Some considerations of structural restoration of S. Giacomo church’s in Gavi (Alessandria)

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ABSTRACT: The aim of this paper is to propose some considerations about structural aspects of restoration of S. Giacomo church’s in Gavi, built in XIII century and damaged by seismic actions in April 2003. The vaults on the lateral naves – built in XVIII century – were damaged by cracks and fractures. This fact happened connecting with a particular static situation of colonnade. Authors propose a new method of restoration based on historical methods of analysis of collapse mechanism developed by Coulomb, Persy, and the new trends in this field developed subsequently to the studies of Jacques Heyman.

1 INTRODUCTION

The aim of this paper regards the analysis on statics and stability of church of San Giacomo Maggiore in Gavi after the earthquake of April 2003.

In that occasion the church was damaged in more parts, in vaults on lateral naves and seriously in near buildings as sacristy and rectory.

2 SUMMARY OF CAMPAIGN STUDIES

To fix an exhaustive and complete description of situation after the seism, the Department of “Scienze per l’Architettura” of Genoa University started a series of researches and campaign activities to study geometric and structural conformation of the church. This “compendium” of activities is aimed to know effects caused by seismic action on church’s masonry structures.

First step has been regarded the general condition of monumental building, particularly the statics and stability of structures. This activity has been started with a series of local inspections, to evaluate the presence of fractures and cracks. Second step has been concerned some historical researches, necessary to comprehension of construction history of the church. Third step has been a topographic and longimmetrical survey campaign; these activities have interested all building to establish the church 3D-geometry. Then, an important part of analyses has been devoted to classify the damage map about the cracked vaults, and then the survey was aimed to know the complete situation of fractures in lateral naves of the church. Especially, these analyses has been addressed to define a complete map of cracks situated on the vaults’ extrados, the minor or greater dimension of fractures, to establish their amplitude and depth, corresponding to a significant numbers of geometrical points. This work has been judged necessary for comprehension of cracking phenomena connected to seismic actions. Then it has been started a series of non-destructive tests on materials, to evaluate their strength and to establish safety coefficients and criteria. Particularly, some analyses were devoted to define materials strength as bricks or stones used in vaults construction and in vertical masonry structures. These analyses were accomplished by tests with sclerometer. Then, an accurate relief of columns overhanging and some tests of structural foundations, to establish the ground strength, accomplished studies about columns and pillars.

3 COMPENDIUM ON THE CHURCH HISTORY

The church of San Giacomo was built in Gavi town’s, for assembling in a only centre all people which, in Middle Ages, lived in houses scattered along the valley crossed by Lemme torrent. The church is consecrated to Santiago de Compostela, known in Gavi through pilgrims which, coming from the hinterland and going to Galizia, crossed the Apennine passes, and that today nominated Passo della Bocchetta, on the road jointing Gavi with Genoa (Desimoni, 1896: 44; Sartore, 1933: 133–135; Morasso, 1955: 10; Ceschi et al., 1959: 233–245; Tacchella, 1985: 74–76; Di Fabio, 1987: 115–117).
The first written document, which noticed church’s existence, is a paper of 15 August 1172: with this act, consuls of Alessandria city award fidelity at Albert marquis of Gavi. The meeting happened in S. Giacomo church and so this document testifies that church was already existent in XII century (Desimoni, 1896: 18; Pistone, 1972: 11–13; Meriana e Manzitti, 1975: 48–52; Caresio, 1998: 191–192; Ottonello, 1999: 148–151).

Moreover, a text datable in 1228 testifies that Gavi’s Marquises “... Manfredus. Anselmus. Johannes and Guillelmus – Albert Marquis children – proposed building of S. Giacomo church when and monastery of S. Eusebio was already existent. The S. Eusebio monastery – the first parish in Gavi – was probably built in the middle of XI century. Since, the Albert Marquis lived between 1121 and 1179, his children probably governed Gavi with the father starting from 1150. In fact, they are mentioned in the oath taken from Marquises to Genoa in the same year, but they are not nominated yet in the text of 1130, when Genoa consuls imposed to Alber Marquis to check road conditions near Gavi. The analysis stratigraphic on the masonry and studies about properties materials employed, manufacturing voussoirs metrology, mortar type, testified that church was erected in the middle of XII century. At this time, were built the inferior parts of apsidal zone and of lateral naves. In second time, were completed perimetrical masonries. In third time, at the start of XIII century, were built the front and the bell tower. The portals are positioned when the building of church was already finished; they are not quoined, but only leaned to masonries.

