EUROCODE 8 AND ITALIAN CODE. A COMPARISON ABOUT SAFETY LEVELS AND CLASSIFICATION OF INTERVENTIONS ON MASONRY EXISTING BUILDINGS

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ABSTRACT
The Eurocode 8 will probably come into effect all over Europe in the next years, substituting all the national codes. EC8 is quite difficult to be applied in Italy due to the presence of existing masonry buildings, aggregated buildings in the characteristic historic centres and of cultural heritage. This paper deals with the problem of the safety level of these buildings that should depend on the class of the intervention and the artistic and cultural importance of the construction, just like the Italian Code permits.

KEYWORDS
Seismic upgrading, seismic improvement, aggregated buildings, preservation, safety level.

1 INTRODUCTION
Considering the forthcoming introduction of the Eurocodes as prescriptive Italian reference about constructions, there will be soon the problem of coordination of the Italian existing standards with the Eurocodes. This problem becomes particularly evident in the arguments discussed in this paper: safety levels and classification of retrofitting interventions of existing masonry buildings located in seismic zones.

The Eurocode dealing with these arguments is Eurocode n. 8, particularly:
- EN1998-1 (definition of seismic action)
- EN1998-3 (existing buildings)
- Italian national annex regarding EN1998-1

In Italy, only in the last five years, a lot of standards and guidelines dealing with the above mentioned arguments have been introduced. Specifically it’s worth to remember:
- Technical Rules for Constructions, proclaimed in 2008 (shortly named NTC 2008);
- OPM n. 3274 (2003), updated with OPM. n. 3431 (2005);
- Guidelines about the preservation of historical and architectonical heritage;
- Rules DT/200 by National Research Council (CNR) dealing with the utilization of composite materials in retrofitting of existing buildings.

The whole of this standards and rules, more advanced than the Eurocodes dealing with these arguments (specifically Eurocode n. 8), is a legacy of knowledge deriving from the Italian
seismic recent experiences (just like the Umbrian earthquake of 1997 and the Molise earthquake of 2002). This knowledge is not to waste because it will be precious in the next reconstruction after the last destructive earthquake that hit L’Aquila.

Among the most significant aspects faced by the Italian Code and ignored by the Eurocode n. 8, it is possible to remember, above all:

- the deep attention dedicated to the question of masonry and its quality;
- the classification of the intervention in “seismic upgrading”, “seismic improvement” and “local interventions”, depending on basic criteria of extension of the intervention, transformation of the original behaviour of the construction and safety levels to be performed;
- the case of aggregated buildings is discussed; this is a typical configuration in the Italian historic centres;
- the case of historical and architectonical heritage is discussed; this is another typical problem of retrofitting of buildings;
- safety factors depend on knowledge of the construction; three levels of knowledge has been defined; in such a way there is a direct correspondence between safety and knowledge;
- a range of possible values of the principal mechanical parameters are defined for masonry;
- the most common techniques of intervention are shortly explained.

The following sections deal with some of the aspects above introduced. Their aim is to show that Eurocode n. 8 needs a deep updating before being used concretely in the Italian reality.

It is remarkable that all what is written in this paper may be a problem not only in Italy. In fact there are other seismic zones in Europe with many existing masonry buildings. This is quite evident looking the Figure 1.
2 THE QUALITY OF MASONRY AND OF THE CONNECTIONS BETWEEN ELEMENTS OF THE BUILDING

The quality of masonry plays a fundamental role in determining the capacity of a construction to oppose to seismic action. This problem cannot be studied only in terms of stress and strain: a masonry which can resist and transfer the vertical and seismic forces without breaking up should have geometric and physical characteristics that permit a monolithic behaviour.

Among the features which the Italian code requires to consider (and model) a masonry like a “good quality” one, we can remember now: horizontal courses, not-aligned mortar vertical joints, square-shaped and big stones or bricks, presence of transversal connections in multi-leaf walls, good quality of mortar and, obviously, an adequate strength of the brick or stones.

<table>
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<tr>
<th>High quality masonry</th>
<th>Medium quality masonry</th>
<th>Poor quality masonry</th>
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Figure 2. Example of out-of-plane behaviour of high, medium and poor quality. High quality masonry has a monolithic out-of-plane behaviour. In the medium quality masonry there is a lack of monolithic out-of-plane behaviour. Poor quality masonry produces a complete disintegration of the wall.

A good quality of the connections between floors and walls, between roof and walls and between crossing walls is also crucial to reach a good global seismic behaviour of the building. Good quality connections will drive the collapse of the construction to a configuration that requires a stronger seismic action.
3 SAFETY LEVELS DEPENDING ON THE CLASS OF INTERVENTION

Italian code considers different safety levels to be reached depending on the typology of intervention that is going to be realized on the building. In fact, the Italian code states a fixed safety level which has to be necessarily reached only in case of “seismic upgrading”, that is in case of heavy and wide interventions (see hereinafter). In case of “strengthening” or “localized intervention” it is necessary only to prove that the safety level of the building will effectively be improved in consequence of the intervention.

