Emilia earthquake
What do we learn and what we already knew

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Abstract: A 5.9 Mw and 5.8 Mw earthquake hit the Emilia-Romagna, region of Italy, on 20th and 29th May 2012 causing 26 casualties, around 350 injured, more than 16000 homeless, an estimated damage of 13 billion and 273 million euro and an economic damage greater than 13,2 billion euro.

As for every strong seismic event, the consequent damage scenario is a lesson for the engineering community where well-known concepts are largely confirmed, some aspects are underlined, and new ones appear or gain relevance. The Emilia earthquakes mainly pointed out as a new aspect the role of a seismic design also for industrial buildings; well-known aspects concerning the behavior of masonry structures have been largely confirmed.

The scenario encountered during one week of post-earthquake assessment made almost one month later the main shocks occurred on the 29th of May is here described.

The field mission, performed on behalf of the Italian Civil Protection, aimed at estimating the safety of private buildings; buildings that in most of the cases, at the moment of the visit, were still inhabited. Three are the questions that the owners of the inspected houses more frequently were asking: “Is this dangerous?”, “What can I do to make my house safe?”, “Come, have you see what happened here?”.

The abacus of damages that we encountered confirms concepts concerning the seismic behavior of masonry structures already observed in 2008 l’Aquila earthquake as well as in 1997 Umbria - Marche events, in particular for those structures characterized by low material quality and structural details.

Three frequent and important questions: three questions whose answers are also well known.

Keywords: post-earthquake assessment, masonry structures, earthquake engineering.

Introduction
A 5.9 Mw earthquake struck the city of Finale Emilia on the 20th of May 2012 causing 7 fatalities, significant damage to historic structures, churches and industrial buildings, leaving 7000 people homeless. A 5.8 Mw event in the same zone (in particular with epicenter in the city of Medolla) on the 29th of May 2012 caused an additional twenty deaths and widespread damage, particularly to buildings already weakened by the previous event. The estimated economic damage from the two combined seismic events is greater than 13,2 billion euro.

The affected area was not completely new to seismic shocks: the city of Ferrara in particular had already experienced with a strong earthquake on November 1570, followed by a long and destructive swarm with over than 2000 aftershocks that lasted till February 1571. The disaster destroyed half the city, permanently marked many of the buildings left standing.

Also recent studies (CARMINATI et al. 2007) had underlined the seismic hazard of the zone (see Fig.1).
Fig. 1 - Tectonic map showing the location and extension of potentially active faults in the Po Plain area. In parenthesis, the year of the last known large earthquake associated to the fault (if known), and the maximum expected magnitude (CARMINATI et al. 2007).

Nevertheless, the scenario observed during a field mission on the zones struck by the 2012 earthquakes reveals that in most of the cases the quality of the structures and materials as well as their structural details was not appropriate to withstand seismic loads. These aspects concern ordinary private buildings, public and industrial ones.

The “in-situ” mission was performed on the cities of Finale Emilia and Ferrara almost one month after the last strong event of the 29th of May 2012 on behalf of the Italian Civil Protection. It aimed at estimating the safety of private buildings; buildings that in most of the case, at the moment of the visit were still inhabited. The assessment was performed filling the so-called AeDES (Agibilità e Danno nell’Emergenza Sismica, fitness for human habitation and damage after seismic emergency) form that is a printed form developed by GDNT (Italian national seismic protection group) for damage assessments after an earthquake emergency.

The following paragraphs present the different typologies of structures encountered and the structural and non-structural damages, observed. No infrastructures, nor public structures, nor industrial buildings were inspected. While for industrial buildings the damage pattern resulted in some way “new”, the scenario observed visiting private buildings confirmed what already seen and learnt from past events as l’Aquila and Umbria-Marche earthquakes.
Finale Emilia
The epicenter of the 20th of May 2012 event was between Finale Emilia and San Felice sul Panaro. Therefore the city suffered a heavy level of damage. Most of the structures visited were two floors brick masonry buildings with reinforced concrete slabs and roof (wood slabs and roof in only one inspected structure), built around 80s or even more recently. During the investigations it was possible to compare the behaviour of the structures with poor quality and lack of adequate structural details (all of them classified as not fitness for human habitation) and the ones with a more accurate and appropriate seismic design, that were clearly safe and even not damage despite for the cases in the proximity of the epicenter. It must be noted that the structures which develop a good response to the earthquake loads are mainly brick masonry structures built before 2003 i.e. before the seismic design became compulsory also for this kind of structures in this region (BRACCHI et al. 2012). This aspect pointed out once again as, in absence of a seismic design, the quality of materials, the structural details and the global structural behavior play a fundamental role in the resisting mechanism against earthquake loads.

Typologies of structures and damage pattern
For reader’s convenience, in Fig. 2 are recalled the well know idea of box behavior (as simplified by Antonino Giuffré, 1991) that allows a structure to better withstand the seismic loads (left) and the most common damage patterns induced by an earthquake when seismic design is not appropriate (right).

Fig. 2 – Idealization of box behaviour from Antonino Giuffré (GIUFFÉ 1991) - left; typical damage pattern (BAGGIO et al. 2009) - right.

Fig. 3 presents a typical damage encountered during the inspection: crack opening at the interconnections among walls and among walls and slab. It is evident the absence of an appropriate interconnections among vertical elements themselves and among horizontal elements as is instead request for a box behavior design.

