

THE PIANURA PADANA EMILIANA EARTHQUAKE

During the seismic event of May 2012 in the Emilia-Romagna Region (Italy), several cultural heritage structures (in particular churches and bell towers) collapsed or were severely damaged. This paper gives a description of the damage/collapse mechanisms observed on some buildings, subject of the investigation of the ENEA expert teams, supporting the Italian Civil Protection Department and the Regional Directorate for Cultural Heritage and Landscape in Emilia-Romagna

Damage and collapse mechanisms in churches during the Pianura Padana Emiliana earthquake

■ Maurizio Indirli, Giuseppe Marghella, Anna Marzo

The seismic sequence, which hit the Emilia-Romagna Region and surroundings (May 20th, time 04:03, principal event Mw 6.0, focal depth about 6 km, epicentre near Finale Emilia; May 29th, time 9:00, principal event Mw 5.8, two strong aftershocks Mw 5.3, time 12:55, Mw 5.2, time 13:00, epicentre near Cavezzo-Medolla-Mirandola; June 3rd, time 21:20, Mw 4.9, epicentre near Concordia sulla Secchia-Novi di Modena), caused 27 deaths, some hundreds of injured people, thousands of homeless, heavy damage to and some collapses of strategic and residential buildings, factories and infrastructures, cultural heritage. This earthquake evidenced that the Po Valley is also prone to seismic risk, although the area has been included in the Italian seismic zonation only after 2003. Immediately after the first event, which struck the Districts of Ferrara, Modena, Reggio Emilia, Bologna (Emilia-Romagna Region), Mantova (Lombardia Region) and Rovigo (Veneto Region), an ENEA team of experts (Maurizio Indirli, Bruno Carpani, Elena

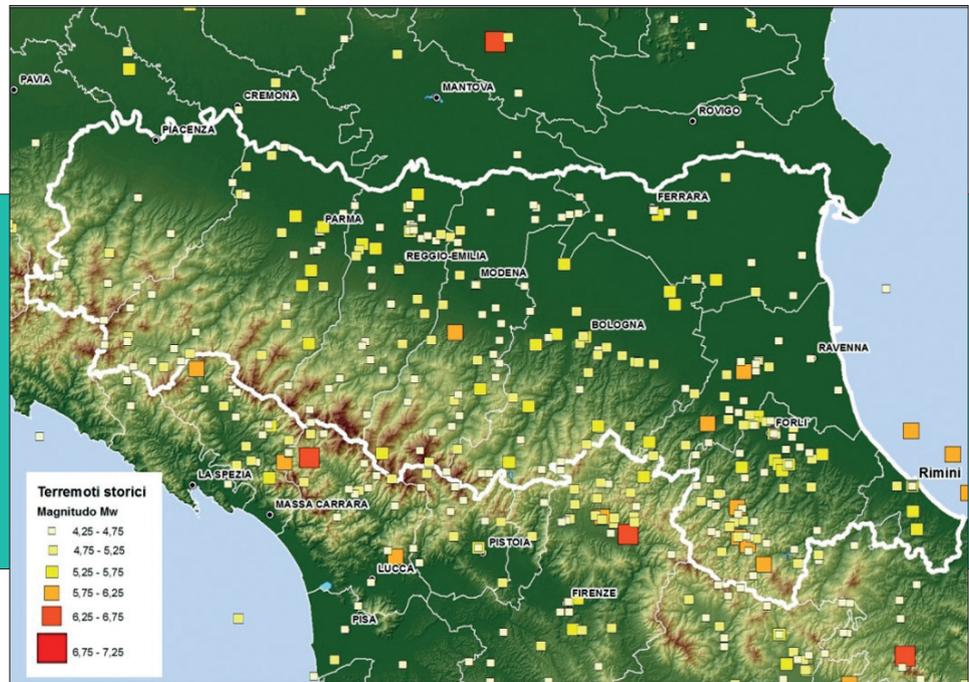
Candigliota, Alessandra Gugliandolo, Francesco Im-mordino, Giuseppe Marghella, Anna Marzo, Giuseppe Nigliaccio, Alessandro Poggianti, Maria-Anna Segreto) supported the Italian Civil Protection Department, in order to perform prompt investigations regarding the safety evaluation of different typologies of structures (bridges, industrial factories, residential houses, etc.), made of various kinds of materials (masonry, reinforced concrete, precast/pre-stressed reinforced concrete, mixed). In addition, from September 4th, 2012, ENEA experts (Bruno Carpani, Elena Candigliota, Maurizio Indirli, Giuseppe Marghella, Anna Marzo, Alessandro Poggianti) joined *ad hoc* teams, arranged by the Regional Directorate for Cultural Her-

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 ENEA, Technical Unit for Seismic Engineering

FIGURE 1

Map of historic seismicity in Emilia-Romagna and surroundings

Source: INGV



itage and Landscape in Emilia-Romagna, devoted to investigations on this category of assets.

In particular, this article focuses on the behaviour analysis of churches and bell-towers, mainly masonry construction, widely affected by the May-June 2012 seismic events.

Historic seismicity: brief information about damage due to past earthquakes

The Padana Plain was hit by earthquakes since the antiquity, including cities and villages of Emilia-Romagna (Fig. 1). In the Roman period, Gaius Plinius Secundus (“Plinius the Older”) wrote in his *Naturalis Historiae* (Book Third) that the place “Campi Macri”, near Modena, was abandoned by the residents after the shake occurred in 91 b. C..

The most important event, cited in several old European documents, occurred in 1117, epicentre near Verona, IX MCS (Mercalli-Cancani Sieberg) Intensity, causing maybe 30000 victims in all the large affected

zone; in the city of Verona, the second circle of the Roman amphitheatre (Arena) collapsed (except the still standing small portion currently named “the Wing”), and most of the medieval architecture ruined (“*terremotus maximus fuit, in quo etiam magna pars Arene cecidit*”, from the *Annales Veronenses antiqui* [1-2]); widespread failures in churches and abbeys (for example, the famous Benedictine complex of Nonantola, near Modena) were registered, but the famous Romanesque cathedral (San Geminiano) and the Tower (Ghirlandina) in Modena, starting to be built a few years before and reaching an intermediate height, showed no damage, and this fact was felt as a miracle by the inhabitants; furthermore, natural overturning affected the River Po, which changed its bed.

Other seismic events (with Intensities from VI to IX) took place in the following centuries between Bologna, Modena and Reggio Emilia (1249, 1365, 1399, 1455, 1465, 1501, 1504-1505, 1547), with different levels of damage (from moderate to strong) to churches, towers, castles and other important buildings. The 1501 earthquake (Maximum Intensity IX) struck



FIGURE 2 Detail of “Torre Mozza” before its demolition (on the left from the Ghirlandina Tower), from a painting located in the Modena Municipality Palace

the belt among the flat and the Apennines between Bologna and Reggio Emilia, with the strongest effects in Castelvetro, Maranello and Sassuolo; the Italian personality Jacopino de’ Bianchi de’ Lancillotti (living in Modena from 1440 to 1502) was the reporter of the partial demolition of the Modena Municipality Palace tower (now known as “Torre Mozza”, see Fig. 2); other damage interested several churches (the Cathedral, San Francesco, Sant’Agostino, San Biagio); Jacopino de’ Bianchi describes the Ghirlandina Tower under the earthquake “as a poplar shaken by the wind”

.The 1671 event (Intensity VII) hit again Modena and surroundings (until Carpi, Correggio and Nonantola), with some damage and the partial failure of the Clock Tower of the Modena Municipality Palace.

Bologna supported heavy earthquake effects in 1365 (Intensity VII-VIII), with some victims and widespread damage to important constructions (palaces, churches, towers); the people joined themselves into religious processions and pilgrimages to the Sanctuary of Santiago di Compostela; in Bologna, in 1504 (Intensity VI) and 1505 (Intensity VII), the seismic crisis was responsible of some casualties and similar damage as 1365; in all the cited events, failure of old towers occurred, and some of them were demolished or lowered.

In the city of Ferrara, the 1346 earthquake (Intensity VII-VIII) caused widespread damage, but the 1570 event was the worst (Intensity VIII, series of after-



FIGURE 3 Argenta earthquake (1624) in a painting of Camillo Ricci (Picture Gallery of Argenta)

shocks until 1574), with about 70 deaths, heavy failures and collapses in the medieval portion of the city (40% of high structures and houses ruined), with the escape of about 11000 inhabitants out of 32000, in an atmosphere of collective panic and prostration. Subsequently, in Argenta (a town close to Ferrara) during the 1624 event (Intensity VIII-IX), the casualties were about 50, and the destructive effects of the earthquake were amplified by sandy soil and shallow aquifers, with the presence of cracks in the ground and outputs of black mud, causing foundation failures and subsequent structural collapses of about 25% of the houses (Fig. 3).