The classification of interventions stated by the Italian Technical Code for Constructions (paragraph 8.4 and paragraph C8.4 of the Circular n. 617/2009) is the following:

seismic upgrading
- A determined safety level has to be pursued. It is quantitatively defined in terms of PGA depending on the estimated life of the structure, the utilization and importance of the construction, its geographic site, etc…
- The whole building has to be modelled and checked.

seismic improvement
- In consequence of the intervention it is necessary to obtain an higher safety level than before the intervention. The safety threshold to be reached is not a priori fixed.
- Safety level valuation concerns the whole building.

local intervention
- In consequence of the intervention it is necessary to obtain an higher safety level than before the intervention. The safety threshold to be reached is not a priori fixed.
- Safety level valuation is “localized” to the element or area of intervention.
It is possible to illustrate a list of some of the most frequently realized interventions on existing masonry buildings classifying each intervention in one of the three above mentioned categories. In this way it will be evident the richness and variety of the effective situation of existing masonry buildings and the need of differentiate the various situations.

3.1 Seismic upgrading interventions
Among the seismic upgrading interventions (paragraph C8.4.1 of the Circular n. 617/2009) appear the following interventions:
- Addition of stories over an existing building;
- enlargements of the building;
- introduction of a new floor at an intermediate quote;
- introduction of independent and important structures into existing constructions;
- construction of underground rooms under existing structures;
- demolition and rebuilding in a different position of a large quantity of main walls;
- realization of seismic joints in order to divide the original building into two or more separate buildings.

3.2 Seismic improvement interventions
Among the seismic improvement interventions (paragraph C8.4.2 of the Circular n. 617/2009) appear the following interventions:
- demolition and rebuilding of some main walls in the original position but with significantly different stiffness and strength, so that the global seismic behaviour of the structure will be significantly changed;
- construction of new main walls which significantly modify the seismic behaviour of the original structure;
- construction of stairs that cause a significant mass or stiffness variation;
- construction of elevators structurally connected to the existing building if the elevators have a very stiff structure;
- systematic substitution of floors and roofs involving a significant stiffness variation or a weight increase;
- systematic strengthening of the masonry walls (i.e. shotcreting by steel wire mesh attached to the existing wall with through-wall ties; grouting with cement grout) on a large number of walls so to significantly modify the stiffness-ratio between the main walls and the distribution of the seismic action.

3.3 Localized interventions
Among the seismic “localized interventions” (paragraph C8.4.3 of the Circular n. 617/2009) appear the following interventions:
- repair or substitution of a single damaged element on condition that the global seismic behaviour of the structure will be not significantly changed (i.e. substitution of lintels, beams, walls, floor or roof on a single room);
- total substitution (on the entire level) of floors or roof without a significant stiffness variation of the floor or roof and without weight-increase;
- construction of little stairs without involving significant variation of stiffness and mass;
- repair or strengthening of the floor-to-walls and wall-to-wall connections;
- installation of metallic ties;
- localized strengthening of floors or roof by the installation of a new concrete slab atop the existing floor. The slab has to be well anchored to the existing main walls.
3.4 The EC8 point of view

Compared to all this cases discussed by the Italian Code, the Eurocode n. 8 (EN1998-3), on the contrary, seems to be quite rigid and inadequate. EN1998-3 states only a single procedure for retrofitting of existing (masonry) buildings and it always states to reach a fixed safety level for every typology and extension of the retrofitting intervention.

In the section 6.1 of EN1998-3 it is possible to read:

" 6 Design of structural intervention
6.1 Retrofit design procedure
(1) The retrofit design procedure shall include the following steps:
   a) Conceptual design,
   b) Analysis,
   c) Verifications.
(2) The conceptual design shall cover the following:
   (i) Selection of techniques and/or materials, as well as of the type and configuration of the intervention.
   (ii) Preliminary estimation of dimensions of additional structural parts.
   (iii) Preliminary estimation of the modified stiffness of the retrofitted elements.
(3) The methods of analysis of the structure specified in 4.4 shall be used, taking into account the modified characteristics of the building.
(4) Safety verifications shall be carried out in general in accordance with 4.5, for both existing, modified and new structural elements. For existing materials, mean values from in-situ tests and any additional sources of information shall be used in the safety verification, modified by the confidence factor CF, as specified in 3.5. However, for new or added materials nominal properties shall be used, without modification by the confidence factor CF.
(5) In case the structural system, comprising both existing and new structural elements, can be made to fulfill the requirements of EN1998-1: 2004, the verifications may be carried out in accordance with the provisions therein ".

The comparison between the Italian Code and the Eurocode n. 8 is resumed in the flow-chart reproduced in Figure 5.

4 THE CASE OF CULTURAL AND ARTISTIC HERITAGE

The Italian body of laws and codes about constructions faces the problem of the artistic buildings in the “Guidelines for valuation and decrease of seismic hazard of cultural heritage referring to technical construction code”.

