Restoration of the bell tower on the Church of Vistabella del Maestrazgo, Castellón (Spain)

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ABSTRACT: The bell tower of the church of Vistabella del Maestrazgo, Castellón (Spain) has recently been restored by the authors of this paper in its first phase under the pressure of an official emergency plan due to the bad state of the structure. The main pathologies were the general cracking of the four facades (some of them 20 cm wide and 1,20 m deep), the serious loss of mortar in the stone walls, the movement and distortion of the voussoirs of the arches, the risk of collapse of several of these voussoirs and deep abrasions on certain parts of the building. The urgent character of this commission required a quick intervention without time to study the pathologies of the stone wall properly beforehand. This paper describes this first intervention made to these major problems and the accurate surveys that were done to understand the causes of these pathologies.

1 INTRODUCTION

1.1 Description of the church

The village of Vistabella del Maestrazgo, Castellón (Spain) is located in a mountainous area, on top of a hill, in an isolated place with very cold winters. The Church of Nuestra Señora de la Asunción is built on the East side of the village, outside of the former medieval walls. This new bigger temple, in relation to the little church inside the city walls, was conceived with a view to enlarging the space for the pilgrims that passed by in their way to a famous sanctuary further up the mountains. The comparison of the dimension and the medieval fragmentation of the urban structure of the village with the shape of the new temple helps to evaluate the expectation that this new building aroused.

The church bell tower (fig. 1) was built at the foot of the nave on the right side, just at the end of the main street, where there was a historical gateway to the village. The location of the bell tower directly on the first vault of the right-hand nave, the foundation of the temple supposedly on the former ditch of the city wall where the soil usually comprises a pile of former rubbish, washed by water table pockets or underground streams, may have had an influence in the present conditions of vertical stability of the bell tower.

There is hardly any historical data concerning the construction of this church, and even less about its pathological history. It seems certain that the building of this church began at the end of the 16th century.
(Fernández 1995). The dates 1604 and 1624 are written on the main front, as the only historical reference that we have of the construction of this facade.

There is no other historical data about the birth of this church, its life, evolution and circumstances. The oldest evidence about the bell tower was the last zebras, who reached a very old age and said that the bell tower cracks had been degenerating due to the passage of time, rainwater and ice. That meant that the present state of the bell tower does not correspond to a form of initial construction and evolution, but to a gradual and progressive worsening of its pathologies, starting four hundred years ago and continuing until today.

The Church of Nuestra Señora de la Asunción is designed with three naves divided by two rows of big pilasters. The central nave is larger and higher than the lateral ones. All of them are covered by crossed vaults. The central nave is crowned by a big polygonal apse. The bell tower is located at the foot of the church, over the first vault of the right-hand nave, supported at the corner of the South and West walls of the church and the inside pilaster. Its thirty metres walls are built with ashlar work in the most conspicuous areas of the facade, combined with masonry walls in the less visible areas of the construction of this facade.

It can be asserted that the master builder's decision to create a secondary large access under the bell tower does not help the stability of the whole in the least, because it reduces its supporting area at its foot to three simple big buttresses connected by arches and, as it will be possible to see, a masonry wall weakened by the presence of the round stairway that leads to the bells at the top precisely in the corner. Indeed, this stairway placed just on the Southwest corner of the bell tower (fig. 2) weakens the supporting wall and, on the other hand, makes the structural junction of the corner rigid, obstructing the transmission of the torsion movements of the bell tower.

In the second level of the bell tower, between the cornice of the temple and the base line of the bells body, there is a clock that was inscribed in the ashlar wall at the end of the 19th century. This insertion was made by directly perforating the wall and installing the machinery inside on a wood slab, but no arch was added to support the weight of the upper wall.

Three crossed vaults of similar shape and construction cover these three internal spaces. The first is the same internal vault of the right-hand nave of the church. The second covers the wood slab that shelters the clock machinery and supports the base of the upper bell body of the tower. The third is the roof forming vault. Both the second and the third, and particularly the third, show traces of multiple repairs and different plasters on their lower face.

