Earthquake's effects on the Fabriano, Nocera Umbra and Sellano's buildings

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Summary
The damage data relevant to the buildings of Sellano, Nocera Umbra, Fabriano, where detailed microzonation investigations were carried out after the 1997 Umbria-Marche Earthquake, are presented. Some comments are provided on the most peculiar aspects of the seismic behaviour of some building types.

1. Introduction
The microzonation studies carried out in Sellano, Nocera Umbra and Fabriano, after the 1997 Umbria-Marche Earthquake, required a detailed analysis of the damage to buildings, in order to correlate damage state with possible amplification effects.

To this end, an extensive and exhaustive survey of the damage and the vulnerability characteristics of buildings was carried out in the areas subjected to detailed microzonation investigations of the municipalities of Sellano, Nocera Umbra and Fabriano. The damage data were collected on suitable survey forms, of the same type utilised for the post-earthquake inspections to check the safeness conditions of buildings [Martinelli, 1998]. They were also complemented with an exhaustive set of pictures for each building, illustrating their main characteristics and the most important damage. During the survey, the position of each building was reported on a map of the relevant area, so that the geographical distribution of damage is depicted for each investigated site. The damage data base, including the main items of the survey form and the pictures of each building, as well as the maps with the damage distribution, were collected in two CD-ROM's [Dolce, Larotonda, 1999]. A general overview of the damage produced by the Umbria-Marche Earthquake can be found in Dolce et al. [1998].

In the present paper the main outcomes of the damage survey are described and commented, paying particular attention to the most peculiar damage observed, which turned out to give important hints to reduce the seismic risk related to building vulnerability.

2. Damage to buildings in the historical centre of Sellano
Most of the buildings in Sellano were built approximately in the 13th century, but many of them were heavily modified during the 17th and 18th centuries. They were built with stone masonry walls made of a double masonry layer with very poor masonry filling in between ("a sacco" masonry type). Sometimes the outside layer is made of roughly squared stones. Original floors were built with wooden or iron beams or with brick vaults, while roofs were originally built with wooden structures.

The most superficial part of soil shows detrital sheets and embankments, that induced many local damage to buildings.

An extensive campaign of seismic retrofitting was started after the 1979 Umbria Earthquake. Most of the works were completed within 1986, although some buildings were still interested by strengthening works in 1997. The most usual works were vault strengthening, roof and floor replacement with R/C tile-lintel floor. R/C tie beams were inserted in masonry walls, in purposely made breaches. Sometimes masonry was also strengthened using cement mortar injection without any reinforcement, while mortar joints were almost always improved externally with cement mortar and strengthened with cement mortar plasters. In general, then, the buildings of Sellano, considering also the most recent ones, should have shown a good earthquake resistance, apart from the buildings having works in progress and the few old ones not retrofitted yet.

62 building structural units were surveyed, 1.6% of them (one structural unit) is made of R/C structure, while 79% is made of recent masonry or retrofitted masonry structure (with design actions at least equal to 0.28g), and 11.4% is made of original poor quality masonry structure, without any upgrading or with in progress retrofitting works.

In Fig. 1, damage to buildings is shown with coloured bullets (red: heavy damage to collapse, blue:

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moderate to heavy damage, green: no or light damage). Each bullet is referred to a single building, which can correspond to a structural unit or be a part of it. In the entire building population, only 1.6% had no structural damage, 27.4% had structural damage, 30.6% had moderate to heavy structural damage and 40.4% had very serious damage or collapsed.

From the above damage description, only the one reinforced concrete building had no damage, while all masonry buildings show at least light damage. Among them, those which were in bad conditions or even with strengthening works in progress or not completely built had very serious structural damage, while 26.5% of the new or retrofitted buildings were very seriously damaged, 38.7% had moderate to heavy damage and the remaining ones had just light to moderate damage.

It is, perhaps, striking that two third of the buildings that had to be very resistant to seismic actions underwent, instead, moderate to very serious damage. This aspect deserves a more detailed description of what actually happened.

The conditions of the retrofitted buildings after the September 26, 1997, shake were satisfactory until the October 14, 1997 shake. Actually, only one building was not usable. In this building the separation of a corner appeared, which was caused by the ground settling due to the movement of a retaining wall.