The San Giorgio Church and its Bell-Tower (Trignano, San Martino in Rio, Reggio Emilia, Italy)



(a)



(b)



(c)



(d)

Cracks on the Bell-Tower (a, b) and rotation of the upper structure (c, d)



(e)



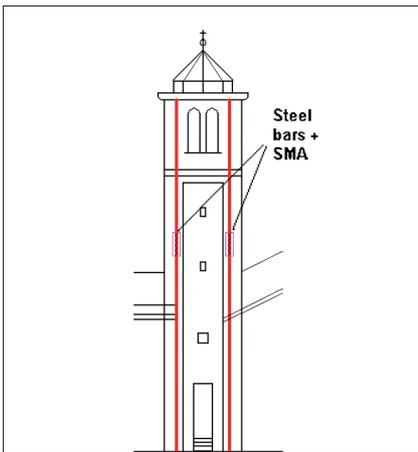
(f)



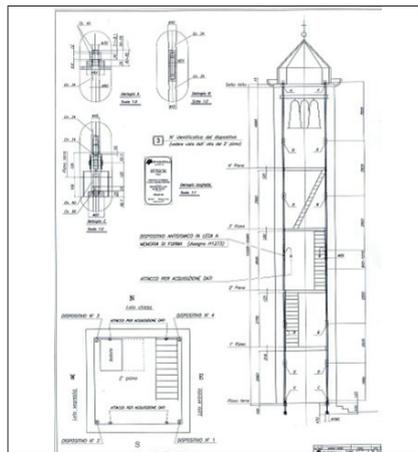
(g)



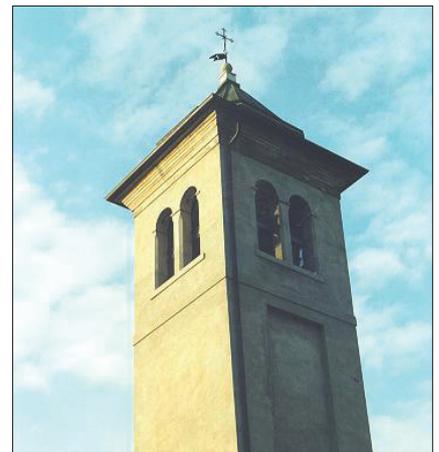
(h)



(i)



(j)



(k)

Application of 4 steel tie bars including SMADs: intervention scheme (i); anchorages at the building top (e) and at the foundation (f); SMADs before (g) and after (h) assembling; intervention details (j); bell-tower after restoring (k)

FIGURE 4 The Bell-Tower restoration at the San Giorgio in Trignano Church (San Martino in Rio, Reggio Emilia)

More recently, an earthquake struck the Districts of Reggio Emilia and Modena on October 15th, 1996 (Mw 4.8 and VII MCS). A significant number of damaged structures was observed, especially concentrated in the historical heritage. Also in this case, immediately after the seismic event, ENEA placed some personnel to investigate the performance of the structures, operating in some towns, but principally in the Municipality of San Martino in Rio (Reggio Emilia, Italy), located inside the more affected area [3-4]. During the reconstruction phase, ENEA carried out some studies for improving seismic protection of cultural heritage, in the framework of the ISTeCH Project (“Development of Innovative Techniques for the Improvement of Stability of Cultural Heritage in Particular Seismic Protection”, funded by the European Commission), leading to the rehabilitation intervention of the San Giorgio in Trignano Church Bell-Tower (San Martino in Rio).

It concerned the experimental dynamic characterization of the church plus bell-tower complex, and its post-earthquake restoration, including the insertion of 4 vertical steel ties in series with Shape Memory Alloy Devices (SMADs), an innovative technique conceived in the framework of the aforesaid ISTeCH project [5-6]. Damage, restoration and intervention schemes are reported in Fig. 4. A subsequent seismic event, with about the same epicentre, occurred at 9:42 on June 18th, 2000 (Mw 4.5, MCS Intensity VI-VII). Immediately after the main shock, the bell-tower was again investigated with great accuracy by the ENEA personnel, but it showed no damage of any type. The 2000 seismic event had been the best verification of the retrofit.

The May-June 2012 events and their effects on churches and bell-towers

General view during the phase devoted to safety investigations, in support to the Civil Protection team

During the investigations done supporting the Italian Civil Protection Department (May-June 2012), moving inside the affected area, it was possible to carry out a quick general view on some cultural heritage assets damaged by the earthquake, although targeted technical surveys were not possible.

In this first period, an ENEA team (Maurizio Indirli, Giuseppe Marghella, Anna Marzo), operating in the vast territory of the town of Cento (Ferrara), had the opportunity to see directly some cases of damage/collapse of churches and bell-towers. The most impressive general collapse, due to the first shock (maximum May 20th peak ground acceleration, PGA: Mirandola recording station, 0.30g; Medicina recording station, 0.04g) and aggravated by the following ones (maximum May 29th PGA: Cento recording station, 0.30g), occurred in the church of San Martino di Tours (Fig. 5), located in Buonacompra (Cento, Ferrara). The construction probably started in 1399, but it was strongly modified during the XVIII-XIX centuries. A controlled demolition of the bell-tower, cut in at least three portions by the earthquake, was underway at the time of the visit, removing the masonry bricks line by line (Fig. 6).

The church of San Lorenzo at Casumaro (Cento, Ferrara) was founded in 1449 by the Bishop of Modena, but many changes were done (together with the bell-tower) during the XVIII-XIX centuries. Immediately after the first shock (the maximum PGA values are the same as the previous case), the church showed a clear out-of-plane detachment in the façade, together with shear cracks in its masonry panels and tympanum overturning; the bell-tower was close to collapse, due to deep cracks originated by bending and torsion movements during the earthquake (Fig. 7).

About a similar incipient collapse occurred to the bell-tower of the Sant’Anna church (built in 1772 and subsequently modified in the XIX century) in Reno Centese (Cento, Ferrara, PGAs as before), which has been divided into two portions by the seismic event since the first shake (Fig. 8); after a long discussion between the experts about its possible demolition, the structure has been put in safety through an innovative intervention, spraying jets of mortar and structural fibres in the cracks [7].

Also the church of San Sebastiano (XV century, modified in the XVIII) in Renazzo (Cento, Ferrara, PGAs as before) was damaged (Fig. 9). Several works of art were removed by the firemen, including a famous painting of Guercino (the miracle of San Carlo Borromeo), put in a temporary safe place.



FIGURE 5 Damage in the San Martino di Tours church and bell-tower in Buonacompra (Cento, Ferrara) and main collapse mechanisms



FIGURE 6 Controlled demolition in the San Martino di Tours church bell-tower in Buonacompra (Cento, Ferrara)

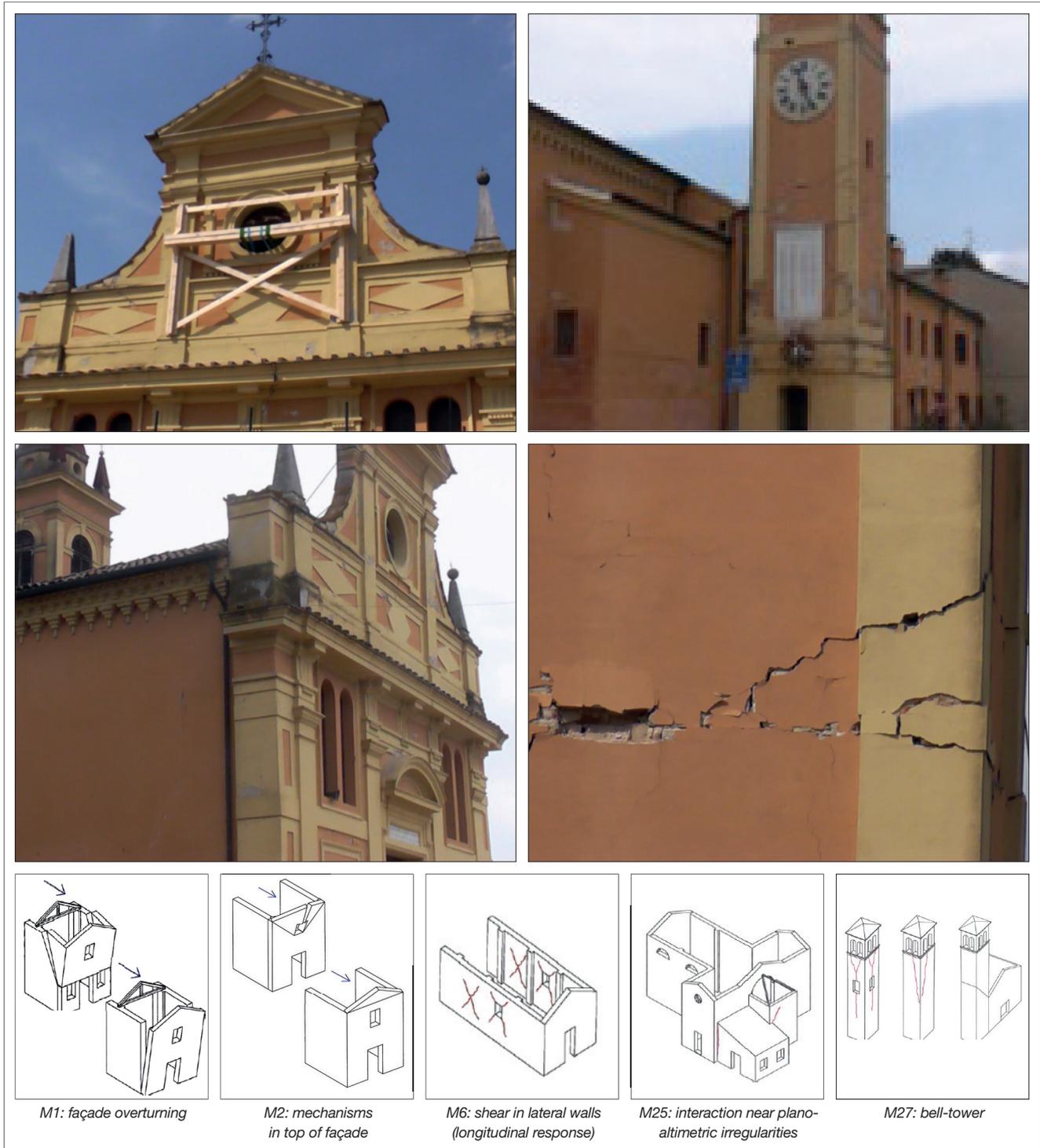


FIGURE 7 Damage to the San Lorenzo church in Casumaro (Cento, Ferrara) and main collapse mechanisms