2 METHODOLOGY USED IN THE SURVEY

The work made using traditional measure methods simultaneously with technological methods such as theodolite or laser measuring machines. Theodolite allowed a very precise measuring of spatial coordinates at long distances. The laser system allows a very accurate measuring of the deformations of the objects represented such as arches and vaults, whose exact shape can be drawn by taking as many measurements as there are joints between these arches and the ribs or filling of crossed vaults.

The facades were surveyed with the help of calibrated and rectified photographs. Once the scaffold for the urgent intervention was built, this survey was enriched with the data that was obtained from direct contact with the stone wall. A topographical survey of the bell tower edges was also developed, and a precise laser survey of the internal spaces of the bell tower in order to detect their respective deformations. Finally, from the scaffold a survey of the horizontal deformations of four entire sections of the bell tower was made.

2.1 Previous studies

All the previous studies that are explained in the following pages were developed parallel to the restoration works. Our aim was to resolve the real influence and responsibility of every factor studied in the state of conservation of the bell tower.

2.2 Georadar subsoil studies

Several georadar explorations in the subsoil were made, in order to draw and identify building remains or other anomalies in the bell tower area that might have had an influence of these soil irregularities in the bell tower foundation problems and consequent overhanging, leaning or cracking (García 2002). The possible existence of these irregularities under the bell tower could be an explanation for its pathologies.

These explorations detected several anomalous areas at a depth of 1–1.5 m, and a uniform line at a depth of about 2 m that was identified as a possible water table pocket. This fact was corroborated by the presence of water at the same level in the underground crypt of the church, just near the bell tower.

2.3 Archaeological survey

These results obtained by the use of the georadar suggested us to dig two archaeological surveys at the bell tower base, which allowed us to identify remains of buildings ranged in the area of the crypt or even the Islamic wall (Rivera 2002). Nevertheless these findings could not justify the bell tower pathologies. Perhaps the problem resided in a lower layer. These shallow archaeological surveys permitted us to make this type of identification so we did not provide any information about deeper soil layers.

2.4 Geotechnical survey

This lack of information about the deeper soil layers suggested the idea of making a geotechnical survey around the bell tower to identify the irregularities in the layers underneath that could have an influence on the state of the bell tower or, on the other hand, allow us to rule out the possibility of the soil as main cause of the bell tower pathologies. The final combination of the georadar diagrams with the archaeological surveys and the geotechnical survey allowed us to know the state and composition of the foundation soil very accurately.

The stratigraphic section of the geotechnical survey (compare with fig. 1) detected three main levels: the first, from 0 to 1 m, is composed of concrete and filling; the second, from −1 m to −5 m, with grey clay and the inclusion of Horizontal vaults of the bell tower; and the third, from −5 m to −10.60 m, with the presence of muddiness with the inclusion of sandstone. In this stratigraphic section there is no mention of the water table pocket at a depth of −2 m, as the radargrams or the partial flooding of the bottom of the crypt suggested, but only the location of the main water table at a depth of 1 m, approximately.

The results of the geotechnical survey analysed by competent professionals (A. T. Control 2002) made it possible to draw up a hypothesis of the behaviour of the foundation. Considering a foundation width similar or larger than the walls, with an approximate depth of 1 m to reach the grey clay layer, and considering that no soil irregularities had escaped the survey, this analysis concluded that there was a self-drainage coefficient against sinking, as the bell tower settling has occurred completely, saturating the clay of the subsoil. This hypothesis concludes as a result of the survey and the available data, that the subsoil is not the main cause of the bell tower pathologies.

2.5 Conclusion of the subsoil study

This hypothesis was assumed to be valid, although the unequal sinking in the Southwest corner of the bell tower had generated some of the vertical cracks in V shape that runs along its South and West facades. This unequal sinking may have been caused either by the presence of some irregularity under the Southwest corner (a bag of cracked sandstone inside the clay layer, which could have settled more than the adjacent areas), or by the influence of any of the buildings remains in the subsoil detected by the georadar, or by a phenomenon of flattening or debottoming of the ashlar of the corner brought about by the reduction of the supporting section because of the void of the stairway in the corners.

