; Masonry

1. Introduction

The last decade or so has witnessed a growing interest in assessing the seismic vulnerability of European cities and the associated risk; not surprisingly this interest was stronger in Southern Europe where the largest part of the seismic activity in this continent takes place. As a result, a fair number of earthquake damage (loss) scenario studies appeared over this period [4,5,10,14,15,19,25] wherein some of the most advanced techniques have been applied to a number of European cities (or parts thereof). Whereas risk analysis refers to all the possible arriving earthquakes, estimating the probability of losses over a specified period of time, scenario studies refer to a given earthquake (maximum credible, standard design, frequent) and provide a complete picture of what happens when such an earthquake occurs. Combined with GIS technology they are also powerful tools to check and visualise the effects of any risk mitigation strategy.

Earthquake damage scenarios can be referred to different kinds of damage and losses. Consequently, preparing a scenario requires contributions from a wide range of topics and disciplines, spanning from Seismology and Geology to Structural and Geotechnical Engineering, from Urban Planning and Transport Engineering to Social and Economical Sciences. However, it often happens that each specialist interacts very little (if at all) with the other specialists. Furthermore, each country has its own specifics for the numerous aspects involved by seismic problems, such as: characteristics of structures, seismological features of the territories, socio-economical conditions, etc. Even in Europe, where common cultural roots and similar characteristics of structures could make the exchanges easier and very fruitful, it is difficult to find a

* Corresponding author. Tel.: +30 31 995 743; fax: +30 31 995 614.
E-mail addresses: dm142ing@smtp.unibas.it (M. Dolce), ajkap@civil.auth.gr (A. Kappos).

0141-0296/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2005.08.009

common language among researchers from different countries, to exchange data and, finally, to set up common approaches to risk mitigation.

To this purpose, earthquake damage scenarios relevant to the case study of Potenza, a small city in Southern Italy, have been prepared using different methodologies that can be considered as the prevailing ones utilised in Italy and in Greece. The main objectives of this study, part of which was developed in the framework of the EU-funded ENSeRVES Project [16], are:

- to compare vulnerability and damage assessment procedures for residential buildings in the two countries;
- to identify similarities and differences in databases on damage from past earthquakes;
- to suggest possible improvements in vulnerability assessment procedures for buildings through the integration of different approaches (statistical, mechanical, expert-heuristic, etc.).

It is pointed out here that in the remaining of this paper reference to the 'Italian' and 'Greek' methodologies for vulnerability assessment, should by no means be construed as implying that these are the only methods used in either country; other methods have also been suggested and used, particularly in Italy. Having said this, the methodology based on damage probability matrices is by far the most commonly used in scenario studies, both in Southern Europe and in most of the remaining world, while the particular DPMs used herein are certainly the ones predominantly used in either country.

Earthquake damage scenarios relevant only to building damage and the associated economic losses are presented in this paper. As is typical in the preparation of earthquake damage scenarios [13], they are based on information regarding: (i) the characteristics of ground shaking in the area under consideration, i.e. the consideration of a maximum probable or maximum credible earthquake based on the results of seismic hazard studies; (ii) the description of the seismic vulnerability of the buildings of interest, i.e. the probability of damage to given building types for a given ground shaking; (iii) the inventory of the buildings of interest, i.e. location and characteristics of buildings.

2. Typological analysis of the building stock

The preparation of the earthquake damage scenarios is based on a comprehensive inventory of buildings, obtained from a survey carried out after the 1990 earthquake that struck Potenza and its hinterland, whose local magnitude was $M_l = 5.2$ [3]. The maximum intensity felt in nearby villages was VII on the MCS scale.[1] Following the earthquake, a survey in 41 villages was carried out by local engineers and architects, under the co-ordination of the Regione Basilicata, with the co-operation of the Civil Protection Department and the Italian National Group for the Protection against Earthquakes (GNDT). 21 villages, where intensity was estimated between VI and VII (MCS) in the post-event macroseismic survey, were fully surveyed. The surveyors used the first level GNDT90 inspection form,[2] for damage and vulnerability evaluation. About 50,000 buildings were surveyed, 12,000 of which were in Potenza. In addition to damage data, geometrical and qualitative characteristics were collected, such as height, configuration in plan and elevation, age, type of vertical and horizontal structures, type of foundation and of roof, retrofitting (if any), state of preservation, etc. [14].

In 1999 that inventory was updated with data relevant to R/C buildings built after 1990. The update was carried out by the DiSGG of the University of Basilicata, on the basis of the technical documentation provided by the Municipality of Potenza. In this case too, the data were collected using the first level GNDT90 inspection form. About 300 buildings were surveyed, with about 1500,000 m^3 total volume. The smallest R/C structures, mainly situated in rural zones, were not considered.

More details on the characteristics of the building stock obtained from the two surveys can be found in Dolce et al. [14, 17], where the database obtained merging the two surveys has been examined to obtain a complete description of the Potenza building stock.

The property status, as well the use, of buildings is mostly private (about 95%), only a small percentage of buildings being public property. Surprisingly high percentage (about 50%) of buildings used for production activities, as classified in the 1990 survey, was noted [14]. What really happens, in many cases, is that they are very small structures separated from the main building and used as agricultural warehouses or garages.

In this paper, only the largest (private and public) buildings are considered, leaving out the smallest rural masonry structures, thus resulting in an inventory of about 9000 buildings.

The composition of the building stock is very different, depending on whether the number or the volume of the buildings is considered. In terms of *number* of buildings, the sample is mostly made of masonry (62%) rather than R/C structures (36%). On the contrary, in terms of *volume* there is a strong prevalence of R/C (66%) over masonry structures (33%). It has to be noted that a very limited number of steel and mixed (masonry and R/C) buildings is present in the building stock of Potenza. With regard to the structural type, most masonry buildings have vertical load bearing elements made up of not hewn (rubble stone) masonry, called "sacco", whereas most R/C buildings are frame structures.

[1] The MCS scale is a 12-point scale still in use in Italy, mainly by seismologists. Set up by Mercalli, Cancani and Sieberg in 1912, it is rather different from the MM and EMS scales. The following relationship can be established among MCS and EMS (or MSK) values [27]:

$$I_{MCS} = 1.17 * I_{EMS} - 0.76$$

hence, for example VII on the EMS is equivalent to VII–VIII on the MCS.

[2] The first level GNDT90 inspection form is a vulnerability and damage survey tool widely used in Italy. The form contains data on building identification, dimensions, age, conditions, vertical and horizontal structural type and roof type, damage to structural and non-structural elements.