

SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING  
AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014



## Seismic response of historical monuments and structures: The state of the Cathedral of SS. Massimo e Giorgio (L'Aquila, Italy) after the earthquake of April 6th, 2009

Marta Brancaleoni<sup>1</sup>

<sup>1</sup> PhD, Pell Frischmann former University of Tor Vergata

marta.brancaleoni@gmail.com

**Abstract:** *This paper aims to presents the situation of the cathedral of SS. Massimo and Giorgio after the earthquake of April 6<sup>th</sup> 2009, when L'Aquila, together with surrounding villages, suffered extensive damage. These studies was carried out by the author as part of a Ph.D. thesis about the history of the Cathedral and the Archbishop complex, with the purpose of given an exhaustive database about traditional building technique, materials, and decorative elements and seismic strengthen of the fabric during the centuries<sup>1</sup>.*

### 1 INTRODUCTION

The cathedral of SS. Massimo e Giorgio is located in the main square of L'Aquila, named after the church *piazza Duomo* and known also as *piazza del Mercato*, as the main location since centuries. The church occupies a rectangular block about 110x84 m, between the square, *via Roio*, *via del Seminario* and *via San Marciano*.

The building is part of a larger compound that includes the Archbishop Palace, with its offices, the S. Luigi's Chapel, the seminary and a number of private apartments. The square was the central spot in the ancient city, where political, public and spiritual life took place<sup>2</sup>. Several ancients' maps show that, probably, both square and cathedral were present since the earliest urban settlement. The Archbishop Palace was placed in one of the houses that occupied the side of the church: The actual form of the palace is due to the recasting of the XVIII century's buildings, on the south side of the site, and the additions made during the XIX century.

---

<sup>1</sup> Marta Brancaleoni, "La cattedrale dei Santi Massimo e Giorgio all'Aquila e il complesso arcivescovile. Storia architettonica e storia sismica nella prospettiva del restauro", Dottorato di ricerca in Storia, Conservazione e Rappresentazione dell'Architettura, ciclo XXIV.

<sup>2</sup> GIZZI S., "La città dell'Aquila: fondazione e preesistenze", *Storia della città*, 28, 1983, 11-42: The author affirms that the square was at the beginning a military camp; cfr. anche CLEMENTI A., PIRODDI E., L'Aquila, Roma 1988, pp. 28- 29.

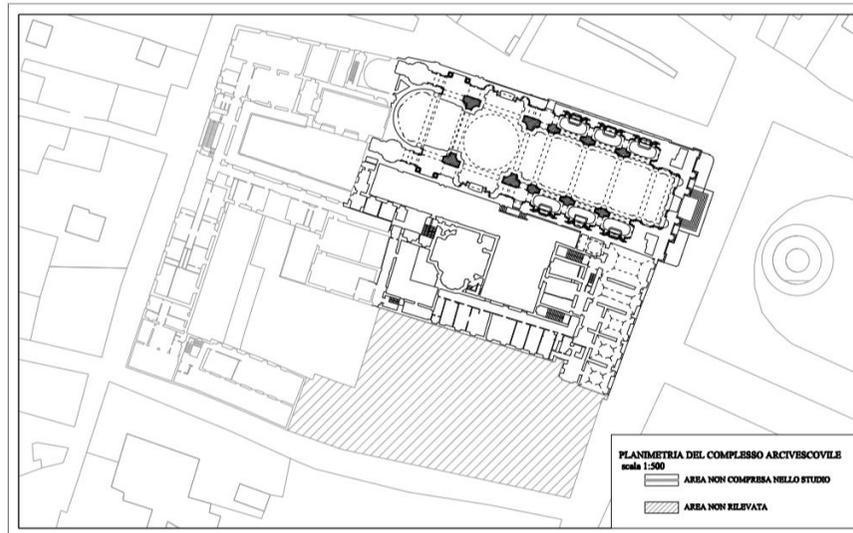


Figure 1 – Site Plan of the Cathedral and Archbishop Palace.

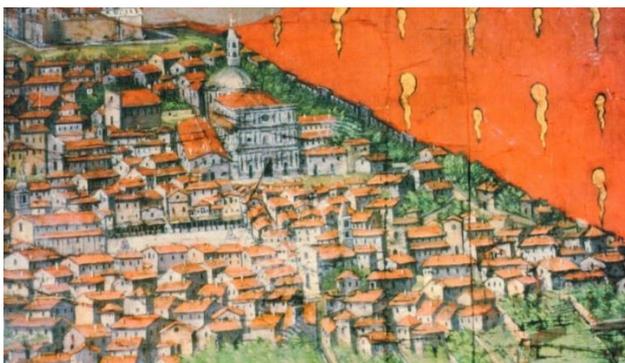


Figure 2- 1579, Giovanni Paolo Cardone, *Gonfalone* (Gonfalon), the cathedral of SS. Massimo e Giorgio is visible on the left side of the painting.