2.6 Survey of the materials of the building

A parallel survey of the materials during the restoration works was made. The aim of this new survey was to determine the possible influence of the different materials in the pathologies that affected the bell tower. The main materials used in the bell tower are stone two types (limestone and sandstone) and several forms of stonework (ashlar, rough ashlar, masonry) and lime mortar of different composition.

It was realized that the choice of a different type of stone had a direct relationship with the type of surface pathologies, even without taking into account the relative position or orientation in the bell tower. In any case, it could be demonstrated that this choice had no influence at all on the structural cracking of the bell tower. As this possibility was ruled out, the idea that the mortar quality, really brittle in some places, could have had some influence on the structualization of the bell tower wall stone considered bell tower stone wall, since the following factor was taken into account. The mortar is the conglomerating material of the stone wall consisting of two faces of ashlars or masonry and an important amount of filling inside that adds or reduces
strength depending on its quality. Most of the mortar in the joints of the stone wall had been washed and lost, not to mention the cracks (some of them 20 cm wide and 1.20 m deep), which permitted rain and ice to seep inside the stone wall.

The stone wall was built with a similar aggregate, probably extracted from an area near the village. The proportion aggregate/mortar is sometimes very diverse, although the most usual proportion to be found in the bell tower is 2:1 or 2.5:1 (Martin 2002).

The upper body of the bell tower has a very poor mortar, with proportions of 4:1 and even 4.5:1 (Martin 2002). This mortar is brittle and can be crumbled with the hand. The comparison of such different mortars with the irregular and chaotic distribution of limestone and sandstone ashlars suggest either a similar chaotic building site at this level of the bell tower or former undocumented restoration works on the upper body of the bell tower.

Maybe this historical restoration could be related to the collapse of the bell tower's upper vault, which happened at least twice in the past, but the absence of any trace on the main vault of the church (nowadays this vault is covered by a layer of concrete) does not allow this hypothesis to be confirmed.

2.7 Monitoring of the cracks in the stone wall

Nine movement monitors were installed on both sides of the significant cracks, and another one that exclusively measures the variation of temperature, all in order to obtain a two-year record of the possible movements of the bell tower walls (Serna 2003).

At the moment of writing this paper, provisional measures that correspond to one year's monitoring have already been collected. These results are not definitive but permit us to make a structural hypothesis of the behaviour of the bell tower, to be confirmed at the end of these two years of monitoring. Special attention should be paid to the monitors on the main cracks in the South and West facades, which show an opening of 1 and 1.5 mm, respectively, in only one year.

3 STRUCTURAL PATHOLOGIES

3.1 Roof vault

The restoration works have helped to confirm that the vault had already been repaired, as could be seen from the patches of plaster. This vault collapsed, at least partially, at least twice, and was repaired afterwards. The causes of these collapses can be found in the opening of the crowning walls of the bell tower, owing to unequal foundation sinking, the opening of the side walls caused by the thrust of the vault, the important vibrations caused by the movement of the bells, or any combination of these three possibilities.

3.2 Clock vault

The crossed vault that shelters the clock machinery has some cracks in its lower part, particularly, at the joint of the ribs and the keystone. These cracks may respond to the same phenomenon of opening of the upper part of the bell tower stone wall, and a possible overload caused by an important amount of filling to constitute the base of the bell tower upper body.

3.3 Deformation of the church arches under the bell tower

The two interior arches of the church on the base of the bell tower that support the East and North facades walls show a deformation map that helped understand some of the movements of the bell tower. The arch under the East façade had settled in such a way that it had dragged the upper masonry wall down with it.

The arch under the North façade has also suffered deformation, settling and leaning towards the West wall at the foot of the church, accompanying the movement caused by the thrust of the last vault in the central nave on the closing wall at the foot of the church.

