

THE PIANURA PADANA EMILIANA EARTHQUAKE

The paper reports the most common mechanisms of damage in churches, oratories and steeples as a result of the damage survey carried out by ENEA researchers in the areas of Emilia-Romagna region affected by the earthquake of May 2012, with particular reference to the historical centres. The surveys, mainly carried out immediately after the event, concerned the mere observation of the damage from the outside. Considering the great extent of the area affected, from the province of Ferrara to those of Bologna and Modena, and the large number of churches in any Italian town, it is easy to imagine the amount of damage caused by this earthquake to religious, architectural and artistic heritage. The earthquake showed the high vulnerability of the religious heritage of Emilia-Romagna and, more generally, of the Italian heritage, mostly located in areas of high seismicity, too often subject only to unsystematic interventions of repair, consolidation, renovation

Damage to religious buildings due to the Pianura Padana Emiliana earthquake

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An ENEA scientific team, composed by architects, conservators, engineers and geologists visited several towns damaged by the Emilia-Romagna earthquake during the period between the quakes of May 20th and 29th, and in the post-May 29th event. The mission, which is currently ongoing, has been focused on AEDES surveys of housing and commercial building at first, then several surveys were made to realize the level of damage to historic centres. Of the 2000 events occurred in the first month after the first main event, 7 had magnitudes greater or equal to 5.0 and 27 magnitude values ranging between 4.0 and 5.0 [1]. Over time, these continuous shocks worsened the historic monuments' condition, so that a certain

number of structures which had been standing up after the first events eventually collapsed. Although this work shows many buildings suffering serious damage to the exterior, many others churches and bell towers without evident outside damage were declared unsafe. The present paper reports on a preliminary qualitative survey exclusively made on the outside damage of the buildings affected.

Territorial context

Damage to the historical heritage covers a wide area (Fig. 1) from the province of Ferrara to the east to the province of Modena to the west, affecting some towns in Bologna territory too. In Italy, each city has several religious buildings, country churches, parish churches and cathedrals, towers and historical buildings, hence thinking about the extension of the area affected it is easy to imagine the extent of damage to historical heritage. Furthermore, many of these

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FIGURE 1 Localization of the epicentres of the main events, of the city visited and images of their monuments become the symbol of this earthquake (on image by Google Earth)



FIGURE 2 Historic centre of Finale Emilia on the morning of May 20th
Source: G. Idone

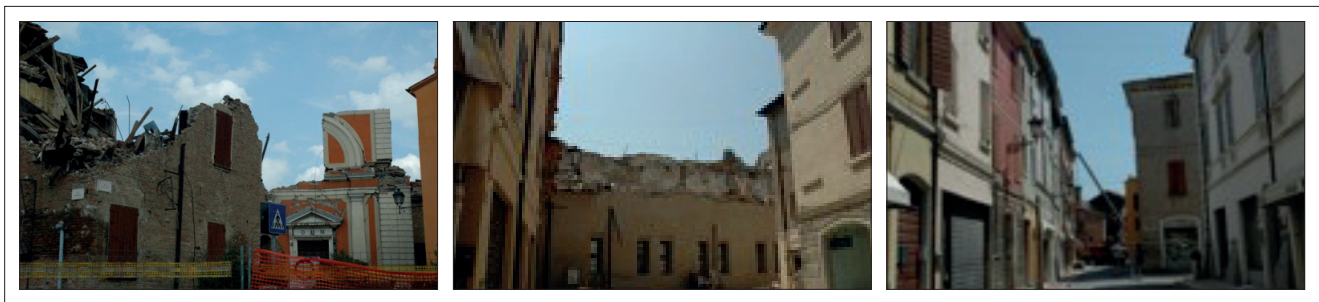


FIGURE 3 Historic centres of San Felice sul Panaro (photo 1) and Mirandola (photos 2 & 3)

ancient buildings served as symbol places for people. Some of these are now completely destroyed, while others, albeit without evident damage, were declared unsafe due to inside structural damage.