FIGURE 8 Damage to the Sant'Anna church in Reno Centese (Cento, Ferrara) and main collapse mechanisms

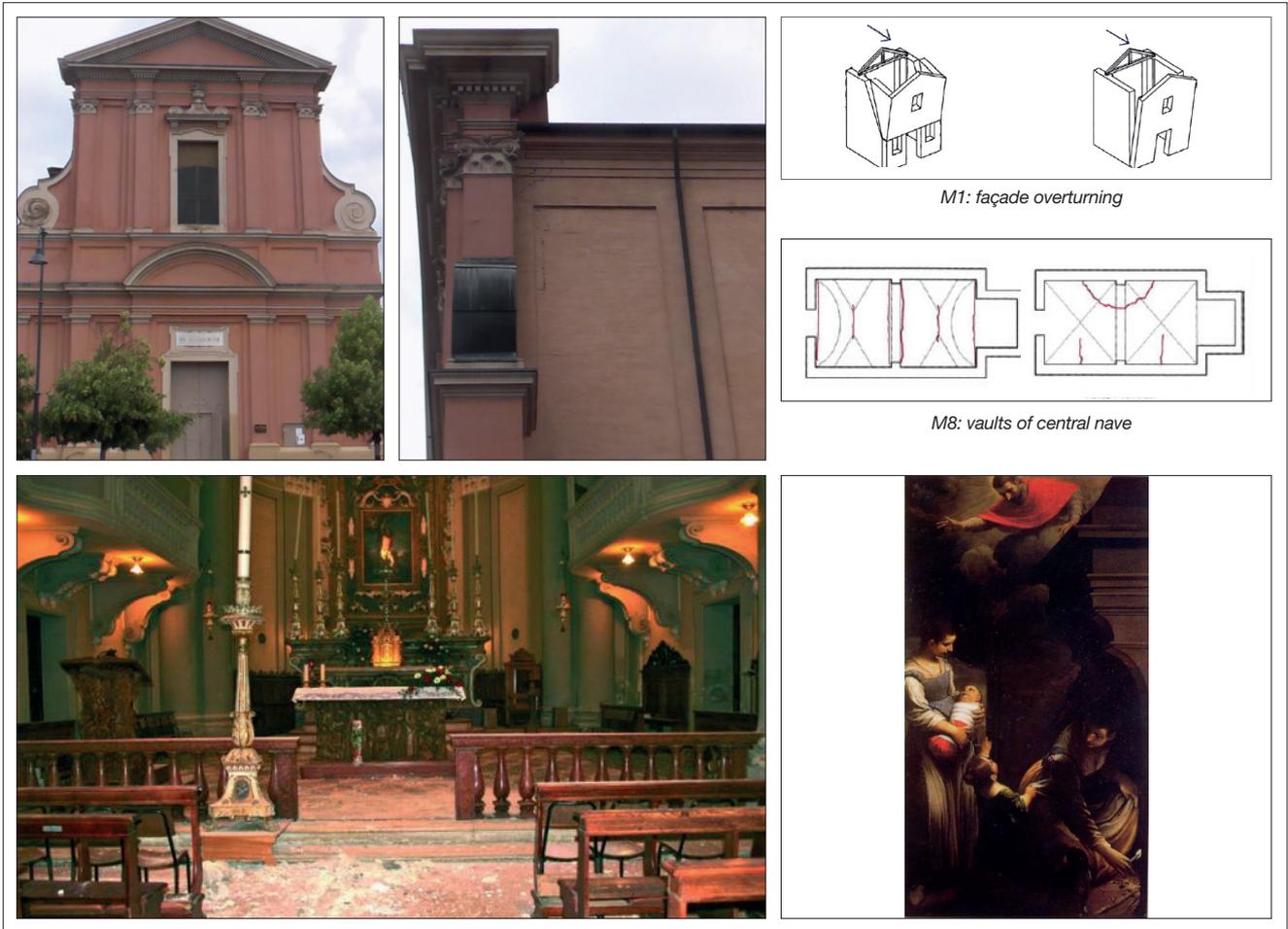


FIGURE 9 Damage to the Church of San Sebastiano in Renazzo (Cento, Ferrara) and main collapse mechanisms



FIGURE 10 Cento (Ferrara) historic centre: the church of San Filippo Neri and main collapse mechanisms



FIGURE 11 Cento (Ferrara) historic centre: the Church of San Sebastiano and San Rocco (Convent of Friars Capuchins) and main collapse mechanisms



FIGURE 12 Cento (Ferrara) historic centre: the Church of San Biagio and main collapse mechanisms



FIGURE 13 Cento (Ferrara) historic centre: the Church of San Pietro and main collapse mechanisms (middle above)

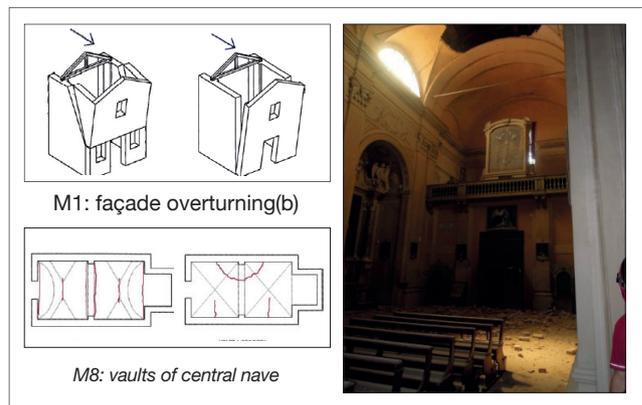


FIGURE 14 Cento (Ferrara) historic centre: the Church of the Rosario and main collapse mechanisms (middle bottom)

Inside the historic centre of Cento (Ferrara), most of the damage occurred after the shock of May 29th (Cento recording station, PGA 0.30g): Church of San Filippo Neri (detachment of the façade, Fig. 10); Church of San Sebastiano and San Rocco (collapse of the tympanum, Fig. 11); Church of San Biagio (instability of the top part of the bell-tower, Fig. 12); Church of San Pietro (detachment of the façade, Fig. 13); Church of the Rosario (vault collapse, Fig. 14).

Surveys carried out under teams arranged by the Regional Directorate for Cultural Heritage and Landscape in Emilia-Romagna

A first team involving ENEA experts and the representatives of the Regional Directorate for Cultural Heritage and Landscape in Emilia-Romagna (Paola Ruggieri, Valentina Oliverio, Sandra Manara, and other experts) operated in Modena, investigating the Temple of Fallen, the Cathedral of San Gemini-ano together with its Tower Ghirlandina, in Minerbio (Parish of San Giovanni Battista in Triario), and Budrio (Church of San Lorenzo).

The methodology adopted is a well-established quick survey form, specifically conceived for churches [8], whereas a similar one was used for monumental palaces and other buildings [9], which is not dealt with in this article.

The Monumental Temple of Fallen in Modena

Description - The Monumental Temple of Fallen in Modena (Fig. 15), located in Natale Bruni Square, was built for the perpetual memory of the Fallen of Modena, dead during the First World War. The building, designed by the architect Domenico Barbanti in cooperation with Achille Casanova, is dedicated to St. Joseph.

The edification started in 1923 (completed in 1929), at the presence of King Vittorio Emanuele III and Archbishop Natale Bruni, main creator and benefactor of the temple.

His funeral chapel, with a beautiful medallion sculpted by Giuseppe Graziosi, is located inside the building. The names of the 7300 Fallen are carved on the pillars and the walls of the crypt. The church has a Greek cross plan, surmounted by a main dome, which is surrounded by four small towers.

Both the dome and the small towers have an internal iron skeleton: a reticular structure for the dome and polygonal frames for the small towers. In the main facade is possible to admire the bas-reliefs made by Adam Rubens Pedrazzi.

During the 2012 seismic events, the church experienced a PGA maximum value of 0.037g and 0.055g (Modena recording station), respectively on May 20th and 29th.

Damage survey and observed mechanisms

- The survey evidenced damage due to the recent seismic event, but also previous ones. The latter are caused by subsidence, because of different soil mechanical properties.

In particular, the ground under the crypt is more deformable in comparison with the adjacent area; therefore, this part of the construction shows an in-progress sinking mechanism.

The old cracks (Fig. 16) increased with the recent earthquake, which originated new local/global damage mechanisms.

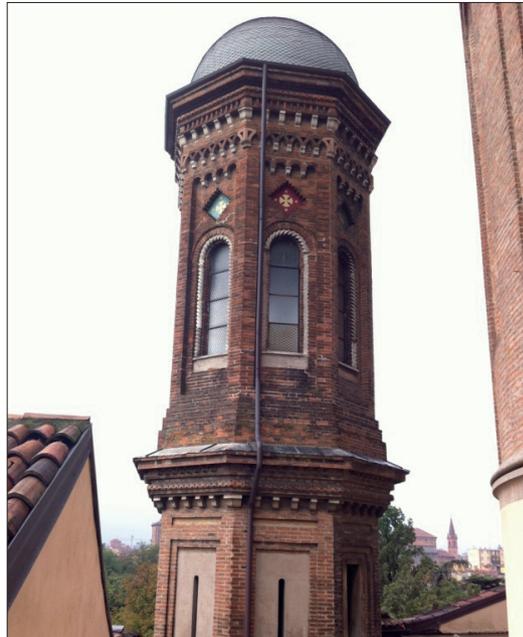
The major cracks of the main façade are highlighted with a red line (Fig. 17), and the mechanisms plotted in Fig. 18. It is worth noticing that the mechanisms related to church lateral apses have been considered as chapel mechanisms (M22 and M23).