The October 14 shake, instead, produced a dramatic change of the damage conditions. As said above, serious and very serious damage occurred to most of the buildings of Sellano. A lot of total or partial collapses occurred in not retrofitted buildings, while in the retrofitted ones damage to “a sacco” masonry wall structures occurred, even if strengthened according to the above described techniques. Partial collapses occurred in two not yet completed buildings. Especially one of them was in a very delicate stage of the works, owing to the absence of a stairway, which made a load bearing wall very slender.

Damage can be ascribed to two types of causes:
Lack of resistance of masonry walls to in-plane and out-of-plane actions as well as to vertical loads, due to the very bad quality of mortar and the almost total absence of connection between the two outside wall facings;
Bad soil conditions, due to the steep slope and the relaxation of the embankments supported by retaining walls.

In both cases actions, like the replacement of original floors and roofs with R/C floors and roofs, as well as the introduction of breach R/C tie beams, limited or avoided the disjunction between the walls, producing an overall box-like behaviour of the building. However they were not able to avoid the damage to masonry walls, because of the low intrinsic resistance of masonry, but rather favoured this type of damage, because of the weight increase produced by the new heavy R/C horizontal structures. There were, also, some cases where parts of a big building were separated without producing any collapse, due to the improvement of the overall resistance.

In many cases, however, the inability of the strengthening interventions to avoid the separation between the two outside masonry layers of a wall produced some partial collapses and a lot of serious damage. In this respect, the use of tie beams in a breach, which extended at the only inside masonry layer, and without any swallow-tail anchor, was a wrong choice. In fact, it resulted in the lack of connection between the two wall layers, while the inner one supports the whole floor loads and is then subjected to buckling.

In some cases, it is possible to observe the separation of building parts constructed in different times and not well connected to the main body, either after retrofitting.
The two new building schools, placed in the SSW part of Sellano on an artificial embankment made on a heavy slope, had a lot of damage produced by foundation settlements. One of them had very serious damage, with partial collapses.

3. Damage to buildings in Nocera Umbra and its suburbs

The Municipality of Nocera Umbra has a large territorial extension, with many suburbs. It is important to focus the attention also to earthquake effects in some suburbs. The damage survey was, then, carried out in the town, as well as in the following nearby villages: Nocera Scalco, Stravignano, La Costa, Bagni, Isola, Le Molina, Pasciglione and Poggio Parrano.

The existing building stock is almost completely made of masonry buildings, often neither originally earthquake resistant nor upgraded. There are also some recent R/C buildings. The most usual strengthening works made on masonry buildings were the replacement of roofs and floors with R/C tile-lintel floor, the insertion of R/C tie beams in purposely made breaches, the remaking of plasters using cement mortar, sometimes reinforced with a steel grid.

401 buildings were examined, 91.75% having masonry structure, 5% R/C structure, 3% R/C-masonry mixed structure, 0.25% steel structure.

46.5% of the surveyed buildings suffered slight or no structural damage, 5.2% light to moderate damage, 20.6% moderate to heavy damage and 27.7% very serious damage.

It results from survey data that steel, R/C and mixed R/C-masonry structure buildings did not suffer structural damage. 52.7% of masonry buildings, seldom provided with any seismic resistance, presented damage from moderate-heavy to very serious, while 47.2% suffered no or slight damage.

Considering separately the suburbs and the historical town centre, the damage distributions summarised in Tab. I and illustrated in Figs. 2 to 9 are obtained.

Tab. I – Distribution of damage in Nocera historical centre and suburbs.

<table>
<thead>
<tr>
<th>Town or village</th>
<th>No. of buildings</th>
<th>Slight or no damage</th>
<th>Moderate to heavy damage</th>
<th>Very serious damage or collapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nocera historical town centre</td>
<td>181</td>
<td>53.6%</td>
<td>31.5%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Nocera Scalco</td>
<td>46</td>
<td>69.6%</td>
<td>15.2%</td>
<td>15.2%</td>
</tr>
<tr>
<td>Stravignano</td>
<td>29</td>
<td>63.6%</td>
<td>12.1%</td>
<td>24.3%</td>
</tr>
<tr>
<td>La Costa</td>
<td>58</td>
<td>60%</td>
<td>10.8%</td>
<td>29.2%</td>
</tr>
<tr>
<td>Bagni</td>
<td>8</td>
<td>25%</td>
<td>8.3%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Isola</td>
<td>48</td>
<td>8.3%</td>
<td>12.5%</td>
<td>79.2%</td>
</tr>
<tr>
<td>Le Molina</td>
<td>6</td>
<td>16.7%</td>
<td>16.7%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Pasciglione</td>
<td>14</td>
<td>35.7%</td>
<td>7.2%</td>
<td>57.1%</td>
</tr>
<tr>
<td>Poggio Parrano</td>
<td>11</td>
<td>33.4%</td>
<td>18.2%</td>
<td>45.4%</td>
</tr>
</tbody>
</table>

Fig. 2 – Nocera Scalco, structural damage.