Many historical buildings are located in high-risk areas; there are whole towns of particular architectural value with churches and palaces worth preserving. Unfortunately, the Emilia-Romagna earthquake revealed, once again, the vulnerability of the historical Italian heritage. In Figure 1, the earthquakes epicentres are marked in red, and the towns and places (in yellow and green, respectively) most affected are shown, each with the image of the building become symbol of this earthquake. The historic centres have lost their symbols, the places that characterized the city – often meeting places of the community – are now inaccessible and towns show ghostly landscapes with piles of rubble and impassable fences (Figs. 2 & 3). Figure 2 shows the historic centre of Finale Emilia a few hours after the

quake of May 20th. The first photo of Figure 3 shows a view of the square in front of the cathedral of San Felice sul Panaro, with the church damaged by repeated shocks; photos 2 and 3 of the same figure show two views of the historic centre of Mirandola, the first close to the cathedral whereas the second offers a view of what remains of the church of San Francesco.

The churches: centuries of history destroyed

The earthquake damaged a very large number of churches, maybe some hundreds, several of which with major collapse, others with severe structural damage and many still unusable; some of them were in poor condition, also many of those which had survived over the centuries through specific maintenance interventions, often in roofing. Examples considered relevant to the type of damage are shown below.



FIGURE 4 Church of Natività, Rivara, San Felice sul Panaro (drawing by [2])



FIGURE 5 Church of Annunziata in Finale Emilia (photos 1&2); Church of S. Possidonio, San Possidonio (photos 3&4)

Mechanisms of the top of the façade

One of the most common failure mechanisms in cases of severe damage was the out-of-plane collapse of the tympanum. In some cases the damage displays a horizontal crack and the collapse of the entire macroelement (Figs. 4 & 5).

In other cases, the collapse occurred with a V shaped crack and the crumbling of the masonry, as in the badly damaged church of S. Luca in Camurana (photos 1 & 2 in Fig. 6). Another case of V shaped crack is shown in the church of S. Francesco d’Assisi in Finale Emilia (photo 3 in Fig. 6).

There have been cases of overturning of the tympanum and disaggregation of the underlying part of

masonry in such a way as not to make the collapse mechanism clear (photos 1 & 2 in Fig. 7), or cases of horizontal cracks in a position lower than the base of the tympanum (photos 3 & 4 in Fig. 7).

Overturning of the façade and mechanisms in the plan

Another mechanism observed in many damaged churches is the detachment with consequent overturning of the façade as in the church in Vigarano Mainarda (Fig. 8). The beginning of the mechanism in the top part is quite widespread, and required many interventions for safety with provisional tie rods (photo 3 in Fig. 12).



FIGURE 6 Church of S. Luca, Camurana, Medolla (photos 1&2), Church of San Francesco d’Assisi, Finale Emilia (photo 3) (drawing by [2])



FIGURE 7 Church of SS Filippo e Giacomo, Cathedral, Finale Emilia (photos 1&2), Church of Santi Senesio e Teopompo Martiri, Medolla (photos 3&4)



FIGURE 8 Church of Natività della Beata Vergine Maria, Vigarano Mainarda (drawing by [2])