Finally, a damage index of about 0.27 has been obtained. Soil geotechnical survey and seismological microzoning is considered mandatory, in order to evaluate how to enhance the foundations.

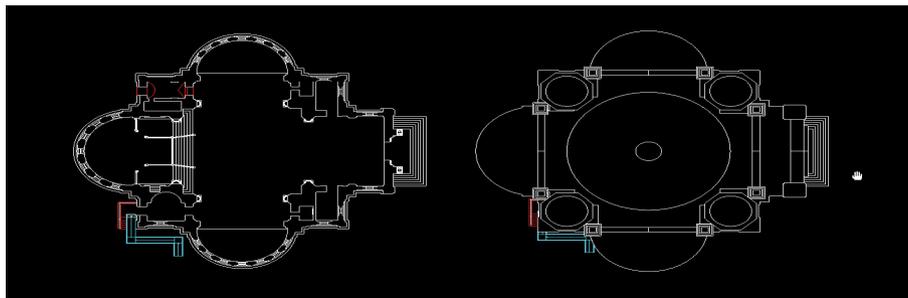
Moreover, also extensive material diagnostics and dynamic characterization should be carried out, aiming at a general (conventional and/or innovative) anti-seismic reinforcement. Restoration should regard all the decorative apparatus.



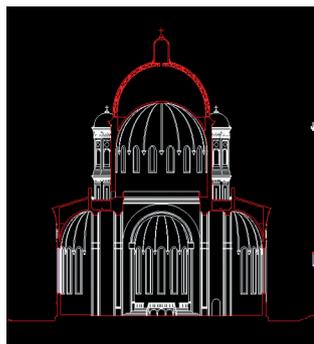
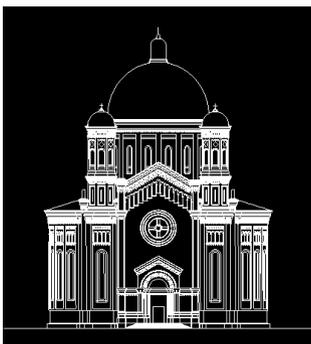
Main façade



The small tower



Plan



Prospects



Internal dome iron frame



Internal iron frame of the small towers

FIGURE 15 The Monumental Temple of Fallen in Modena



FIGURE 16 Subsidence phenomena: a) external view; b) internal view



FIGURE 17 Façade overturning mechanism (M1), internal view

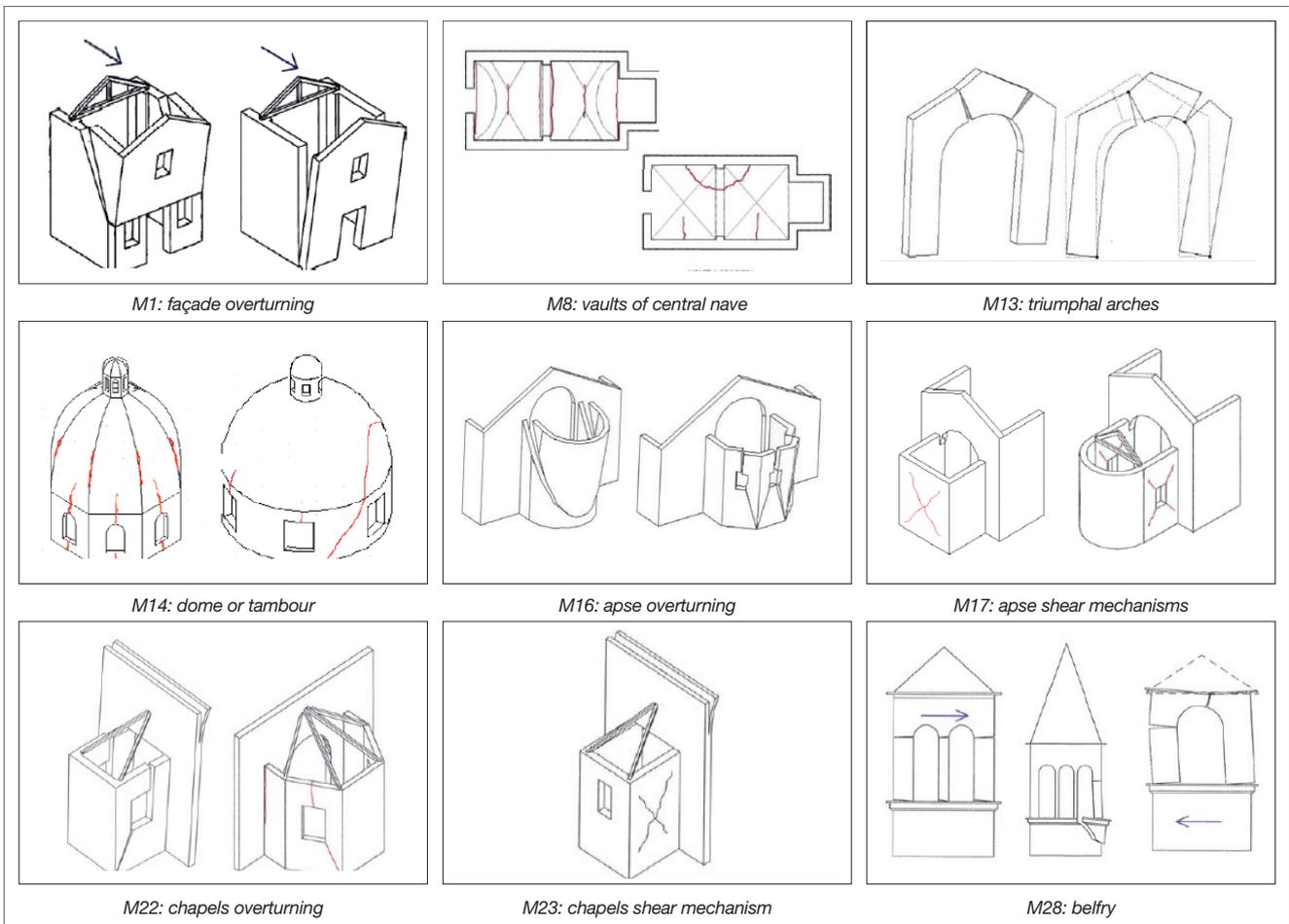


FIGURE 18 Damage mechanisms observed in the Monumental Temple of Fallen (Modena)

The San Geminiano Cathedral and the Ghirlandina Tower in Modena

Description - The San Geminiano Cathedral in Modena was constructed from 1099 onwards, on the rests of two previous churches, and consecrated by Pope Lucio III in 1184. It is one of the best masterpieces of the European Romanesque, thanks to the architectural structure of Lanfranco and the sculptural pieces of Wiligelmo (Fig. 19). In 1106, the building was already covered and the rests of Saint Patron Geminiano were moved from the old church to the new cathedral crypt. As told in Section 2, during the 1117 catastrophic seismic event, the church did not suffer any damage. The original project was later modified, starting from 1167, by the Campionesi Masters; they: opened the gothic rose-window and two lateral doors on the fa-

çade, together with the Regia Door, which enriched the lateral prospect on Piazza Grande; modified the presbytery, building the beautiful pontile; completed the Ghirlandina Tower.

Other main structural interventions, realised during the following centuries, are: the original wooden-truss covering structure was hidden by a new one (masonry cross-vaulted ceilings, between 1437 and 1455); the floor was lowered about twenty centimetres, in order to give a greater upsurge to the internal area; the external lateral buildings, firstly laying on the church perimeter walls, were demolished (from late XIX to early XX century); realisation of the new elevated walkway to the sacristy; construction of the two transverse walls with arches, linking (without a real structural connection) the cathedral to Ghirlandina and sacristy (Fig. 20).