Figure 3- Polyptych of *San Giovanni da Capestrano*, the upper right image show the Saint preaches in front of the Cathedral (XV century).

## 2 DESCRIPTION OF THE BUILDING

The building history is strictly connected with the foundation of the city, started during the XIII century. The construction of the building lasted until the XX century, when the main façade was completed in its present configuration. The history of the buildings is also connected with the seismic history of L'Aquila's region: During the centuries several earthquakes struck the town, and the church suffered many time of hardly damages. The present fabric is the result of different phases of damage and reconstruction: The most important reconstruction took place after the earthquake of January 2<sup>nd</sup>, 1703. The design of the building was credited to Sebastiano Cipriani, roman architect, according to the XVIII century's notary deeds stored at the *Archivio di Stato dell'Aquila* (L'Aquila States Archive).

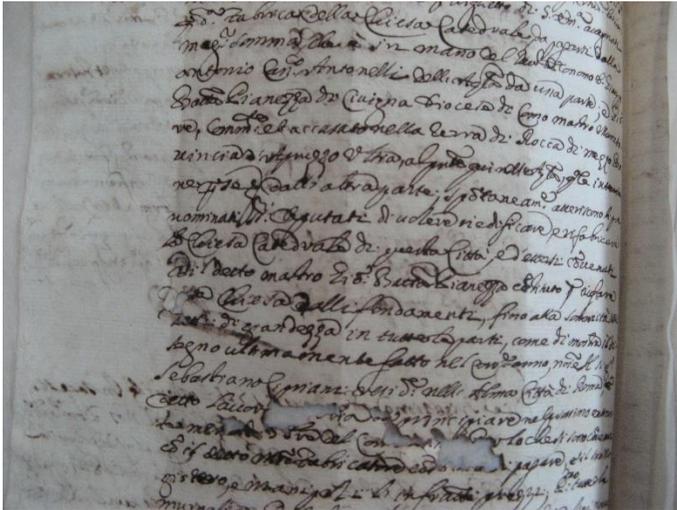


Figure 4- Detail of the 1711's notary deeds.

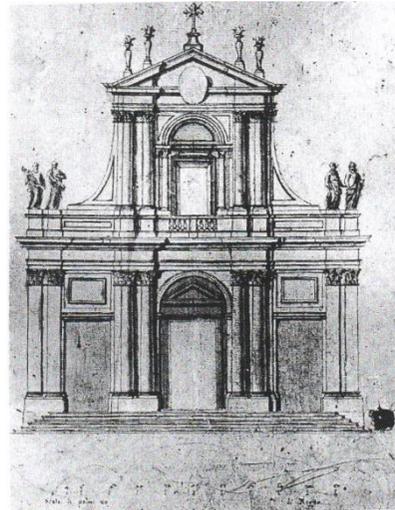


Figure 5- Main Façade of the Cathedral, drawing credited to Sebastiano Cipriani.

The cathedral has a Latin cross plan, divided in three naves: The main nave measuring more than 70 m and the side naves are formed by intercommunicating chapels, covered with elliptical masonry domes. The communication between the chapels is so large that the final effect is to have side aisles. The lighting is provided by semi-circular windows, obtained in the raising part of the walls.

The main body of the cathedral ends with a vaulted apse containing the choir and the major altar. Beside the apse, in a separate position, are located two small round rooms covered with vault made in incoherent stones, as it is possible to see after the collapse. The left room is the stair case that connected the church with the sacristy. The apse was covered with a truss roof supported by four masonry pillars. The transept was covered with a painting on canvas with a perspective projection of a dome<sup>3</sup>. The main nave was covered with a false barrel vault made with *camera canna* system<sup>4</sup>, settle on a cornice; the elevation is divided by pillars with Corinthian capitals.

The external wall on *via Roio* is the only remaining of the medieval church: The wall measures 32.20 m, the masonry texture presents a variation of proportion between the squared shaped stones used in the courses (*opus pseudo-isodomum*). The wall is divided by ten lesenes with a quadrangular base lay on a socle of 30 cm.



Figure 6 – The interior of the church before the earthquake.

<sup>3</sup> The original design considered the idea of a dome which was never built. The canvas was added in 1888 and painted by Teofilo Patini.

<sup>4</sup> The ceiling is made with canes supporting the plastering. The canes should be both round or flatten.

### 3 DESCRIPTION OF THE DAMAGES

The main shock occurred at 3.32 a.m. and was rated as 6.3 in the moment magnitude scale (MMS), equal to 5.8 in Richter scale.