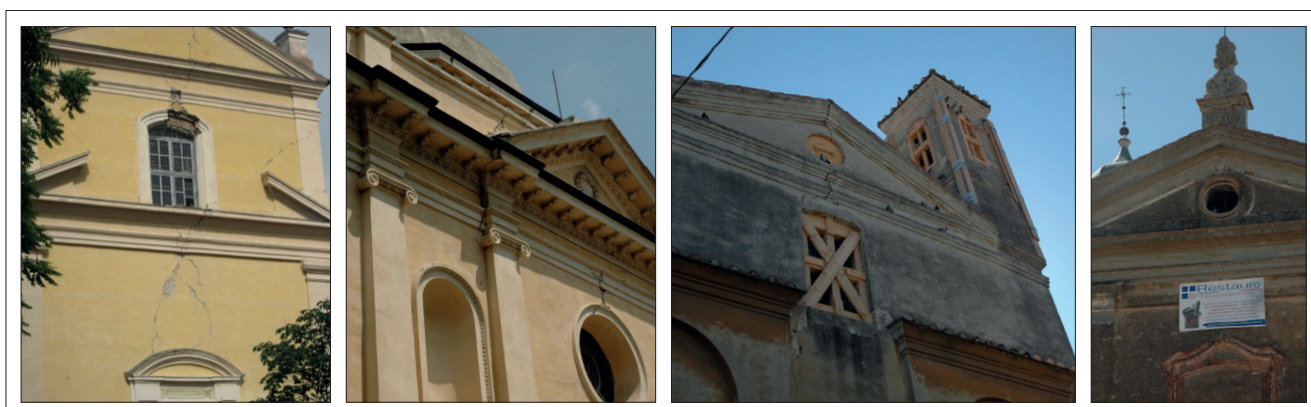


FIGURE 9 Church in Finale Emilia (photo 1); Church of Madonnina, Mirandola (photo 2); Church of SS. Rocco e Sebastiano (photo 3), Pieve di Cento; Church of S. Giovanni, Bondeno (photo 4)



FIGURE 10 Church of the Madonnina, Mirandola (drawing by [2])

In plane, the damage mechanism of the façade – often with vertical cracks from the tympanum to the architrave of the entrance portal through the rose windows of the churches – has been observed too. Figure 9 shows the various severity levels of this type of damage.

Damage of domes, drums and tiburium

The figures below show some cases of this typology of damage. The drum of the Church of Madonnina in Mirandola was seriously damaged, from the outside it is not possible to see any damage to the dome because of the covering.

The *tiburium* of the cathedral of Carpi shows clearly visible cracks in the front facing the square (Fig. 11), whereas the dome of the church of S. Maria Maggiore in Pieve di Cento has completely collapsed and its drum is now bounded with provisional tie rods (Fig. 12).

Damage in the lateral chapels

Significant shear cracks are present in the lateral chapels of several churches. The detachment of the outer walls of the chapels from the walls of the church and shear cracks in the walls of chapels and side aisles are often observed (Fig. 13).

Structural collapses

The figures below show some important collapses of structural parts. The church of S. Egidio Abate in Cavezzo was particularly damaged with the collapse of roof and vault. The first photo of Fig. 15 shows the church of S. Francesco, already severely damaged by the earthquake of May 20th, almost completely collapsed after the event of May 29th.

Already damaged by the earthquake of May 20th, also the cathedral of Mirandola, with the event of May 29th, saw the partial collapse of the façade and the roof. The roof



FIGURE 11 Cathedral of S. Maria Assunta, Carpi (MO)



FIGURE 12 Church of S. Maria Maggiore, Pieve di Cento (BO)



FIGURE 13 Church of S. Silvestro, Crevalcore (BO); Church of San Michele Arcangelo, Poggio Renatico (FE); Church of San Possidonio, San Possidonio (MO); (drawing by [2])



FIGURE 14 Church of Sant'Egidio Abate, Cavezzo (MO)



FIGURE 15 Church of S. Francesco (photo 1) and Cathedral (photo 2) in Mirandola; Church of Santa Caterina d'Alessandria, Rovereto di Novi (photo 3, by courtesy of P. Clemente)

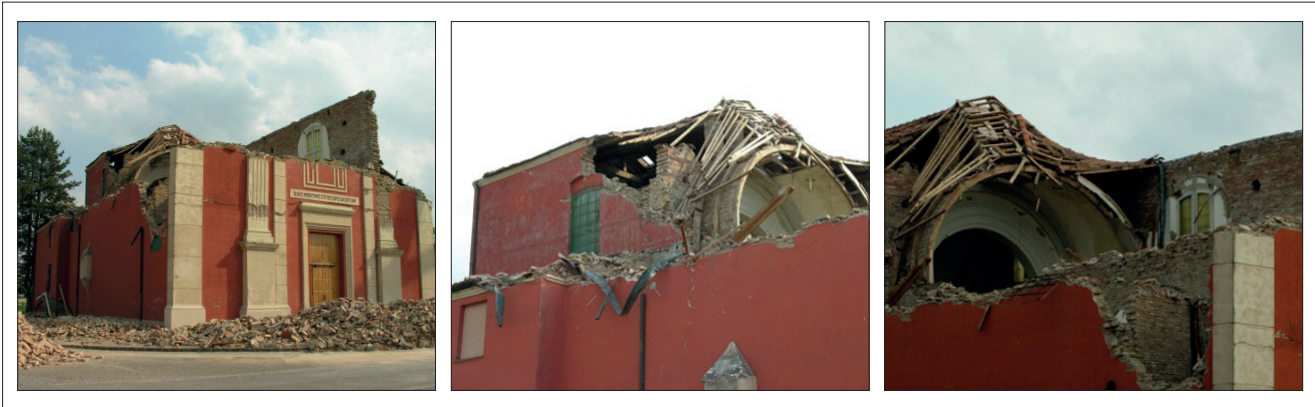


FIGURE 16 Church of S. Martino, Buonacompra, Cento (FE)