Fig. 4 presents other typical damages observed. On the left, damage types 3 and 5 of Fig. 2 are combined, i.e. the X-cracking in bearing wall and the cracking starting at the edge of openings. On the right, the failure of the masonry element under the window, another typical damage (see damage type 2 of Fig. 2).
During the survey, same typologies of structures as the ones reported in Fig. 3 and 4 that did not presented any relevant damage were also inspected. Fig. 5 represents one of those: a brick masonry structure built just in front of the structure in Fig. 4 (right). The two structures therefore experienced most likely the same acceleration and no soil reduction or amplification can be supposed. However, the one in Fig. 5 presented only some small and superficial cracks on internal walls. The structure was not design for horizontal loads (only for vertical) but, most probably due to the good quality of materials and of structural details, could resist in a better way to the earthquake loads.
**Ferrara**

The most frequent typology of structure encountered in Ferrara downtown is the historic brick masonry house with 3 or more stories and built between two adjacent buildings with shared common walls. The main facade of the house usually faces the narrow roads of the city center; the ground floor level (with openings on one side only) is used for storage, while the upper stories are used for residential purposes. All the walls are made of unreinforced brick masonry in lime mortar, while the floor resisting structures are vaults at the ground floor level, and timber floor structures at the higher levels (D’AYALA et al. 2002).

These structures date back to medieval age and usually present several “alterations” to the “typical housing” plan. The opening layout has been frequently modified over time, due to the continuous changes in the living requirements. A very common change is made at the ground floor entrance door which is widened in order to allow for car passage (D’AYALA et al. 2002).

The performance of those structures is not only influenced by their original intrinsic characteristics (and eventual retrofits, if applied) but also by the characteristics of the adjacent structures.

Fig. 6 - 11 presents a representative case in which the original configuration has been heavily changed involving a dramatic reduction of the global bearing capacity of the resisting system.

The structure has irregular wall texture and very low material quality. Fig. 6 on the left presents the wall texture on the external bearing wall where different typologies of brick and stones have been mixed. On the right instead a detail on how the stairs have been built, is reported. The structure is a mix of poor quality materials not properly joint together and that are already undergoing a degradation process.

From a static point of view, the structure has absolute absence of bearing capacity in one direction due to irregular-window openings or insertion of chimneys. In fact on the only bearing walls (the one marked in black in Fig. 7) an opening has been created (most probably for creating the access to a garage) and, on the upper part, the wall is reduced just to a fake layer that hides chimneys beneath.

Also the horizontal elements of the structure were in a state of degrade: the wooden slab (a very flexible one, already heavily inflected) was damaged and also wooden beams were cracked (see Fig. 8).

A rich abacus of damage was observed. In Fig. 9 are represented some examples of X-cracking on the bearing walls (damage type 3 on Fig.2). In the figure on the right, the crack is almost completely covered by the frames but it was cutting the wall from one edge to the opposite one.
Fig. 6 – Irregular and with poor quality wall texture.

Fig. 7 – Masonry structures with complete absence of resistant vertical elements due to irregular opening and hidden chimneys.
Fig. 8 – Damage on horizontal elements: wooden beam – left - and wooden slab – right.

Fig. 9 – X cracking on bearing walls.

Fig. 10 (on the left) presents the damage type 2 with crack opening under the window while on the left the crack interests the lintel as in type 1 Fig.2. Both those elements have almost completely lost their bearing capacity and they are still standing most probably thanks to the friction among the bricks.

In addition, non-structural damages could be observed; at the top level, almost everywhere the wattle ceiling was close to collapse (Fig. 10). Wattle ceiling or cannucciate, as called in Ferrara, is a very common practice in Ferrara historical houses: in most of them (in particular at the top floors) the slabs were hidden under a wattle ceiling where frescos were painted on. The most common way to make them is represented in Fig. 11.
The previous one is a very comprehensive example of structure that, due to its original design, to the state of degradation and to the structural modifications made with time, has not resistance against a strong horizontal load. Most probably the structure is still standing thanks to the containing effect provided by the adjacent structures that, although similar in typology and period of construction, had been recently retrofitted. The last ones did not experience any particular damage. An additional hazard for them is actually provided by the structure here presented with which they share at least one bearing wall.

In other structures surveyed in Ferrara, the damage was not particularly significant. In most of the case, the major hazard for the inhabitants was represented by the collapse of non-structural elements as the wattle ceilings, the skylight (see Fig. 13) or the fall of chimneys.
It is worth to recall also that in case of earthquake not only the structures represent a hazard but also the furnitures that are inside might be dangerous. To this purpose, is significant the example in Fig. 14. The picture, shot in one of the inspected structure, represents the effect of the earthquake on a heavy stove previously fixed at the wall: the restraint broke and the stove shifted almost 10 cm.

**Conclusions**

The aim of the paper is to describe the scenario encountered during one week of post-earthquake assessment made after the 2012 Emilia earthquakes in the cities of Novi di Modena and Ferrara. The abacus of damages that have been encountered confirms concepts concerning the seismic behaviour of masonry structures already observed in 2008 l’Aquila earthquake as well as in 1997 Umbria - Marche one, in particular for those structures characterized by low material quality and structural details. Structures with similar typology but with good quality of the material and with good structural details could withstand the earthquake, reporting minor (mainly non-structural) damages.
References