Fig. 2 – Nocera Scalco, danneggiamento strutturale.
As far as Le Molina is concerned, only 6 buildings were surveyed, as the other ones had been already demolished at the moment of the survey. Considering also the demolished buildings as collapsed or seriously damaged, it can be supposed that about 90% of the buildings existing before the 1997 earthquake suffered very serious damage or collapsed.

The historical town centre of Nocera rests on a long-shaped north-southwards oriented hill. It presents a quite extended moderate to heavy damage and almost a total lack of collapses, except for the civic tower and a few other buildings. It must be emphasised that the buildings in the median part of the hill benefited of a widespread presence of iron ties, producing a good behaviour of masonry walls with respect to out-of-plane actions, showing also a fairly good box-like behaviour of all the buildings. The buildings on the hill slopes are partly built on the ancient city walls and partly on the embankment retained by the same walls and, for this reason, they suffered heavier damage. Their foundation soils are characterised by detrital layers and anthropical embankments, that sometimes have remarkable thickness. These footing conditions were responsible of most of the damage, coming from differential foundation settlement together with unfavourable vulnerability characteristics. They resulted in very critical situations, like the separation of whole façade walls.

As far as Nocera suburbs are concerned, according to the percentages given in tab. 1, the damage was heavier and more widespread on the average.

Bagni, Isola, Le Molina, Pascigliano and Poggio Parrano suffered widespread heavy or very heavy damage, that produced an extended condition of unusability for almost all buildings. Among these villages, Isola presents very heavy and extended damage to almost 80% of the buildings, with a lot of total and partial collapses, although many of them were subjected to retrofitting measures, which probably were not correctly designed and/or executed.

In Nocera Scalo, a village built on the Topino river alluvium, the average damage level was not very high, although the damage suffered by some masonry buildings was very serious. This is the case of a church, where the façade wall was completely separated from the remaining part of the building. The damage observed on a new earthquake resistant reinforced concrete building was emblematic. An incorrect stiffness distribution caused the shear failure at the top of all external columns on one side of the building, resulting in stirrup failure and concrete spalling.

Finally in Stravignano and La Costa damage to non-retrofitted buildings having a high vulnerability degree was observed.

Fig. 5 – Nocera Umbra historical town centre, structural damage.
Fig. 3 – Centro storico di Nocera Umbra, danneggiamento strutturale.

4. Damage to buildings in the historical centre and in some areas of Fabriano

The historical centre of Fabriano lies on the right bank of the Giano river and is surrounded by medieval ancient walls. Buildings are very ancient. Generally they are made of masonry vertical structures with brick vaults, wooden or iron beam floors. The common wooden roofs are often thrusting.

Many types of vertical structures have been found. They pass from regular and good quality masonry, in the most important historical buildings, where often iron ties are also found, to poor masonry, made of stones with very bad mortar, in common buildings.

Past restoration of these buildings was generally limited to re-making of roofs and plasters. There
Fig. 4 – Stravignano, structural damage.
Fig. 4 – Stravignano, danneggiamento strutturale.

Fig. 5 – La Costa, structural damage.
Fig. 5 – La Costa, danneggiamento strutturale.

Fig. 6 – Bagni, structural damage.
Fig. 6 – Bagni, danneggiamento strutturale.

Fig. 7 – Isola, structural damage.
Fig. 7 – Isola, danneggiamento strutturale.
were few static strengthenings or seismic retrofits. From such description, it is easy to infer that most of the buildings were already very vulnerable before the earthquake.

816 buildings were surveyed, 2.5% R/C, 0.12% mixed masonry-R/C and 97.4% masonry buildings.