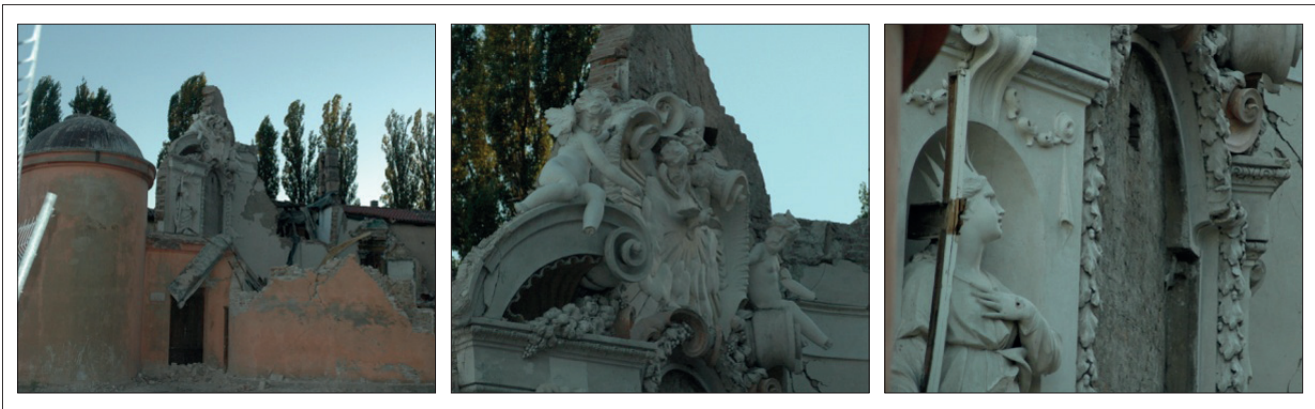


FIGURE 17 Oratorio Ghisilieri, San Carlo, Sant'Agostino (FE)

collapse in the badly damaged church of Santa Caterina d'Alessandria in Rovereto di Novi, in Novi di Modena town, has become infamous for causing the death of the priest. Little is left – except for the perimeter walls and piles of rubble to recover – of the church of S. Martino in Buonacompra, and of the Oratorio Ghisilieri in San Carlo, in Sant'Agostino town.

Bell towers damaged, collapsed or demolished

In addition to the churches, in many cities affected by the earthquake there are steeples damaged and declared unsafe, in some cases collapsed or demolished, with belfries destroyed or removed by fire-

fighters due to the high risk of collapse. At the end of June, there were already reports of 147 church steeples in need of safety interventions and measures [3]. This type of construction, particularly affected by this earthquake, constitutes an important set of cultural heritage in Italy. Its seismic behaviour is dependent on many factors, such as the slenderness of the structure, the degree of gripping of the walls, the presence of adjacent lowest structures able to provide a horizontal constraint, the presence of tie rods, the presence in the top part of slender architectural elements (spiers, bell cells, etc.), or other vulnerable ones (belfries) [4]. In some cases the vulnerability is influenced by pre-existing damage, for example due to problems in the founda-

tion (frequent cases in the area where inclined steeples are found) and to masonry in bad state of conservation. The bell cells, with large openings, show serious shear cracks in the little columns, with sliding in the most severe cases (Fig. 18). Some of them are disaggregated under the action of the earthquake, others have been

removed from firefighters, others made safe. When the steeple is placed in contact with other structures of lower height, this can cause local damage; an example is the bell tower of church in Cavezzo (Fig. 19). In the pictures in Fig. 20, two cases of severe damage are reported; the first two photos show the bell tower

