SEISMIC VULNERABILITY OF HISTORIC CENTRES: THE CASE STUDY OF NOCERA UMBRA, ITALY

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SUMMARY

The paper presents the case study of the seismic vulnerability assessment of the Historic Centre of Nocera Umbra, Italy. The proposed procedure used for assessing this kind of problem, is the TOSQA 99, developed by the authors and already applied in several occasions. After an introduction to the methodology, the constructive and typological characteristics, are discussed and the results achieved, in terms of vulnerability, will be compared with those on damage, surveyed in these building after the last earthquakes. This comparison will help to focus the reliability of the procedure and its possible further improvements.

1. THE VULNERABILITY ASSESSMENT METHODOLOGY

1.1 Methodological approach

This methodology, presented in 1995 ?1? and first applied in 1996 in a district of Lisbon ?2?, was used in 1997, following the Umbria-Marche earthquakes, to carry out a comparative assessment of three historic centres (Nocera, Assisi and Sellano) ?3?, and a study on different building typologies ?8?. More recently the procedure has been reviewed and further data on damage and vulnerability have been collected in the historic centre of Nocera Umbra ?6?.
Differently from other statistical procedures ?4? ?5?, this methodology is aimed at satisfying the necessity of carrying out extensive surveys without renouncing a mechanical interpretation of the seismic behaviour of masonry buildings. Its approach is based on a simplified analysis of the structural characteristics of the buildings. The data to be collected during the on site inspection are reduced to just those which can qualify the seismic performance of masonry

buildings and which, at the same time, can be surveyed from the street. For this reason, the on site inspection is quick but at the same time extensive, and it collects meaningful information all referred only to the external features of the buildings, without getting inside.

According to this criterion, the block shape, the building position within it, number of free walls and floors, and so on, can give precious indications for what concerns the intrinsic level of vulnerability of the structures, especially in terms of likely mechanisms. The on site survey is also aimed to register the damage level, for each building, in a post earthquake situation. This aspect represents an important step in vulnerability assessment, because it enables to obtain correlation curves between the earthquake intensity with damage levels, therefore showing a sort of damage scenarios.

In a further development of the procedure [6], the criterion for assessing the damage has been widened in order to associate, when possible, the failure mechanism/s occurred in the buildings. Therefore, the damage assessment is not intended like simple registration of its entity and or extension, but can tell something more, implicitly suggesting a simplified structural interpretation of what is happened in a structure.

The basic tool by which the seismic performance of a building is analysed, under a structural point of view, is represented by the identification and forecast of possible failure mechanisms. This tool offers a sort of "*mechanical dictionary*" through which it is possible to examine, in a simplified and reliable way, the way of damaging of masonry constructions.

1.2 Failure mechanisms calculation

In a pre-earthquake situation, the forecast of the more likely forms of collapse, which could be triggered in occasion of a future seismic event, is obtained by means of load factors associated with the calculation of some chosen mechanisms, carried out on the basis of the limit state analysis.

The capacity of a building to resist to an earthquake is measured by the ESC, equivalent shear capacity, measured like percentage of gravity acceleration. This index, which represents the minimum equivalent static acceleration borne by a given structure, is directly obtained by calculations of mechanisms.

Although the damage survey, after an earthquake, has been organised in order to recognise a wider range of failures (up to 25) [6], the analytic formulation proposed in this application takes into account four common kinds of collapses (Figure1):

- A1 – Overturning of the entire wall;
- A4 – Vertical arch effect (due to constraints at the top of façade, like ties or ring beam)
- B2 – Overturning of upper portion (due to lateral constraints like effective quoins)
- C3 – Horizontal arch effect (associated to the lateral action of transversal walls or ties)

The possibility of triggering for each of these mechanisms strictly depends on the presence of constraints in each wall. As a matter of fact, while the first mechanism, the simplest under an analytic point of view, only depends on the slenderness of the wall, the others three rely each on the presence of specific strengthening devices (like ties, strong quoins).