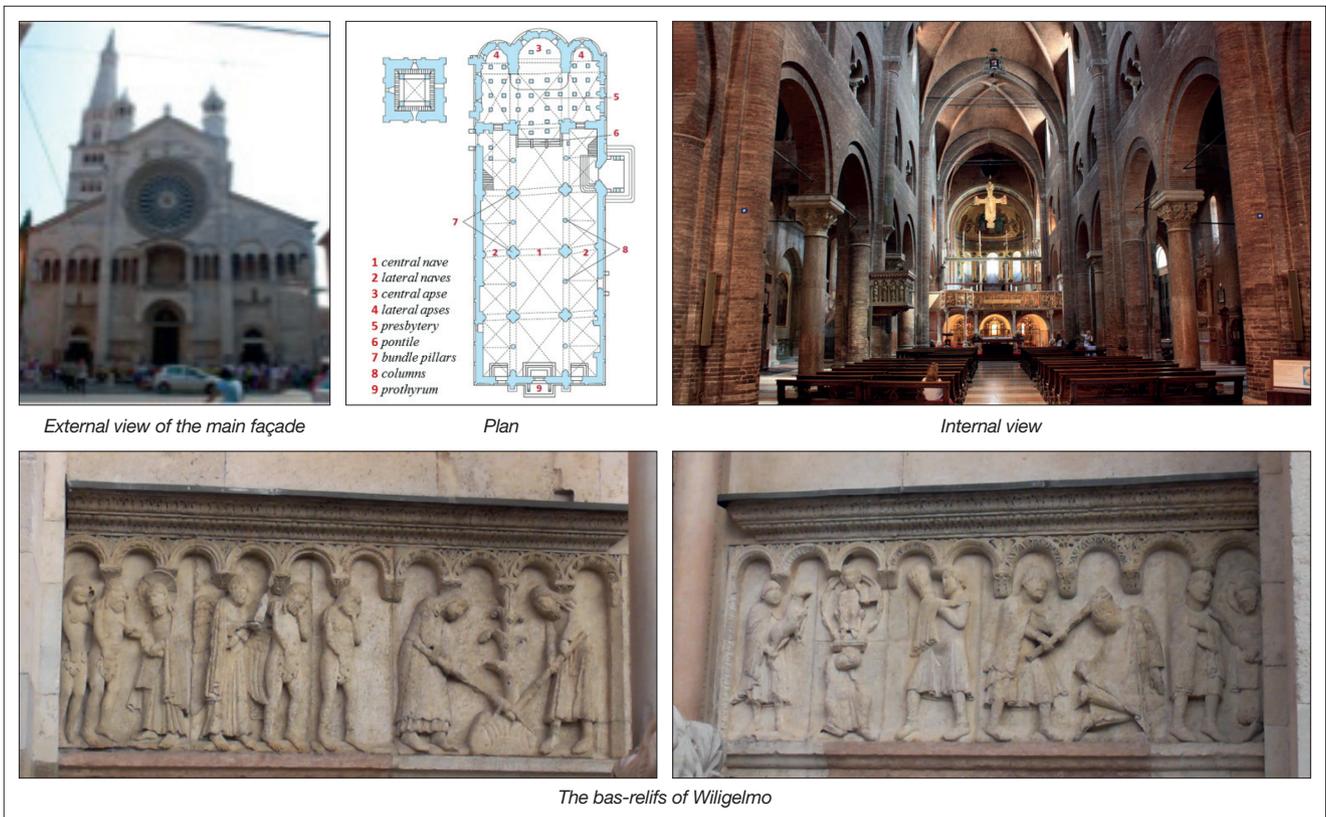


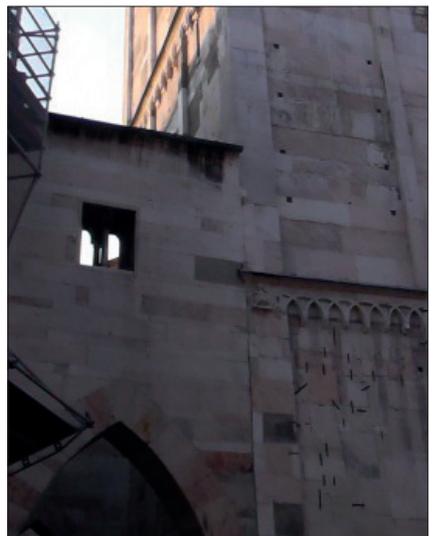
FIGURE 19 The San Geminiano Cathedral in Modena



The Ghirlandina Tower



The Ghirlandina Tower



Arches between Tower and cathedral

FIGURE 20 Pictures of the Ghirlandina Tower

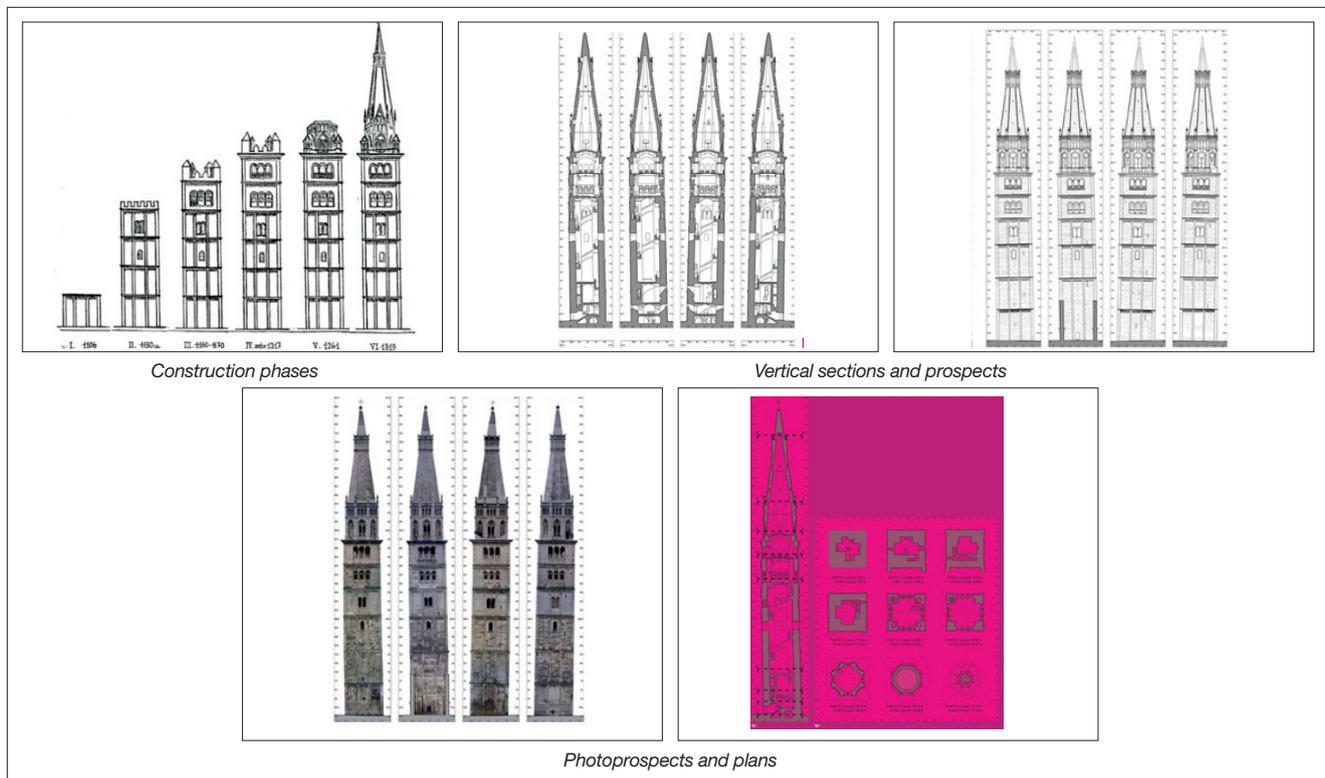


FIGURE 21 Drawings of the Ghirlandina Tower [10-11] in [14]

The chronology of Ghirlandina (pictures in Fig. 20) is still uncertain, as primary historical sources were destroyed during a fire in the XI century. The Tower (height 88 m) knew different construction phases over time (Fig. 21, [10] in [14]); the square levels can be attributed to Lanfranco and Wiligelmo (XII century), while the Campionesi Masters realised, in exquisite gothic style, the octagonal tambour and the cusp between 1261 and 1319. Prospects, sections and plans are reported again in Fig. 21 ([11] in [14]). Since the beginning, the Tower was subjected to subsidence and inclination ([12] in [14]). The constructors placed the heaviest stones on the opposite side of the slope; therefore, the centre of mass changes level by level. Nowadays, the sinking depth is about 1 m and the inclination more than 1.5 m. In 1997 UNESCO inscribed the Cathedral and the Ghirlandina Tower in the World Heritage List, together with the Piazza Grande.

The 1996 earthquake (see again Section 2) affected all the complex, which was restored between 2007 and 2008; the cathedral underwent: the substitution of some timber trusses, the repairing of masonry cracks, the restoring of the rose window, the small columns and the XV century polychrome glass-windows, together with diagnostic and monitoring campaigns [13]. Ghirlandina was subjected to a whole conservation project [14]. Among other interventions, monitoring systems and reinforcement devices are shown by Fig. 22. During the May 2012 seismic events, the whole complex supported the PGA maximum value of 0.037g and 0.055g (Modena recording station), respectively on May 20th and 29th.

Damage survey and observed mechanisms
- The cathedral survey permitted to detect some damage, mainly related to the masonry cross-vaults of

the lateral nave. Cracks along the ribs and falling of bricks were found. Such damage has been repaired through prompt interventions (almost completed at the time of our visit), ringing of the ribs with metallic plates fixed to the vaults (Fig. 23a), and filling the cracks with resin (Fig. 23b).

In addition, the main façade showed a potential overturning mechanism, slightly triggered, highlighted with a black line in Fig. 24. Moreover, the opening of the transversal walls (corresponding to the lateral nave) from the longitudinal one has been observed (Fig. 25), due to the variability of the mechanical properties of the soil foundation.

All the detected main mechanisms are summarised in Fig. 26 (Cathedral, global damage index equal to 0.16) and Fig. 27 (Ghirlandina, global damage index equal to 0.27), respectively.

The following several interventions were suggested after the investigation: structural re-establishment of damaged vaults, arches, ribs and unconnected wall portions. The implementation of the monitoring system – for a deep and permanent dynamic characterization of the whole complex, evaluating in particular church/tower interactions – is considered necessary and propaedeutic to complete the existing strengthening systems, in both the Cathedral and the Ghirlandina.