The following description was carried out from the visual inspection of the damages, during the months after the earthquake.

The pillars of the main nave, that support the false ceiling made with *camera canna*, present cracks with vertical development visible along the height of the pillar, as well as at the base with spalling and/or fall of the elements of the plasters, especially the parts that compose the corner. All elements indicate that the damage is to be associated with excessive vertical load. The described damage occurs in a diffuse way, but in a very different extent in distinct areas. The three pillars remaining in the area of the presbytery are extremely damaged, in particular towards the apse, while the same signals are present to a much lesser extent, although well detectable, in the pillars of the nave, with further regression less evident, but noticeable as one moves away from the presbytery.



Figure 7 – Vertical cracks on the transept pillar.

The evidence is that the pillars suffered from increase of vertical, in addition to horizontal, seismic action<sup>5</sup>. This increase is particularly relevant for the pillars of the transept that bear the pendentive of the fake dome. The masonry of these pillars does not have an ordinary setting and the mortar presents poor grading of the aggregate and an inadequate tooling. The mortar usually used for masonry joints can be classified on the basis of the binding materials: lime mortar, gypsum mortar and cement mortar. Lime mortar can be found in the original brickwork and at large in all the work done before the XIX century. Gypsum mortar and cement mortar can be found in the most recent structural strengthening. The quantity of mortar per masonry unit is not enough to guarantee a proper connection between the stones, one of the reasons for the damage occurred to the structure during the seismic events. Similar behaviors can be found in several of the masonry buildings in L'Aquila. It is easy to understand how one of the main load-bearing elements of the fabric reached the ultimate compression strength and collapsed: The collapsing of the pillar caused consequently the collapse both of the roof elements and the wall next to it.

<sup>5</sup> Cf. The presentation of Prof. Franco Braga during the conference “Il sisma del 06 aprile 2009”, Università La Sapienza, Rome 19 June 2009.



Figure 8, 9 – Vertical cracks on the transept pillar.

The remaining pillars of the transept undergone unloading, when the roof collapsed, and hence remained standing, although showing significant damage.

The pillars of the main nave show the same type of damage but to a lesser extent and did not approach collapse, due to the lower loads of masonry and roof they carry. In no case compression instability phenomena were observed, despite of the slenderness that is considerable for a masonry column. Compression damage was observed in columns and joints also in studies on modern reinforced concrete buildings, effect attributed to the vertical seismic action and corresponding response of the structures.



Figure 10, 11 – Collapsed masonry.

The remaining parts of the church, although not collapsed, show significant damage, distributed in non uniform levels. Even the side chapels present crackings. On the left side of the nave, in correspondence to the altars in the side chapels, it failed the infill wall within openings that over the centuries have been closed. These closures are probably related to the

elevation of the building in late XVI century and the following reconstruction after the earthquake of 1703. The fall of plaster occurred in all spaces.



Figure 12, 13 - Collapsed infill walls in the lateral chapels of the left side nave.

Also considerably damaged the apse, where it can be observed a cracking state with prevailing vertical alignments, again indicating an excessive vertical load in the rather slender masonry walls forming its perimeter. This can be pointed out as one of the causes of the damage, to which it has most probably given a contribution a partial increase of thrust of the quarter-sphere semi-dome of the apse itself. To confirm this scenario, fall and spilling of lapideous materials, notably in corners, are observable. In the pictures it can also be noticed as the cracks are of small size at the base, progressively grow with height, reaching a maximum for intermediate levels and closing again at the top, in the vicinities of the roof. This aspect, of a certain interest, will be discussed in the following.

The only elements that did not undergo significant damage are the facade on *Piazza Duomo* and the perimeter wall along *Via Roio*, the latter as already pointed out the only element of the medieval church surviving in the seismic history of the building. Attributing this observation to a well defined circumstance it is not straightforward and the author does not wish to put forward statements lacking a solid rationale. Indeed, the masonry manufacture is excellent, showing large ashlar stone elements, well refined and assembled, with thin and uniform mortar joints, of a quality by far superior to the masonry of the later reconstruction works that form the majority of the church.

The perimeter wall on the opposite side, adjacent the bishop palace, show also limited damage, with the exception of the part affected by the transept collapse. Both the longitudinal and transversal masonry walls alignments, of a large bearing capacity for vertical and shear actions, are hence in essence undamaged. In the whole complex there is no evidence at all of diagonal crackings, typically associated with shear and horizontal forces, as a final confirmation of the mechanisms proposed and of the peculiarity of the seismic event that, due to the vicinity of the source fault, produced an horizontal shaking component significant but non dominant for this type of buildings.

For a full outline of the seismic response of the Cathedral it is considered of interest discussing a further aspect: the behavior of a number of reinforced concrete elements adopted in the framework of strengthening works carried out in the Sixties, following the earthquakes of the previous decade.