The four mechanisms are calculated on the basis of rigid blocks kinematisms, therefore assuming the masonry able to develop sufficient cohesion, within its thickness, which only an ideal prototype of opus quadratum can ensure.

The real mechanical quality of the masonry and its level of maintenance surveyed in each sample have been here simply taken into account through a reduction of the effective wall thickness.

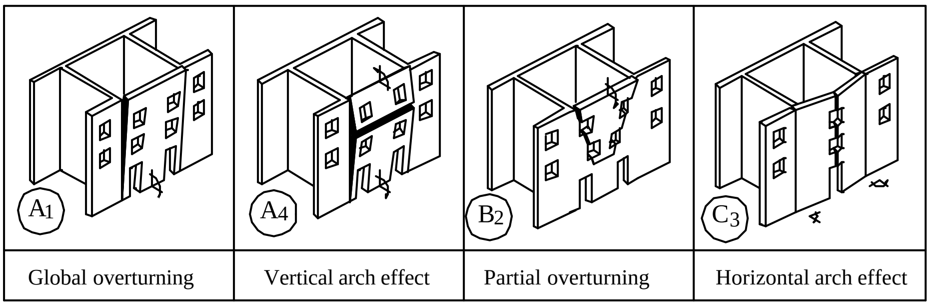

Figure 1 : Failure mechanisms considered in the analysis

1.3 Vulnerability calculation

It is assumed that mechanisms A1, A4, B2 are mutually exclusive, while mechanism C3 can always be calculated. It is further assumed that the mechanism yielding the smallest ESC between the first group and C3, would be the one occurring.

The seismic vulnerability is calculated like the inverse of ESC, and it can be described by four classes, as below specified:

??	Low	$0<V<5$
??	Medium	$5<V<10$
??	High	$10<V<20$
??	Very high	$20<V$

This index can give precious information if combined with the identification of the failure mechanism given by ESC. As a matter of fact, the vulnerability level, obtained in this way, is able not only to express a qualitative judgement, but also to identify, even if in a restricted range, the way of damaging which the building, more likely, will undergone, in occasion of a future event.

This kind of approach could represent a very useful tool for urban planning aimed at seismic mitigation. The identification of the level of vulnerability, combined with the failure mode, for each building, could offer valuable information for strengthening policy at urban scale.

2. APPLICATION OF THE PROCEDURE TO THE CASE STUDY OF NOCERA UMBRA

2.1 Nocera Umbra: buildings typology and structural characteristics

Nocera Umbra is situated on the top of a hill, positioned between the Appenines chain to the East, the Subasio Mountain, the West. The Gualdo plain stands by north, and toward south the

Topino valley with Foligno are placed. Geologycal characteristics are typical for a hill-mountain centre, with limestone foundation soils, with detritus material along slopes.

The urban planning, composed by around 220 buildings, is typical of a medieval town, with buildings arranged in long parallel and almost concentric arrays, following the isoslope curves. Latter interventions, mainly due to historic earthquakes occurred in XVII and XVIII centuries, have however modified the plan with diffused reconstruction and alterations to the original plan.

The typical ordinary houses of Nocera, show a typological design which completely fit with the natural features of this area: the presence of a marked slope, has strongly conditioned their constructive aspects. The buildings are arranged in arrays, usually quite long, with linear or curvilinear shapes. Middle buildings are each other attached, with just two free walls. Particles placed at extremities show instead 3 free walls.

The typical living building is arranged in 4 or 5 storeys, and its internal distribution is generally conditioned by the slope: the lowest level show just one side free, being its back facing the rock, while the upper levels, have a double front.

2.2 Characteristics of the surveyed buildings.

In a recent on site inspection, carried out in the Spring 1999 ?6? a detailed survey was carried out in 3 different blocks, within the historic centre of Nocera, in order to deepen the structural characteristics and in the same time to enable the collection of data necessary to establish a comparison between this procedure with other methodologies ?7?.