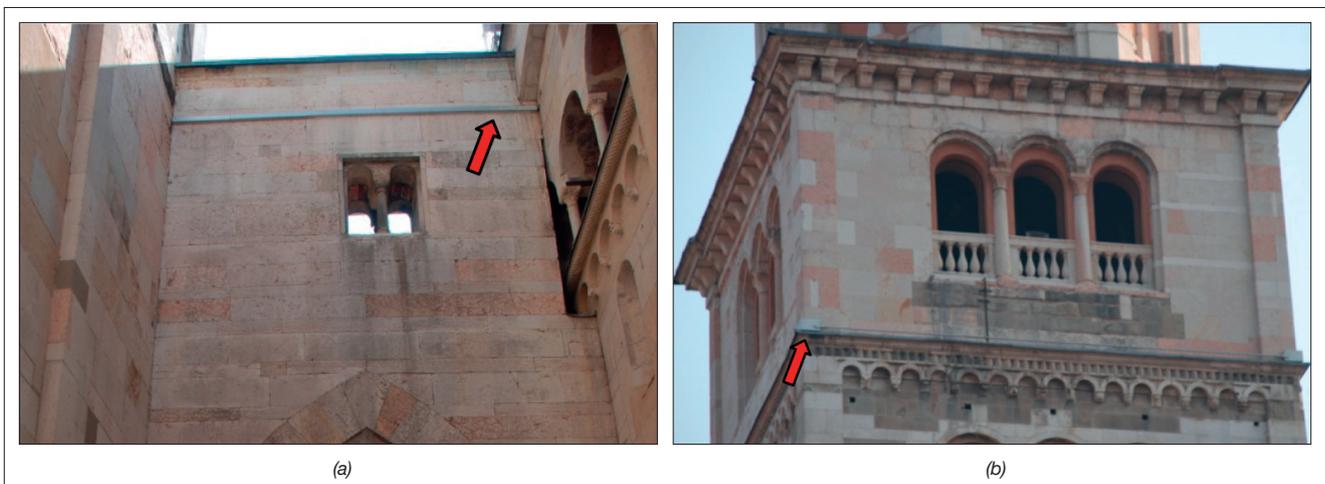


FIGURE 22 Monitoring and seismic devices: relative displacement measure device between Cathedral and Tower (left); b) steel tie all around the last square level of the Tower (right)



FIGURE 23 The San Geminiano Cathedral: a) ringing of the vault ribs; b) filling of the cracks



FIGURE 24 The San Geminiano Cathedral: potential overturning of the façade

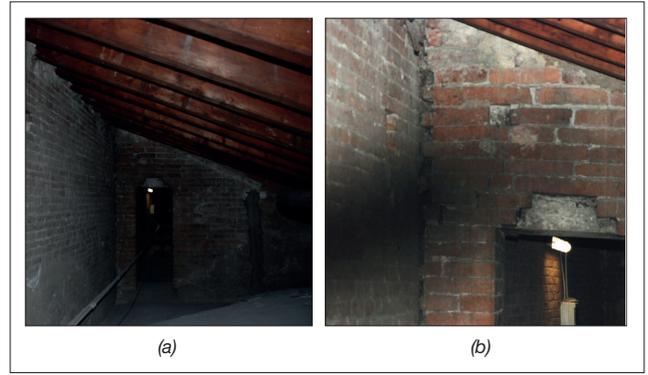


FIGURE 25 The San Geminiano Cathedral: overturning of the lateral transversal walls

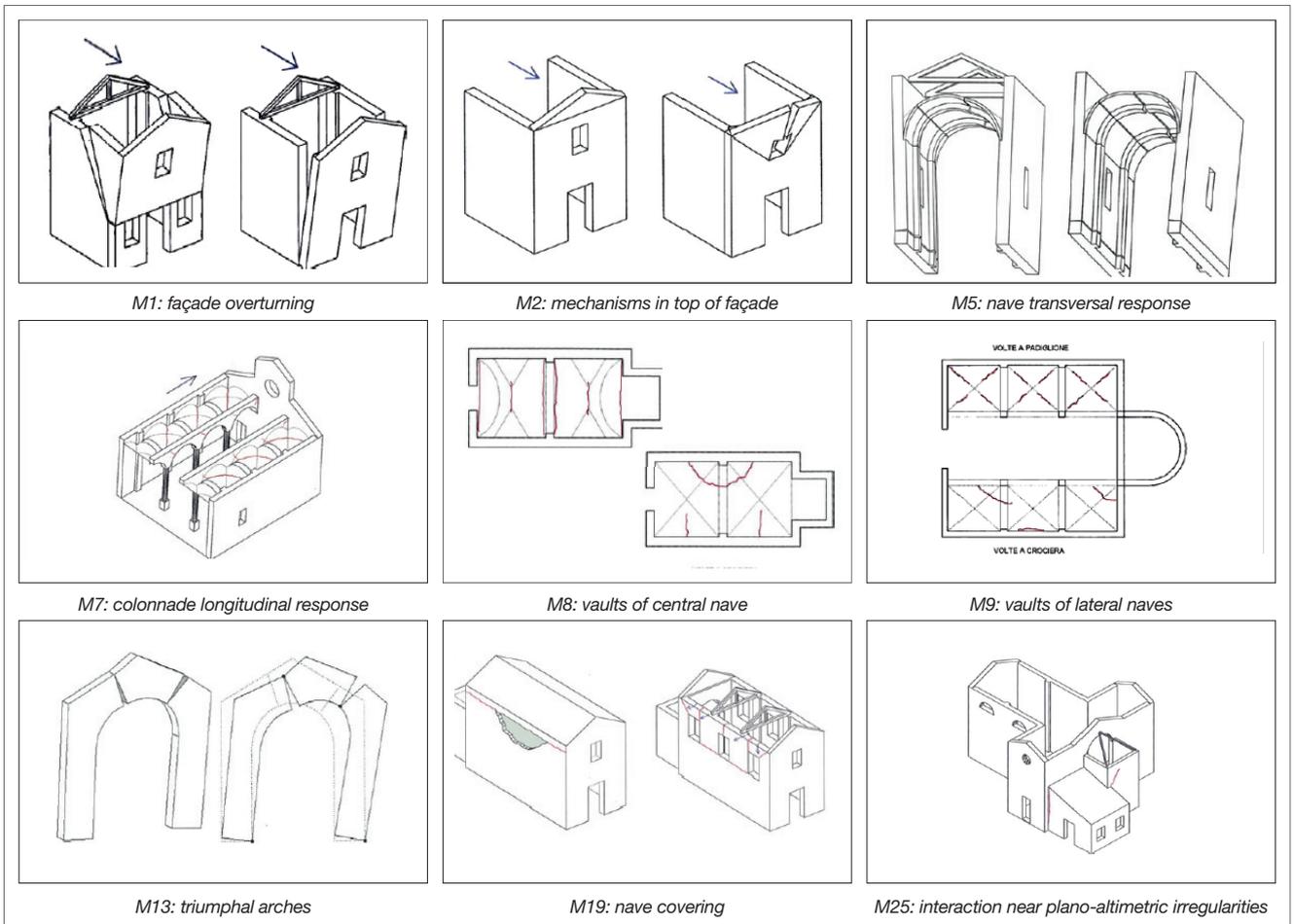


FIGURE 26 Damage mechanisms in the Cathedral of San Geminiano (Modena)

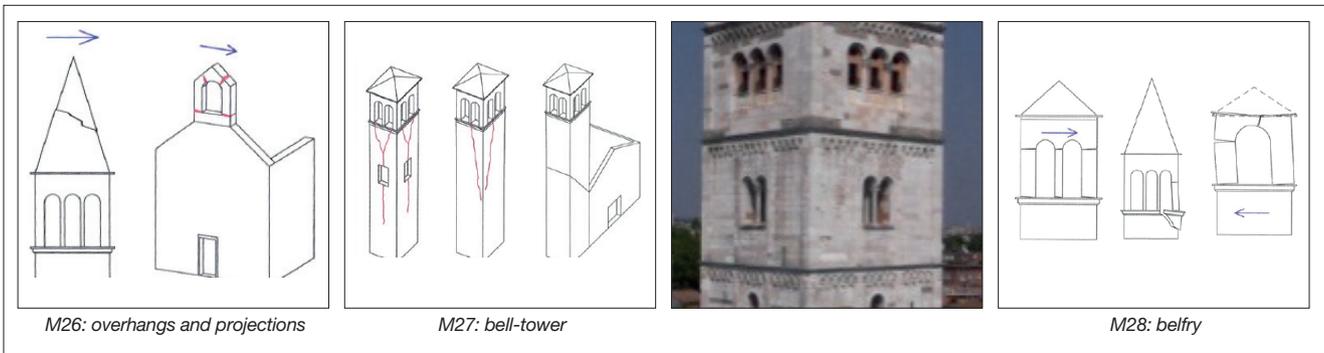


FIGURE 27 Damage mechanisms in the Ghirlandina Tower (Modena)

The Church of San Giovanni Battista in Triario (Minerbio, Bologna)

Description - The Parish of San Giovanni Battista in Triario (Fig. 28) is located in the hamlet of San Giovanni in Triario, countryside of Minerbio, a little town 15 km far from Bologna. The first building was probably built around the XI century, but the current neo-classic construction (full brick masonry, designed by

the architect Francesco Gibelli) is relatively new, belonging to the Napoleonic period (1807-14), still containing an **ancient baptismal font**, as well as paintings attributed to **Daniele da Volterra**. It houses a very interesting **Museum of Popular Religion**. Furthermore, the church has been one of the locations chosen for the 1976 Italian thriller cult movie “*La casa dalle finestre che ridono - The House with Laughing Windows*”, directed by the Bolognese Pupi Avati [15].