These comprise:

1. Extensive string-courses, associated with the replacement of the roofing, running over the top of all the perimeter walls, including the apse;
2. Double shaft columns, cast into deep vertical grooves, located in the external longitudinal walls in correspondence with the transept, showing very poor materials and manufacture quality;
3. A square contour framing the opening where the canvas with the dome perspective painting is located.



Figure 14 - R.c. string-courses framing the transept opening.

Observed behavior is threefold, regarding respectively the string-courses in the collapsed area, the second the double shaft pillars and last the summit string-courses of the perimeter walls. In the first case the patent ineffectiveness in preventing collapse should be not addressed in a negative manner: as the very term states, a “stringer” is aimed at carrying tensile forces, like an internal “rope”, present in certain areas of the masonry structures texture, e.g. connecting wall tops to each other. Here the collapse is due to the lack of a vertical bearing element, the transept pillar that reached its limit load capacity, on which the contribution of a stringer is nihil. Nor one should think that a role was played by the weight of such r.c. elements: simple quantitative evaluations show how minor is the relevance of this additional load with respect to those induced by the masonry itself and in particular by the massive pendentives surrounding the transept.



Figure 15 - R.c. string-courses in the area of the collapsed left side wall.

In the case of the double shaft columns the rationale underlying such strengthening is not completely clear. One may think them to be aimed at increasing the vertical bearing capacity of the walls or, more probably, at increasing the out of plane bearing capacity of the same. If no certainty can be stated about the objectives, it is a fact that these works, badly conceived and manufactured, are addressed to an element that revealed not to be the weakest. Again, on the whole a strengthening that revealed to be of minor or no influence in the collapse mechanism, either positively or negatively.



Figure 16 - Double shaft columns, left side wall.



Figure 17 - Double shaft columns, left side wall.

Last, the evaluation of the behavior of the summit string-courses of the perimeter walls. Here one can safely state that they did play a positive role, made clear by the well visible, thin and diffuse cracks they show in the perpendicular direction with respect to the string axis, present throughout the building and more evident in the apse. Unmistakable sign of having undergone significant tensile force that the masonry structure would have been unable to withstand. This allowed the vertical cracks in the walls of the apse to remain limited and to close in the upper levels, closet to the course. It was hence developed an effective tie function that has most probably prevented the complete apse collapse.



Figure 18 - Summit string-courses, transept.

#### 4 CONCLUSIONS

With no intention to draw conclusions of full general value and with main reference to this study case, as well as without denying the inopportunity in principle of strengthening works that envisage the use of materials and techniques not consistent with the original ones, it is believed what has been observed to offer to scholars a cue for considering how, in any historical span, strengthening measures and conservation in general cannot but refer to available know-how and materials, to be looked at with realism, rationally evaluating their effectiveness in the specific context and refraining from easy prejudiced bans. From this standpoint, the lesson of the *Duomo* of L'Aquila shows how, though disputable, reinforced concrete elements within masonry compounds may show their own effectiveness if well-conceived, well manufactured and addressed at clear, pursuable targets.

#### 5 REFERENCES

ANTONINI O., *Le Chiese dell'Aquila: architettura religiosa e struttura urbana*, L'Aquila 2004

ANTINORI A.L., *Ad historiam Aquilanam introductio*, in MURATORI L.A., *Antiquitates Italicae Medii Aevi*, VI, Milano 1742

BARTOLINI SALIMBENI L., *Delle tipologie religiose nell'architettura abruzzese fra XI e XIX secolo*, in "Abruzzo. Rivista dell'Istituto di Studi Abruzzesi", anno XXXVI, gennaio-dicembre, 1998, pp. 27- 129

COLAPIETRA R., *L'Aquila dell'Antinori: strutture sociali ed urbane della città nel sei e settecento*, L'Aquila 1978

CLEMENTI A., PIRODDI E., *L'Aquila*, Roma 1988

DOGLIONI F., MAZZOTTI P. (ed), *Codice di pratica per gli interventi di miglioramento sismico nel restauro del patrimonio architettonico. Integrazioni alla luce delle esperienze nella Regione Marche*, Ancona 2007

GIZZI S., *La città dell'Aquila: fondazione e preesistenze*, in "Storia della città", 28, 1983, pp. 11-42

GIUFFRÈ A., *Note sull'efficacia delle tecnologie storiche in area sismica*, "Palladio", 5, 1990, pp. 127-134

VARAGNOLI C. (ed.), *La costruzione tradizionale in Abruzzo. Fonti materiali e tecniche costruttive dalla fine del Medioevo all'Ottocento*, Roma, Gangemi, 2008