3.4 Cracking in the stone walls

The cracking picture of the stone walls is complex and due to multiple reasons (Figs 3, 4). General causes of cracking that can be found in the bell tower are fundamentally: settlement of the stone walls, opening because of unequal sinking in the foundation, flattening and opening of the walls because of the settling and horizontal thrust of the arches and vaults, those inside the bell tower and those adjacent to the central nave of the church. All these cracks have been enlarged by everyday weather, particularly, rain and ice.

In the South façade, the map of the cracking corresponds to the unequal sinking of the bell tower foundations, that, as it can be seen below, tilted as much as 13 cm westwards in the Southwest edge, compared with the 3 cm of the Southeast edge. The difference between these two degrees of tilting was absorbed by the V-shaped crack in the South façade.

In the West façade, the picture of the cracking is also due to an irregular foundation sinking that tilted 17 cm southwards on the Southwest edge, compared with the 2 cm of the Northwest edge. The difference between these two degrees of tilting was absorbed by the V-shaped crack in the West façade.

Besides, attention must be paid to the existence of a vertical crack in the joint of the temple wall and the bell tower wall, which took place because of the thrust of the last vault of the central nave in the West wall that is making it tilt it outwards, but does not affect the bell tower because of its greater rigidity and lateral position far away from this thrust phenomenon.

3.5 Dislocation of the upper bell arches

Indeed, one of the most alarming situations was the precarious state of balance that showed three of the upper bell tower arches. The voussoirs and ashlars had lost support and unstable dislocation had taken place, especially in the arches of the East and West facades.

The reasons for this dislocation are the V-shaped opening from the very bottom of the bell tower, and the horizontal thrust of the roof upper vault.

3.6 Tiling and overhang

The bell tower shows a general leaning towards the Southwest, caused by unequal sinking of the bell tower in that direction (Fig. 5). The overhangs are variable so that, as described in the cracking map of the whole, the difference between the tilting of Southwest edge compared with the tilting of the Northwest, Southeast and Northeast edges was absorbed by the appearance of cracks in the isostatic stone wall structure. The bigger overhang is more than 22 cm in the diagonal of the Southwest edge, compared with smaller ones in the Northwest, Southeast and Northeast edges.

3.7 Vertical deformation

These inclinations are not uniform in all the dimension of the edge because of some irregularities. Nevertheless, the vertical deformation is very clear in...
the Northwest edge of the bell tower, where the influence of thrust of the last vault of the church caused particularly serious deformation in this point, combined with the edge overhang described above (fig. 6).

3.8 Horizontal deformation

The horizontal deformation of the bell tower's upper walls was measured in four complete sections. Convex and concave deformations were detected, in some cases reaching more than 4 cm (fig. 7). The convexities of the stone wall in the North, East and South facade sections may correspond to the actions described or dislocation and disintegration of the stone wall caused by the loss of the agglomerating mortar, together with the thrust of the upper vault, at the height of these sections.

3.9 Consequences of the insertion of the clock

As had been seen in the crack map of the South facade, the untimely insertion of the clock in the wall without creating an arch in the wall perforation, either on the outer or inner side of the facade or the filling, had caused the settlement of the ashlars over it, just where one of the upper buttresses of the facade is weighing on the fabric. The installation of a wood support inside to avoid more serious problems was successful, but the whole situation around the clock unnecessarily meant another weak point in the bell tower.

3.10 Stone flattening phenomena

A stone flattening phenomenon was detected at the base ashlars of the Southwest corner, with little vertical fissures. This problem is very serious and must be solved without delay to avoid the complete plasticisation of the stone and the ensuing collapse of the whole bell tower. The flattening phenomenon comes from the more than 22 cm tilt at this edge towards the Southwest and the weakening of the section in the Southwest corner because of the presence of the round stairway.