FIGURE 28 The Parish of San Giovanni Battista in Triario (Minerbio, Bologna)

Damage survey and observed mechanisms - The church was bombed during the Last World War and the original bell-tower collapsed. Never completely restored, at the time of our visit it showed a generalised previous damage in walls, vaults and arches, worsened by the earthquake (Fig. 29). The main mechanisms are reported in Fig. 30, corresponding

to a global damage index equal to 0.16. During the May 2012 seismic events, the church experienced a PGA maximum value of 0.040g (Medicina recording station). After the survey, it was considered safe, but the maintenance poor (previous cracks, humidity due to rain). Tying enhancements of nave and tympanum have been suggested.



FIGURE 29 Damage mechanisms in the Ghirlandina Tower (Modena)

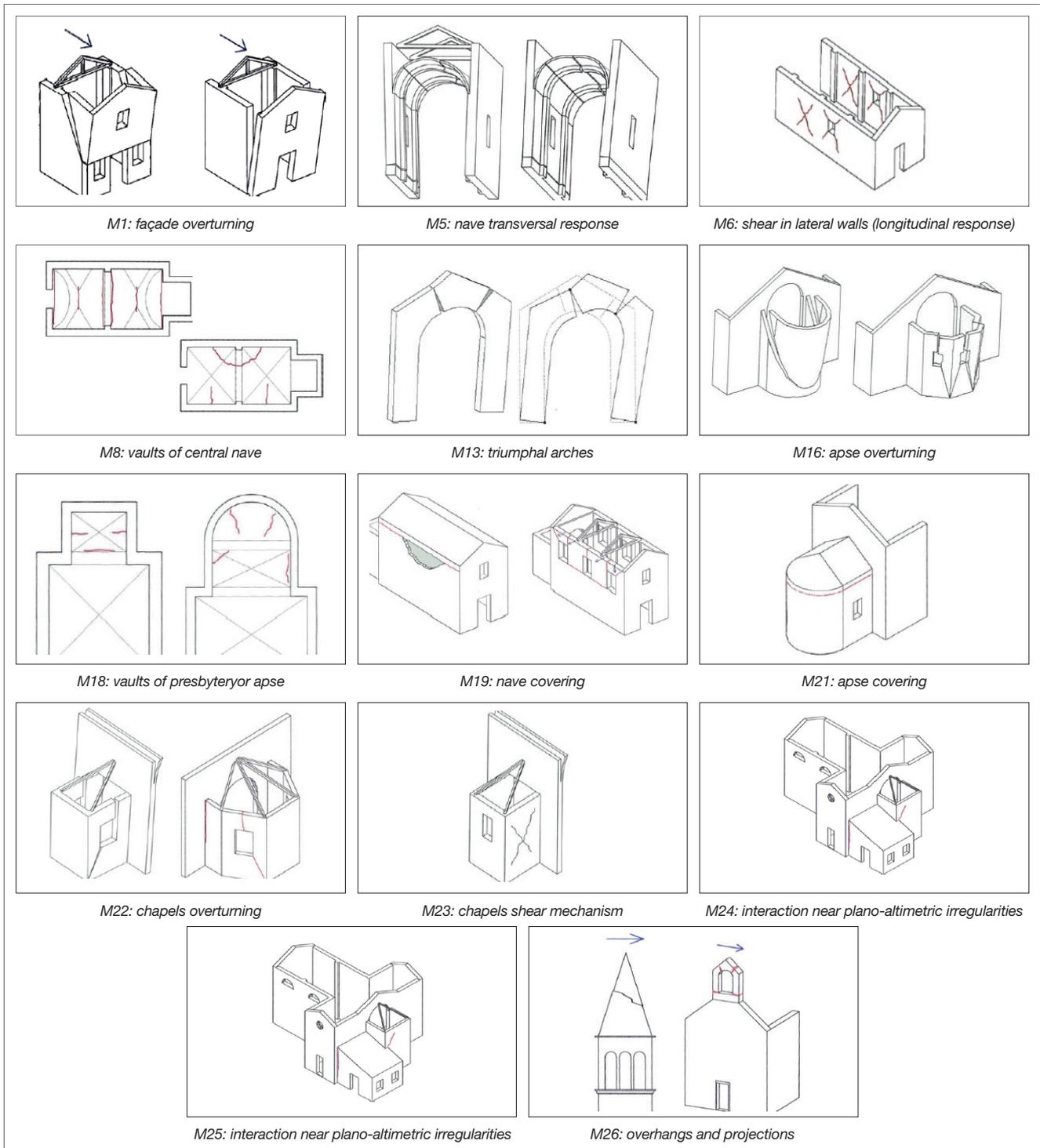


FIGURE 30 Damage mechanisms in the Parish of San Giovanni Battista in Triario (Minerbio, Bologna)

The Church of San Lorenzo (Budrio, Bologna)

Description - The Church of San Lorenzo (full brick masonry, see Fig. 31) is located in the historic centre of Budrio (Bologna), just in front of the Municipality Palace. Founded together with the convent between the XI and the XII century, it saw restorations and extensions after 1406, when the Friars Servants of St. Mary became the regents. Building modifications continued over time, and the final version took place in the XVII-XVIII centuries, when the church was com-

pletely renovated by the architects Alfonso Torreggiani and Giuseppe Tubertini. The original bell-tower was destroyed by the German soldiers in 1945 (fortunately without victims), ruining on the Western part of the cloister.

The current church showed external buttresses and transversal steel ties in the central nave arches. In good conditions of maintenance, it was declared unsafe after the last earthquake (shaken by a maximum PGA of 0.040g, Medicina recording station), and partially unsafe after our investigation.

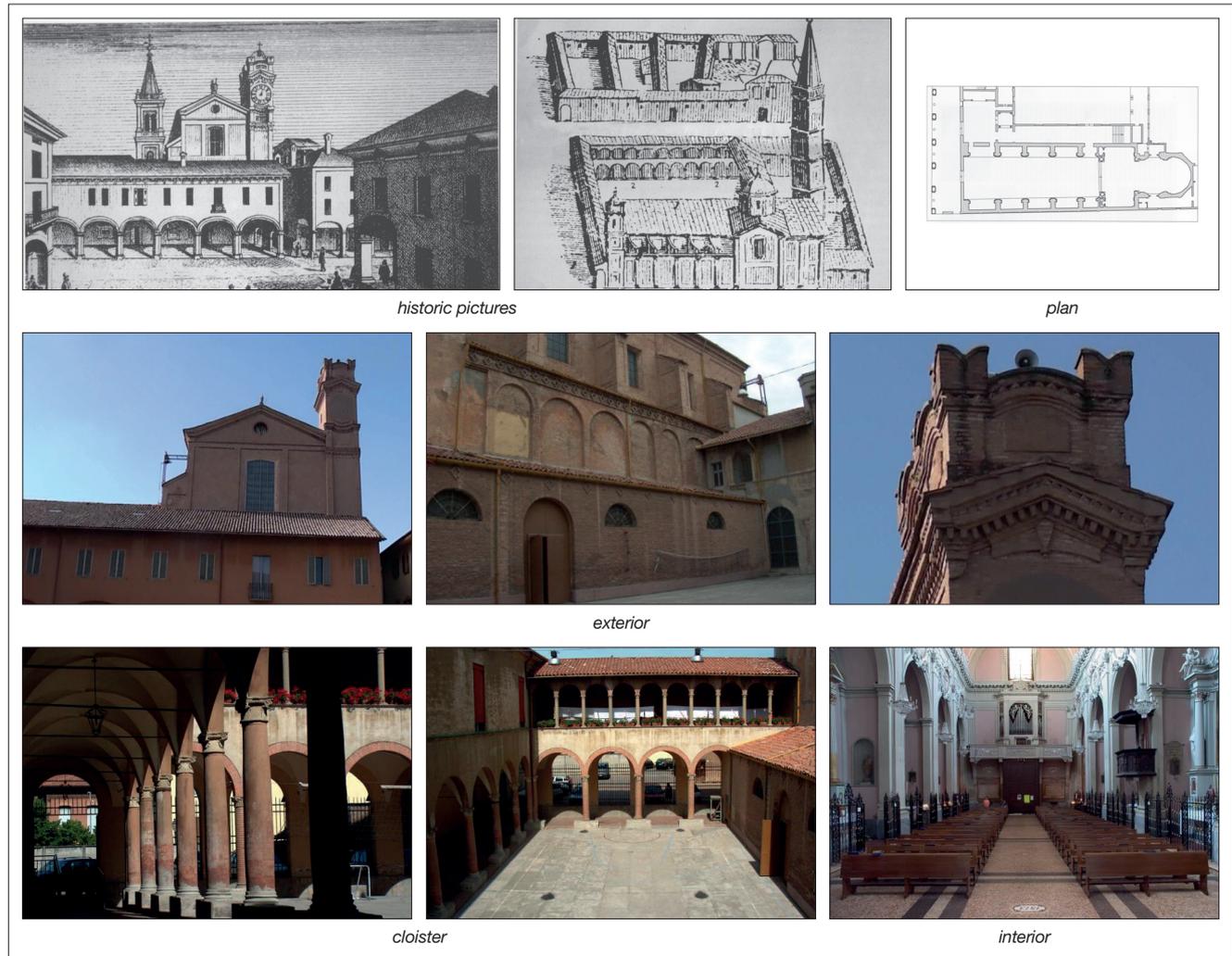


FIGURE 31 The Church of San Lorenzo (Budrio, Bologna)

Damage survey and observed mechanisms - The observed damage in the church was clear enough: in the dome, in the triumphal arches, in the central nave (vaults and colonnade); in the vaults of the lateral naves; in the apse vaults (Fig. 32). Probably, the construction moved with a longitudinal response, because steel ties were present only in the transversal direction. Many stucco pieces detached from the rich

decorations and were collected by the church personnel. The fresco of the dome was also injured. The main mechanisms are reported in Fig. 33, corresponding to a global damage index equal to 0.13. Together with an overall restoration of the harmed parts, a strengthening intervention is recommendable, in particular in the nave longitudinal direction, anticipated by an accurate dynamic characterization of the structure.