The church has basilican geometry, with three naves and originally three semicircular apses: actually, it is visible only lateral left apse, while other on the right was incorporated in the sacristy built in XIX century, while the polygonal central apse is datable at the end of XVII century (Morasso, 1955: 24–35; Ceschi et al., 1959: 233–245; Chierici e Citi, 1979: 292–293).

The perimetrical masonries are opened by original medieval single lancet and baroque windows; beside the south wall is placed an arcade eighteenth century, which hides original openings. Subsequently, at the end of seventeenth century, outside masonries were made higher, when, at the end of the XVII century, masonries vaults with another roof substituted the wooden roof. The central nave was kept at the medieval height. Consequence of this transformation was the disappearance of transept, visible only for his height above naves level, but not projecting by church sides. His existence today is testified by two simple lancet windows opened in both sides a higher altitude than other holes, and by little suspended arches removed when the church was raised. The suspended arches are guides to recover original roof level.

The church façade is higher above naves level at the back, concealing that in medieval time was a difference between the height of central nave (10.70 metres) and lateral naves (5.40 metres). The major portal is framed by columns, which supported “crochet” capitals. The architrave shows the best piece of sculpture of all the church: this is decorated with an image of the “Last Supper”, united, in accordance with a burgundy tradition art, to the “Majestii”, in two scenes which
converge on the central Christ image, sharing in both representations.

The church is surmounted by an octagonal bell tower, on three planes, supported by four pillars at the cross between transept with central nave. Only the first plane is original because the bell tower was built at the same time of medieval church; instead, probably the columns are positioned during the baroque transformations; they are more interesting because show a particular inclination, but the church has not any statics or stability problems. The church was built using sandstone voussoirs, which are squared with precision and also the putting on is regular: this testifies a good structural technical.

The researches confirm that Gavi was an important cultural centre, which receives a lot of influences from Genoa (which controls Gavi for the most part of his history), Po Valley and France, which realised the church of San Giacomo, masterpiece of Romanesque art. Models for sculpture and architecture come, respectively, from “lombardo-padana” school and from the “antelamica” structural technical, which are present also in Genoa. Instead, the sculpture iconography derives from tympana of burgundy churches, while the geometric models – particular transept, different height between naves, octagonal irregular bell tower – result from the western Piedmont, and probably from the near France. In Gavi it is possible there were skilled workers, submitted to Marquises and employed for the most important buildings, which join French models and Genoese technical.

4 ANALYSIS OF STRENGTH OF MATERIALS

The non-destructive analyses and tests with sclerometer on stones demonstrated that church was built with good materials. The sandstone has good limit strength to compression so as the bricks used in cracked vaults on lateral naves. Particularly, the stones of transept pillars have a strength value medium equal to 32.6/33.5 N/mm²: this value is comparable to a medium of 33.0 N/mm². Then, it is possible to establish a weighed average equal to 21.7/30.9 N/mm² and so a medium of 26.3 N/mm². These are optimal values of compression and similarly optimal values of traction if related to 1/10 of strength to compression (respectively 3.3 and 2.6 N/mm²). Instead, the mortar joints have a strength medium value equal to 21.9/24.9 N/mm² and so a weighed average equal to 16.2 N/mm².