4. RESTORATION PROJECT AND WORKS

4.1 Reconstruction of the ashlars and voussoirs in the arches

The reconstruction of the ashlars and voussoirs in the arches required the complete dismantling of two arches in the bell tower and the upper ashlars right up to its crowning (fig. 8). A third arch only required the relocation of one of its voussoirs by jacking up it to the former position. All these operations needed the implementation of several security measures to avoid the dismantling of one arch to affect the adjacent one.

For this reason, first of all, a restraint system for the bell tower's upper body was conceived consisting of four stainless steel cables that tied up the whole perimeter of the bell tower. Besides, it was necessary to shore up the arches in order to avoid the dismantling of one of them to cause the adjacent ones to collapse. This shore system was created to serve simultaneously as support for the dislocated arches to be dismantled.

A very precise design was drawn of the arches to be dismantled to show which ashlars and voussoirs were to be dismantled and another design with their exact position in the restored fabric. Afterwards, they were dismantled with the help of a big crane, clamps especially designed for the occasion and double textile slings to extract the stones. The ashlars and voussoirs moved were numbered according as they were dismantled to ensure their relocation in the correct position.

After the dismantling came the rebuilding of the arches, using wooden wedges to distribute the new distances of the arches uniformly in all the stone wall joints.

4.2 Reinforcement of the bell tower roof vault

The bell tower roof was seen to have a large amount of filling that was weighing heavily on it and causing a great horizontal thrust on the facades. The roof was then dismantled to unload the filling from the roof vault. The terrace had a modern ceramic pavement with cement mortar over a prefabricated concrete slab inserted in the nineteen seventies. That means that this terrace was no longer supported by the vault.

Once this slab was dismantled, the filling of the flat ceramic vault was unloaded (more than one metre at the corners). The precarious state of the vault needed urgent repairs and reinforcement, which consisted of applying a new layer of lime mortar and doubling it with a new ceramic vault to thicken the vault supporting section. The small budget forced us to relocate the prefabricated concrete slab on it provisionally.
4.3 Tightening of the bell tower roof vault and crowning

Once the weight of the filling in the vault had been unloaded, there was no more horizontal thrust on the walls, as the flat ceramic vault has almost no weight. But in any case it was necessary to tighten the bell tower crowning to avoid its continuous opening caused by the V-shaped cracks coming from the base.

It was decided to insert stainless steel braces in to restrain this opening. Six braces were installed in the bell tower crowning, three on each side, one central and one in every side, with inspection hatches that permit the tension to be regulated.

The installation of similar braces is foreseen all the way up the bell tower while the cracks are active and still opening, after the monitoring of these cracks has been completed.

4.4 Other works

The empty joints of the stone wall were injected and filled with to prevent rainwater from entering and the ensuing formation of ice and to restore lost strength to the stone wall. The parapets' ashlars work in the bell tower upper arches was dismantled and relocated and sewed with fiberglass to the existing buttresses to prevent them from collapsing as had happened shortly before the restoration. A structural metallic arch was designed and installed in the clock hole to permit the clock machinery to function normally. The cornices were consolidated, especially where they were threatening to come loose and collapse (Pita 2002).

4.5 Interventions still to be performed on the bell tower

Considering the urgent character of this first phase of intervention, the budget available was used for the more imperative repairs, but some equally urgent interventions still remain to be done, such as:

- Repair of the stone flattening in the Southwest corner
- Injection and filling of the joints of the rest of the bell tower
- Installation of new braces to restrain the living movement of the bell tower cracks.

5 CONCLUSION

The plight of the bell tower of Vistabella del Maestrazgo, Castellón (Spain) required a quick first intervention but the scaffold built to perform it helped to provide a very accurate survey to understand the reasons for these pathologies. The weak situation of the tower, supported only by buttresses and a hollow stone wall corner did not contribute to its present state of health. The precise survey together with the monitoring of the existing cracks in the bell tower made it possible to understand the origin of the problems, which can mostly be put down mainly to the design of the bell tower and the unequal sinking of the bell tower foundation.

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