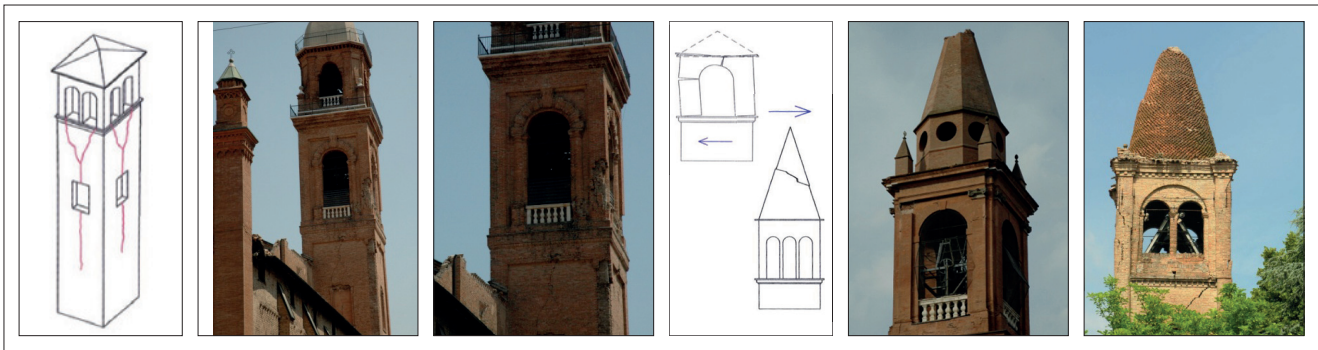


FIGURE 18 Steeples of: Cathedral, Mirandola (photos 1 & 2); Church of Sant'Egidio Abate, Cavezzo (photo 3); Church of Santa Caterina d'Alessandria, Rovereto di Novi, (photo 4, by courtesy of P. Clemente), (drawings by [2])



FIGURE 19 Steeple of Sant'Egidio Abate Church, Cavezzo (drawing by [2], photo 1 by Google maps)



FIGURE 20 Steeples of: Church of S. Martino, Buonacompra, Cento (FE), Church of S. Michele Arcangelo, Poggio Renatico (FE)

of the Church in Buonacompria during the demolition. Photo 2 shows the severe shear two-level damage, due to torsional stress, that led to the decision to demolish the tower. The last two pictures in Fig. 20 show the church of S. Michele in Poggio Renatico deprived of its bell tower, blown up as a threat to public safety due to its serious structural problems.

Hazard caused by non-structural elements

Firefighters intervened many times on the top of the church façades and bell towers to remove slender elements, such as statues and spears, with vulnerability due to their low vertical load and weight, which provides a limited stabilizing effect in regard to the turnover. Spiers, crucifixes, statues that fall from the church roofs, often with metal anchors



FIGURE 21 Church Matildica and Church of the Sante Grazie in Bondeno; Church of San Bartolomeo, Finale Emilia



FIGURE 22 Church of Santa Croce, Crevalcore (BO), (drawing by [2])

weak or too short, represent a danger often underestimated.

Many interventions have been made to put the bell cells in safety and, in some cases, disassemble them. In other cases, overhang host bells have reported shear cracks with displacements due to sliding along the shear cracks, as in the church of Santa Croce in Crevalcore (Fig. 22).

Conclusions

The Emilia-Romagna earthquake has destroyed a significant part of the cultural heritage and the identity of the people living in this region.

Many churches and bell towers were seriously damaged or collapsed, and too many of them are still unusable. In the churches damage was frequently caused by the out-of-plane failure of the church façade and by the collapse of vaults and roof. Some of them are in bad state of general conservation, with poor masonry or wood roofs deteriorated, but there are also damaged churches that have received regular interventions of repair or consolidation. Some churches were apparently well preserved, as the cathedrals, which, in spite of the various maintenance interventions, have been damaged too. As regards the steeples, the most widespread damage occurred to bell cells that show serious shear cracks in the little columns. A type of damage, often underestimated, concerned the fall of decorative elements from the roof of churches and steeples.

The earthquake showed the high vulnerability of the

religious heritage of Emilia-Romagna and, more generally, of the Italian cultural heritage, mostly located in high-risk areas, too often subject to unsystematic interventions of repair, consolidation, renovation, or to local interventions carried out without analyzing the global seismic behaviour of the structures. ●

Acknowledgements

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