The purpose of the Guidelines is to match seismic-safety requirements with preservation requirements when the building is a unique and unrepeatable artistic construction. In fact, in such an eventuality, it is necessary to graduate the safety level of the intervention to be the highest possible without modify (or, at worst, damage) the nature and the characteristics of the protected building.

The Italian Guidelines for cultural heritage are based on this concept. The Guidelines, in fact, direct the attention to seismic improvement rather than seismic update interventions because seismic improvement does not imply any fixed safety threshold achievement. The only law prescription is to demonstrate that, in consequence of the intervention, the safety level increases.
In Guidelines much attention is pointed on relief and knowledge of the building, safety calculations to be performed, an adequate structural model (i.e. cinematic model) and monitoring the building after the realization of the intervention.

Seismic design actions depend on the importance of the artistic building and its utilization-class (occasional presence, frequent presence, very frequent presence).

In order to prevent the seismic collapse of objects and decorations in the building, an appropriate “artistic limit state” (SLA) has been introduced in the guidelines.

On the contrary, although EN1998-3 clearly admits (paragraph 1.1) that cultural heritage needs a different approach than ordinary existing buildings, no indication can be found in the European Code. It is evident from the flow chart in Figure 5.

Here the paragraph 1.1 of EN1998-3 is reproduced:

“(5) Although the provisions of this Standard are applicable to all categories of buildings, the seismic assessment and retrofitting of monuments and historical buildings often requires different types of provisions and approaches, depending on the nature of the monuments.”
It is hoped that such a gap will be corrected by releasing a specific Eurocode dealing with all the problems of cultural heritage in seismic zones, just like the Italian Guidelines.

5 AGGREGATION BUILDINGS

The Circular n. 617/2009 deals with one of the most important problems of the Italian buildings in seismic zones: the behaviour of aggregated constructions under seismic actions. It is a really frequent eventuality, specially in the historic centres deriving from a building process which lasts for centuries.

The aggregation could be defined as a construction delimited by open spaces (Figure 6). It is formed by Structural Units (U.S.) which could be defined as portions of the aggregation which have a unitary behaviour from a static and seismic point of view.

U.S. are defined thanks to structural criteria (i.e. a rigid floor defines a single U.S. or two parts with a different kind of masonry are two U.S.) and thanks to historical criteria, according to the age of construction of the several parts.

![Figure 6. Aggregation and structural unit.](image)

The analysis of a structural unit belonging to an aggregation is different than the case of an isolated building because of the several interactions that the adjacent buildings do on the structural unit which is analysed.

The basic structural interaction phenomena may be classified in two categories:

a) vertical loads or horizontal pushes (specially under the seismic action) coming from adjacent buildings;

b) buttressing or constraining effects offered by the adjacent buildings.

These interactions modify the collapse mechanism of the building introducing new different actions and changing the constrain configuration.

Hereinafter in the Figures from 7 to 10 some typical situations of interaction between aggregated buildings are listed.
Even in this case, EN1998-3 appears quite inadequate. In fact, the problem of aggregation buildings is faced only in the paragraph C.2.1 where it is only possible to read:

“(1) The following aspects should be carefully examined:

 […] omissis […]

vi. Information on adjacent buildings potentially interacting with the building under consideration”.

6 DIFFUSION OF SEISMIC IMPROVEMENT AND INTERVENTIONS ON CULTURAL HERITAGE

With the purpose of showing how frequent are the seismic improvement interventions in the Italian building praxis, some informations regarding the Umbrian 1997 post-seismic reconstruction are reported hereinafter (data by Provincia di Perugia).

In the time-extension from 2001.08.01 to 2006.12.31, in a sample of 1479 random-checked masonry buildings which suffered damage from earthquake of 1997, the intervention-design can be classified in this way:

- seismic improving: 1148 buildings (78%);
- seismic updating: 153 buildings (10%);
- rebuilt buildings: 178 buildings (12%).

Moreover on the total sample of 1479 buildings, the ones which are protected by special laws dealing with cultural and artistic heritage are 164 buildings (11%).

7 CONCLUSIONS

The EC8 in the current version is not appliable to all the Italian constructions. Particularly it is difficult to design a retrofitting intervention of an existing masonry buildings (the most diffused and the most seismic vulnerable typology of building in Italy). The paper focuses on three questions that should be resolved: the absence, in EC8, of a graduation of safety levels depending on the class of the intervention, the absence, in EC8, of any indication about preservation techniques of the buildings belonging to cultural heritage and, finally, the absence, in EC8, of any indication about aggregated buildings of historic centres. The paper
indicates a simple solution of the mentioned problems: to update EC8 taking into account the recent Italian Codes. This should be done before EC8 come into effect, at least in Italy, where the Abruzzi reconstruction is now starting, even if the problems may concern other European nations.

8 REFERENCES

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