The different vulnerability levels of the buildings match the surveyed damage. Damage was found in bad quality and not upgraded structures, while retrofitted buildings or originally antiseismic structures, as well as buildings realised with care (presence of ties, thick and well executed walls, floors well connected to vertical structures), turned out to be substantially undamaged.

However it must be emphasised that the situation can generally be described in terms of light da-
Fig. 12 – Borgo, structural damage.

Fig. 12 – Borgo, danneggiamento strutturale.

Fig. 13 – Borgo, non-structural damage.

Fig. 13 – Borgo, danneggiamento non strutturale.
mage, with the exception of a couple of poor quality masonry buildings, which, however, did not collapse. In Figs. 10 and 11, the distribution of structural and non-structural damage to buildings is shown for the historical centre of Fabriano. A coloured bullet identifies the damage level of each building (red: heavy damage to collapse; blue: moderate to heavy damage; yellow: light damage; green: no damage).

The area of Borgo is very interesting. While not suffering structural damage, many R/C buildings suffered important non structural damage, thus showing the very high seismic vulnerability of some non structural arrangements. It appears then opportune to describe the reasons for this damage.

Borgo is placed in the west side of Fabriano and it is one of the recent expansion areas of the town, with buildings not older than 10 or 15 years. In Figs. 12 and 13, the distribution of structural and non-structural damage to buildings is shown. Coloured bullets identify 10 buildings, 9 of them have R/C structure, while only one is a masonry building with earthquake resistant design. All the buildings did not suffer any structural damage, while, if non structural damage is considered, out of 9 R/C buildings, 5 suffered light damage, 2 moderate damage and 2 very heavy damage, with collapse of most of the external brick walls.

The evident discordance between the damage to the structure and to the non structural elements is justified by several factors, the most important being the lack of connection between the external wall and the structure. The external wall was not made of brick masonry panels infilled within the structural mesh, but by a unique wall, outside the structure, without any intermediate connection with the structure. Two other important factors were the low stiffness of the structure and the soil amplification effects.

The area between Via Spina and Via Serraloggia, on the east side of the city, also presents interesting aspects. This area is characterised by a very strong slope from Via Spina to Via Serraloggia. Buildings are quite recent, being 35-40 years and 7-10 years old.

The older ones are mostly masonry buildings while, the more recent ones, have a R/C structure, and were designed according to the 1986 Italian seismic regulations.

In Figs. 14 and 15, the distribution of the structural and non structural damage to buildings is shown for the Serra-Serraloggia area. Coloured bullets identify the 59 surveyed buildings: 50.8% have R/C structure, 1.7% (one building) mixed R/C-masonry structure and 47.5% masonry structure; 68% had no structural damage, 24.4% suffered light structural damage and 7.6% heavy damage. For R/C buildings, also non-structural damage was evaluated, resulting in 7.3% with no damage, 53.6% with light damage, 17.1% with moderate to heavy damage and 22% with very heavy damage.

As can be seen from the above data, most of all the buildings had no or just light structural damage and only some masonry buildings had heavy structural damage, more evident on the valley side, with corner separations caused by settling and permanent deformations of the foundation soil.
Most of the R/C buildings suffered non-structural damage, particularly the oldest ones. One of them, five stories high and with irregular shape in plan, also suffered structural damage with concrete spalling and buckling of the longitudinal bars of columns within and near joints, thus showing the lack of confining reinforcement. The more recent R/C buildings, four-five stories high with irregular shape, suffered moderate to very heavy non structural damage, with collapses of partitions and external walls. The main reason for this unsatisfactory behaviour has to be found in the excessive flexibility of the structure due to slender columns, slender external beams, often built within the thickness of floor, and long horizontal cantilever.

The external brick walls were realised without any effective connection between the structure and the outside brick layer, which was often subjected to partial or total collapse.

5. Conclusions

The general picture resulting from the analysis of the damage data shows a widespread situation of very heavy damage in the historical centre of Sellano and heavy damage in Nocera Umbra and the nearby villages. On the contrary, in Fabriano the most important considerations are relevant to the heavy non structural damage suffered by some R/C framed buildings located in specific areas.

While old masonry buildings behaved according to their vulnerability characteristics, the most peculiar aspects detected in the damage analysis, as well as the most important lessons to be learned, are relevant to retrofitted masonry buildings and to some R/C framed buildings, which suffered unexpectedly heavy structural and non structural damage, respectively.