The three blocks show different shapes in plan and are composed by buildings with rather typical characteristics within Nocera. The buildings, identified by the number of cadastral particle, are in total 8, respectively:

- *Building 382*: it is placed at the end of a block, so it shows three sides free, and one in common with the rest of the block. It is realised by two storeys. In plan it is composed by three attached masonry cells. Horizontal floors are not original, and are realised by SAP structures.
- *Buildings 394*-395-396: These three particles form a block in the east side of the town-hill. The buildings are with two full storeys at upper levels, while the lowest is set back to the hill. Masonry typology show at least two variety: a very rough masonry with rubble while the other kind is of roughly squared stones. The level of connection within the thickness in both the cases is rather poor. Horizontal slabs are mostly wooden, a part from some cases in which they have been substituted by new typologies.
- *Buildings 143*-144-145-180: These four particles are placed along a circular array and are also positioned in the east side of the hill. In this case the slope is very emphasised because they show two full storeys and, back to the hill, up to 5. The metallic ties are here rather diffused, especially in particle 145. Other buildings like 180 and 145 show a visible condition of neglecting and alteration to masonry integrity. Differently, particles 144 and 145 show recent signs of restoration and strengthening. The slabs, in these cases, have been substituted by concrete ones, in almost all the storeys.

2.3 Calculation of failure mechanisms

The mechanisms of figure 1 have been calculated for all the walls of each building. Although the procedure has been appositely developed for external walls, in this case, because of the detailed measurement of the 8 buildings available, the vulnerability has been assessed in whole the building. The calculation of failures has been developed, once having checked the possibility of occurrence of every specific mechanism for every wall, as the mechanism triggering strictly depends on the constraints conditions. In figure 2 the calculated value of the equivalent shear capacity ESC, for each wall of the 8 buildings, have been sketched, in function of the slenderness of each wall. This one is given as ratio between the total height of the wall and its thickness at the basis.

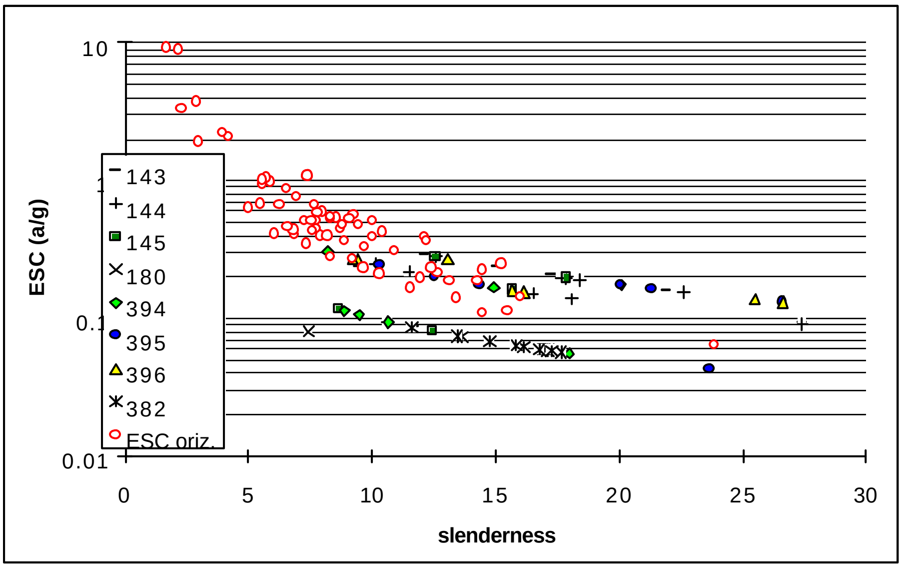

Figure 2 : Distribution of ESC calculated for every wall of the 8 buildings, in function of its slenderness

2.5 Vulnerability assessment for the 8 buildings

The vulnerability calculated for the 8 buildings, according to the criterion exposed in paragraph 1.3, shows a rather weak capacity of these buildings to resist to a future earthquake. The table 1 clearly shows the results obtained for each building.