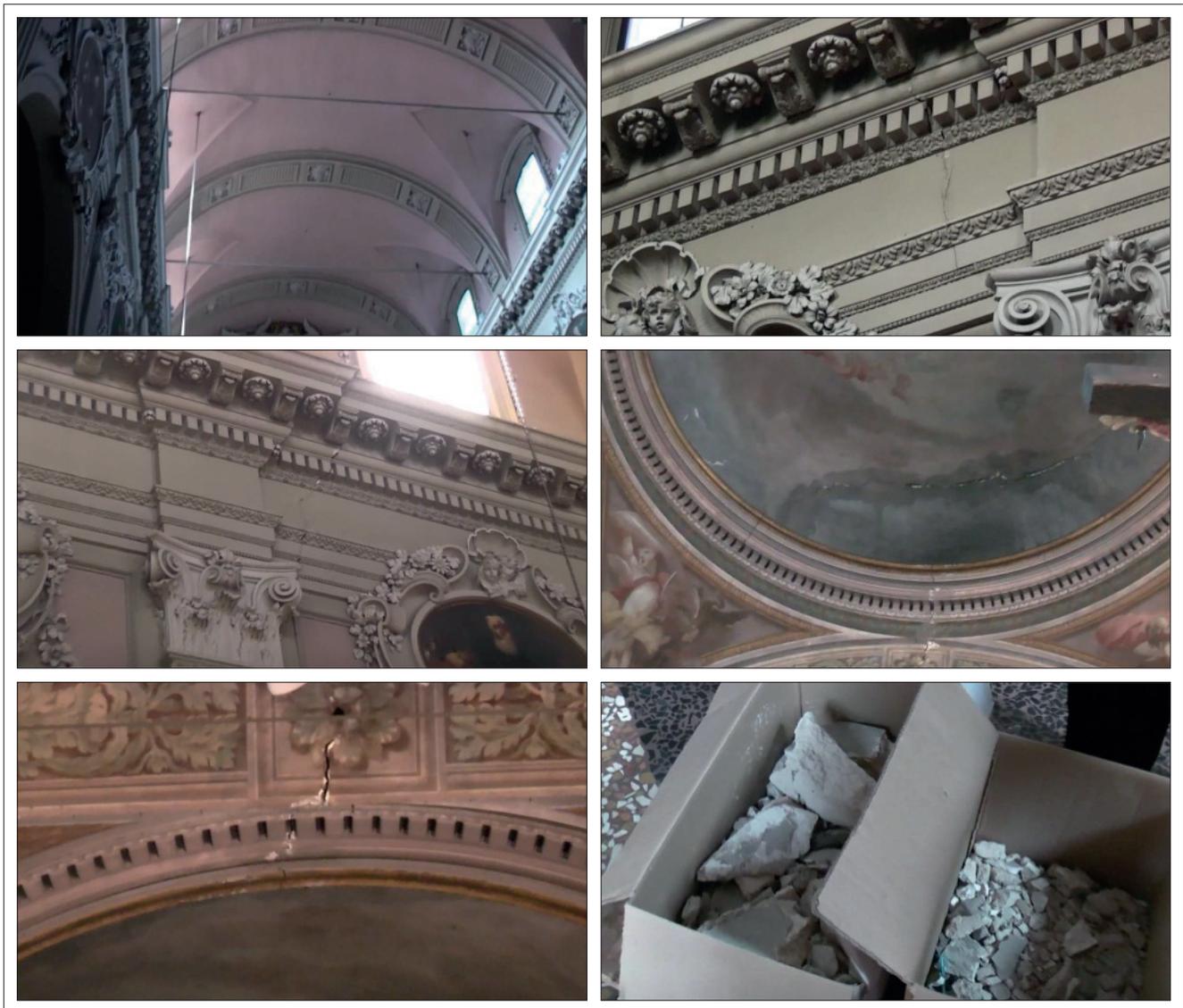


FIGURE 32 Damage to the Church of San Lorenzo (Budrio, Bologna)

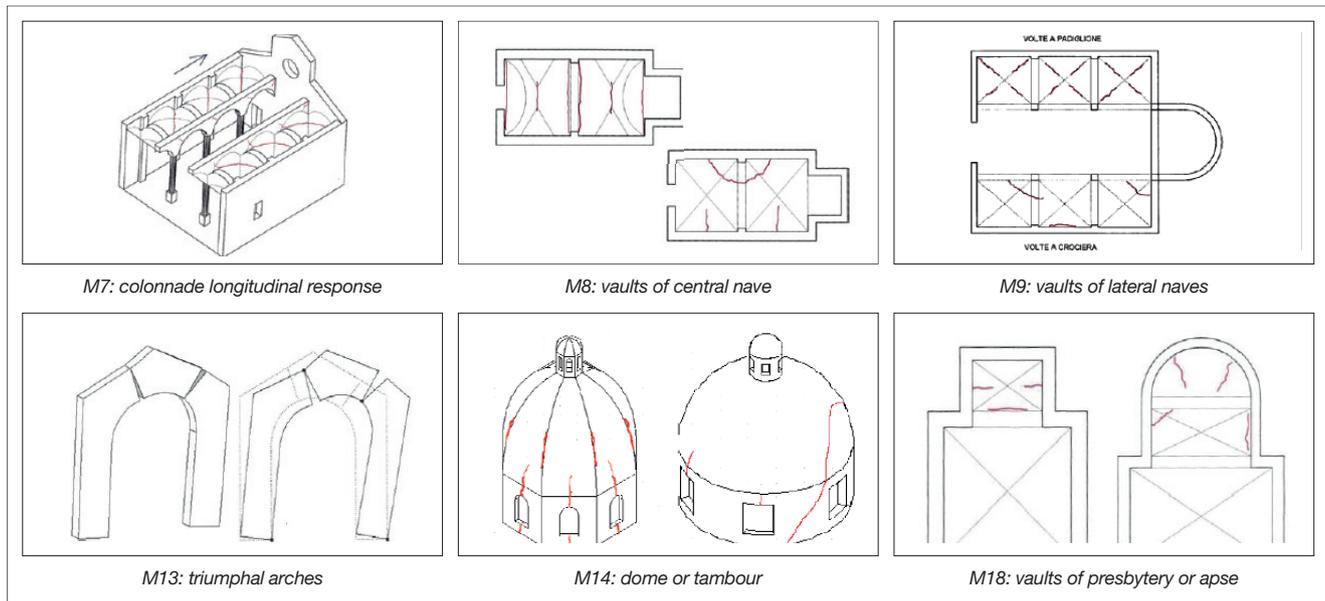


FIGURE 33 Damage mechanisms in the Church of San Lorenzo (Budrio, Bologna)

Conclusions

Although the May-June 2012 Emilia-Romagna seismic events can be considered moderate and geographically circumscribed, they caused heavy and widespread structural damage to cultural heritage construction, as churches, bell towers, palaces, and castles, together with loss and deterioration of mobile assets (frescoes, paintings, statues, ancient furniture, etc.). Several damage mechanisms were activated, at a different level of gravity, until collapse, detected by carrying out quick surveys through a well-established and effective Italian procedures (church and palace forms).

It should be certainly underlined that the Po Valley, including the affected area, was not classified as a seismic zone until 2003, so that past restoration projects did not consider loads due to earthquakes. That implies – particularly for cultural heritage, which must be handed down intact to posterity as far as possible – the duty to carry out our best as of now, in order to meet the antiseismic requirements.

It is not an easy task, because any improvement should be made in harmony with the conservation

criteria, avoiding possible conflicts. About this remarkable matter, a valid reference is represented by the Italian Guidelines for the evaluation and mitigation of seismic risk to cultural heritage [16], which stresses, as first unavoidable step, the need to get a deep knowledge level of the monument.

Above all, the quality of materials is definitely important. In general, the collapse of full brick masonry walls (the most frequent typology encountered during the surveys) was facilitated by the scarce binding features of mortar, whose properties should be improved, in a compatible way, during future interventions. To this purpose, widespread diagnostics experimental campaigns (*in situ* and in laboratory) on construction materials shall be indispensable, together with structural dynamic characterisations and sharp numerical analyses.

In sequence, global and local overturning (out-of-plane) mechanisms should be avoided, achieving a structural “box behaviour” by means of adequate connections or anchors at each level, both in the longitudinal and transversal directions, and linking elements as tympana and sail bell-towers. The analysis

of the heritage stock, presented in this article, has shown that overturning mechanisms (or others related with them) are the most frequent cause of heavy damage/collapse of churches, whereas buildings with stretcher bond stones and/or steel ties always exhibited an evident better response.

Particular attention should be devoted to bell-towers, planning improvements against failure due to pounding, bending and torsion.

Finally, it is necessary to emphasize the role of prevention in heritage preservation, setting up investigation programs before the disaster, focused on the vulnerability evaluation of structures not adequately designed, taking advantage of the outcome of innovative research and technology. On the contrary, medium-long periods of seismic inactivity reduce people's awareness and consciousness of the earthquake danger, resulting in inadequate strengthening of buildings. ●

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