The columns strength was estimated after different analyses on some parts of these, finding that the fourth column in the right has the most uniform results: its strength medium value is equal to 32.6 N/mm², while the weighed average is equal to 33.1 N/mm². It shows an excellent strength to compression and then to
The part of church subjected by fracture phenomena were not founded cracks concerning the central nave with transept. These pillars didn't compression produced by the bell tower weight. The foundations structu r es. There are not any cracks in the arches of connection between lateral and central vaults or with perimetrical masonry. Equally – when the analyses were executed – were not founded cracks concerning the transept vaults, the bell tower with his dome and the room bell. The bell tower discharges its weight directly on the ground, through four big pillars at the cross of the central nave with transept. These pillars didn't give evidence any instability for rotational or sliding collapse mechanisms, corresponding to the great compression produced by the bell tower weight. The salient doesn't show any fractures or displacements masonry.

Cracks in the vaults above-mentioned were analysed for all their extension by a careful topographic survey: this defined the geometrical development on the intrados of each vault, the breadth and depth dimensions, noticing if these cracks going into vaults thickness (from the intrados plan to that extrados plan).

This analysis campaign allowed collecting enough information for expressing some considerations on the global church's behaviour respect to the earthquake. Particularly, in case of cracks founded in the second vault on the left nave, analysis noticed that fractures were present before the earthquake happened in the month of April 2003. Really, tests executed on the materials used to built vaults, particularly mortar and plaster samples used to fill up gaps in the vaults under the plaster finish. It notices that fractures are datable before middle sixties of the last century, because the plaster was made in Gavi until the end of these years. It is very interesting to observe that cracks were already in situ before the earthquake: these were not quoined, but they were simply closed using river stones, bricks, iron wedges and, above all, plaster. The results of sclerometric tests – executed on bricks used to build the second vaults on the left nave – testify that strength is not homogeneous, probably because bricks have different mechanics and material properties (type of clay and cooking). Nevertheless, the analysis of damage map about this vault remarks that crack line follows the mortar joints, while bricks don't show any cracks. It means that instability was caused by no-tension mortar resistance and not by second-rate bricks or by uncertain structure building; the crack phenomena are connected with materials quality (in this case mortar and plaster quality), and they are not caused by a structural problem. The cracks happened for no-tension resistance of mortar joints.

In case of semi-circular vault on central nave, it shows a thin longitudinal crack (corresponding at the vault's key). It was not possible to analyse its seriousness for impossibility to access to the vault extrados: whether to verify the crack depth, or if existent fractures on the vault extrados, corresponding to a collapse mechanisms. The topographic survey didn't remark any structural problems. The church's safety is guaranteed by its general stability.

The analysis about crypt – the first on the left, where it was possible to access – didn't give any information to study columns stability, because foundations are not visible. However the columns, although show a remarkable inclination, don't show signs of subsiding foundations (changes of horizontal plan column support), mortars crushing and materials pulverisation. So it has been also possible to note a great dimension of foundations structures. There are not any cracks in the crypt barrel vault, because trampling plan of church didn't suffer any subsiding phenomena, like shows the marble floor without fractures.

The studies executed on the columns inclination noticed that subsiding foundations did not cause their
slope, but it is connected to material problems. In fact, probably the columns are not original, but these were built during the transformations suffered by church at the end of XVII century, when the wooden beam roof was substituted by vaulted roof and the perimetrical walls of the lateral naves was raised. For this it was necessary to substitute original columns with supports higher. It is possible that the columns were built using stones and bricks jointed with mortar and covered by sandstone paste. This material was produced pulverising the sandstone and using also residual materials from other manufacturings.

The columns inclination is imputable at their settlement when these were charged with the new vault roof, while their basements didn’t suffer any displacements, because they are aligned on the same horizontal plan and don’t show any cracks or crushing signs.

On the basis of topographic survey, the arches, which divide church in three naves, don’t have any crack signs. This attests arches don’t show any collapse mechanisms, whether in the roof or in the set plan foundations; as well, also the perimetrical walls didn’t suffer rotational or sliding actions. It is the same also for transept pillars, which support the bell tower.