				Forecast damage		**Surveyed damage**		
Build.	**ESC**	**V**	**V-Class**	**Orient.**	**wall**	**Orient.**	**wall**	**Dam**
143	0.091	10.9	Medium	South	Internal	West	External	D3
144	0.094	10.6	Medium	West	External	West	External	D1
145	0.059	16.9	High	East	External	East	External	D3
180	0.08	12.5	High	North	Internal	East	External	D4
394	0.055	18.2	High	East	External	East	External	D5
395	0.131	7.6	Medium	North	Internal	North	Internal	D4
396	0.076	13.1	High	South	Internal	South	Internal	D4
382	0.056	17.8	High	West	External	East	External	D3

Table 1 – ESC, Vulnerability and surveyed damage for the 8 buildings.

3. CORRELATION BETWEEN FORECAST AND SURVEYED DAMAGE

The table 1 shows that a good correlation between vulnerability and observed damage, can be found for some of the buildings, such as the 143,180,394 and 396. In these cases the level of calculated vulnerability fully fits the level of surveyed damage. The choice of the most vulnerable wall is instead correct for buildings 144, 145,394,395 and 396. This means that for buildings 394 and 396 the forecasts, as regards both vulnerability and damage position, were totally fulfilled. Moreover, the building 382 shows a rather homogeneous level of vulnerability in all its walls, therefore the choice of the most damaged wall can be considered however succesful. In order to define the reliability of these evaluations, the results achieved in terms of vulnerability, compared with the surveyed damage, are put in relation with the regression curves of vulnerability/damage found out for the whole historic centre of Nocera Umbra after the 1997 earthquake. The results of this comparison are drawn in figure 3.

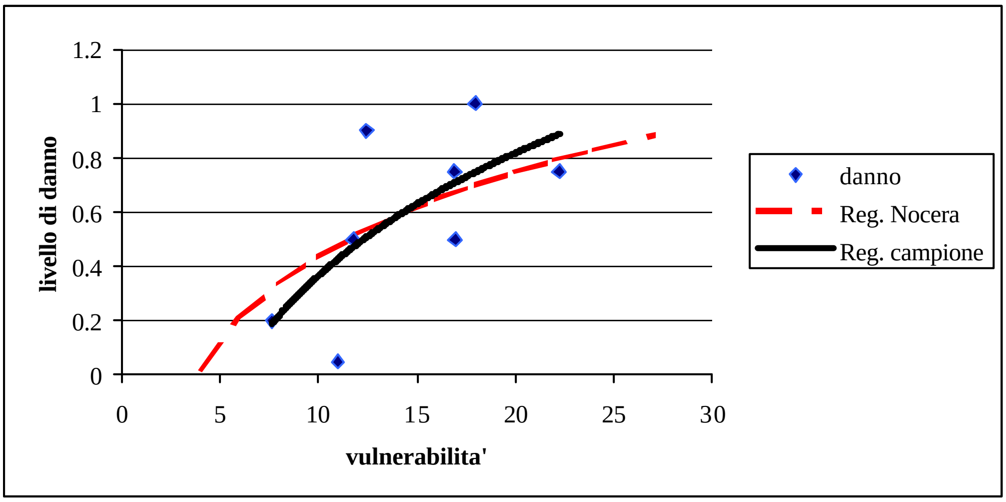

Figure 3 : Relation between vulnerability/damage of the 8 surveyed buildings with the correlation curve found out after 1997 earthquake.

4 ACKNOWLEDGEMENTS

The authors wish to thank the EPSRC (British research Council), and CNR (Italian Research Council), who have supported this research.

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