Although non-retrofitted masonry buildings collapsed, the type of upgrading measures described in the paper resulted to be inadequate to avoid or limit damage, essentially because of their ineffectiveness in improving strength of the original poor quality masonry.

As far as R/C buildings are concerned, some of them having been designed according to the old italian seismic code [D.M. 24 gennaio 1986], three main factors can be identified to explain the heavy non structural damage: the high flexibility of the structure, the position of the external brick walls, particularly of their outside thin layer, some amplification effects of soil. It must be emphasised that the '86 italian seismic code did not have any provision to limit structural flexibility and, therefore, non-structural damage. This problem has, however, been overcome in the more recent italian seismic code [D.M. gennaio 1996], where very severe rules are provided to limit interstorey drifts. Nevertheless, the observation of extensive non structural damage emphasises a very big problem for existing R/C buildings. Important economical damage has to be expected in the future from low-medium intensity earthquakes, i.e. earthquakes having high probability of occurrence during the lifetime of a building, in populated and recently constructed areas, if no suitable countermeasures, i.e. structural upgrading, will be taken.

References


ITALIAN MINISTRY OF PUBLIC WORKS (D.M. 16 Gennaio 1996) – Norme tecniche per le costruzioni in zone sismiche.

Effetti del terremoto sugli edifici dei siti di Sellano, Nocera Umbra e Fabriano

Sommario

Gli studi per la microzonaizzazione di dettaglio effettuati a Sellano, Nocera Umbre e Fabriano, a seguito del terremoto del 1997, hanno richiesto una dettagliata analisi del danno agli edifici, al fine di correlare lo stato di danneggiamento con eventuali effetti di amplificazione locale. A tale scopo è stato svolto un’estesa ed estensivo rilievo dei danni e delle caratteristiche di vulnerabilità degli edifici nelle aree di studio dei comuni di Sellano, Nocera Umbra e Fabriano. I dati di danno sono stati raccolti sulle schede già utilizzate per i rilievi di oggettività dopo-terremoto e arricchiti con un gran numero di fotografie per ciascun edificio. Durante il rilievo ciascun edificio è stato georeferenziato, cosicché è stato possibile ottenere la distribuzione geografica del danno nelle mappe delle singole aree studiate.
Nel presente articolo vengono descritti e commentati i risultati principali del rilevato di danno, rivolgendo una particolare attenzione ai danni osservati più frequenti o peculiari, che forniscono importanti indicazioni sui provvedimenti da prendere per ridurre la vulnerabilità sismica degli edifici.

Il quadro generale che risulta dall'analisi dei dati di danno mostra una situazione diffusa di danno molto grave nel centro storico di Sellano e numerosi casi di danno grave a Nocera e nelle sue frazioni. Per Fabriano, le considerazioni più importanti sono relative ai pesanti danni non strutturali di alcuni edifici intelaiati in c.a. in alcune particolari aree.

Mentre i vecchi edifici in muratura si sono comportati coerentemente con le loro caratteristiche di elevata vulnerabilità, subendo danni pesanti e crolli, gli aspetti più peculiari osservati nell'analisi del danno sono relativi a molti edifici in muratura rafforzati con interventi di adeguamento sismico e ad alcuni edifici intelaiati in c.a., che hanno subito danni strutturali e non strutturali, rispettivamente, inattesi. I provvedimenti di rafforzamento sono risultati inadeguati a evitare o limitare il danno, essenzialmente per la loro incapacità di migliorare la resistenza della muratura "pouca". Per quanto riguarda gli edifici in c.a., di cui alcuni progettati secondo le norme del 1986, si possono identificare tre principali fattori per spiegare il pesante danno non strutturale: l'elevata deformabilità della struttura, le caratteristiche delle tamponature, in particolare delle "fodere" esterne, gli effetti di amplificazione del suolo. Occorre però osservare che la normativa del 1986 non conteneva alcuna prescrizione per limitare la deformabilità alle azioni orizzontali e, quindi, il danno non strutturale. È evidente che questo è un problema esposto ad un gran numero di edifici, anche progettati con criteri antisismici, per cui è da prevedere che terremoti di intensità media-bassa potranno provocare notevoli danni economici anche in aree molto popolate di recente costruzione, se non vengono prese le necessarie contromisure.