All that said notices that the earthquake didn’t cause the remarkable front’s church inclination toward outside, but this was existent before the event seismic of April 2003. In fact, already in 1864, it was decided, to remedy to rotational phenomena, hooking the front to the naves at the back, with introduction of three iron keys with longitudinal development along church’s axis until the threshold of apses zone. It is confutable that was written in report cards about church’s damage, produced just after the seism: the front’s rotational phenomena didn’t accentuate by earthquake. There are not any cracks concerning church’s front or arches between naves. There is not tension stress with horizontal component, toward outside direction west. As well, front’s rotation is possible and obvious in the case of the church of San Giacomo: whether caused by construction sequence – because front was last part built, and leaned at the naves back with weak quoin – or for pushing action of rib and cross vaults, which substituted the medieval wooden roof, lighter and for which the front was planned. In this case, the iron tie-beams have a check rod function, because impede the front’s rotational mechanism opposing to the arches drifts, to vaults and bell tower a tensile force, acting on the horizontal plan, in a west-east direction opposed at the front inclination.

There are not any cracks in perimetrical masonries of church (whether inclined or arched, caused by ground solidification and masonry rotation, consequence of shearing stress); for that there is not subsiding foundations. Outside, in the perimetrical left masonry, in correspondence of cross between transept and lateral left nave, there is a sign existent before earthquake: it is not a crack, but a disjointedness between voussoirs, in mortar joints. Probably this movement was caused by an excessive pushing load of covering; from that it results a horizontal sliding of two masonry parts toward opposite directions. The splitting is in correspondence of a baroque window, which was opened in period following the church’s construction, making the masonry less resistant at the weight stress.

Report cards about damage suffered by church are confutable also where notice a rotational mechanisms of central apse, with disjointedness from arch of access to presbyter zone: this disconnectedness between apse and arch transept was existent before seism.
seepage and saline efflorescence deposits, with consequent pictorial decoration damage, testify this. The disjointedness between two masonries was caused by construction in different periods and because they are not connected with quoin: for this is possible to form a transverse unevenness between two parts of church. As well, were not verified significant motions of the roof tile covering.

In case of rectory, cracks concern disconnectedness on the vertical masonries for a problem of short tensile strength, and formation of kinematic collapse mechanisms caused by rotational and sliding actions of cloister vaults. The disjointedness between masonries happened in the gores connections' semi-circular vault that form the cloister vaults, probably caused by an insufficient quoin.

6 STATICS AND STABILITY OF CHURCH

On the basis of results from analyses executed, it is possible to establish that the earthquake happened on month of April 2003 didn’t cause significant damages in church of San Giacomo Maggiore. In fact, the cracks already formed in past time, were caused by continuos succession of works which church suffered starting from its foundation. The fracture map, studied by an analytic and topographic survey, concerned the cross and rib vaults on the lateral naves. Here cracks formed in correspondence of previous fractures, healed with plaster and coarse inerts of different types, without any masonry mends and/or reparations of vaults, and without thinking a possible formation of kinematic collapse mechanisms in the same vaults. Arches inside the church, even if lean on columns which visible inclinations, they absolutely didn’t suffer the seismic action, because they don’t show any cracks connected with immediate formation of kinematic collapse mechanisms. Also the columns inclination exists before the earthquake.

Vaults fractures were caused by no corrected reconstruction of roof at the end of fifteen years of XX century.

7 CONCLUSIONS

The studies executed testify that the church is in a situation of equilibrium stability (Sinopoli et al., 1997, 1998). It has a good safety conditions, which doesn’t prelude to possible next damage, caused by kinematic collapse mechanisms (Coulomb, 1773; Persy, 1834) or by breaking fragile of materials if it is increase the maximum tensile strength value or compression strength. The vaults damaged on the lateral naves are easily reparable as long as they are remitted in tension, using appropriate technique expedients, non-destructive, non-invasive, reversible and compatible with the structures and materials existent. The best method to give to vaults the original static function, without too modify the static system of all building, is employing “easy machines” to vaults reinforcement, using wedge “Perronet” (Perronet, 1782).

This method consists in a series of hard wood wedges put on the cracks corresponding to fractures of collapse mechanisms. This simple structural reinforcement assures a fixed line thrust capable to guarantee vaults stability and a greater resistance to compression according to Heyman’s theory about Stone skeleton (Heyman, 1966).

REFERENCES


Figure 9. Inclined columns.
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