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RECONSTRUCTED OVERHANGING BATTLEMENTS. EXECUTIVE TECHNIQUES AND THEIR VULNERABILITY IN THE STRONGHOLD OF ARQUATA DEL TRONTO (ITALY)

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Abstract. *The stronghold of Arquata del Tronto was heavily damaged by earthquakes in 2016 and it drew the attention of the experts in reinforcing historic buildings. They regarded it as a case study, a predicting model of the failure in employing specific construction elements in fortified architecture, whose geometric and material data were only approximately considered. The overhanging battlement is the most seriously damaged part of the building and has raised particular attention and interest. As often happens in other castles and fortresses, it dates back to the late 19th and even more to the 20th century. A first close examination of the building's repairs shows how the new additions, whose maintenance is difficult, ended in failure. The additions were inspired by ancient details, but nonetheless they are unreasonable from the point of view of structure and durability: they – and even more the irrational repairs of the last decades – are the principal cause of failure. Material decay – closely linked to circumstances and places – has also played a decisive role. An extensive and rigorous historical research is necessary to find the sources and to evaluate their nature and limits, as well as to relate all information to the building, thus operating in close correlation with the building archaeology, by now a so widespread and consolidated research field. . Jointly, the written documents and the building itself in its historical stratification allow a better analysis of the structural behaviour , an essential step to achieve an effective restoration planning.*

1 THE XIX CENTURY STUDIES ON MEDIEVAL FORTIFICATIONS AND THEIR RECENT USE IN THE FIELD OF STRUCTURAL STRENGTHENING

Recent technical literature on seismic prevention aimed at developing calculation models and identifying typical cases in order to take preventive action. For this purpose, the studies outline a story in broad lines, by types and periods (which only conjure the infinite number of possible variants), and in parallel develop a synthetic calculation of some concrete cases, only in broad terms corresponding to the identified types. By quantitative data, this kind of approach reiterates only some intuitive general remarks. Actually the heterogeneity of construction techniques and decay, peculiar to each building, as well as the numerous repairs carried out in areas of high seismic risk – where damage has repeatedly occurred – determine very different behaviours. So the results could be scarcely useful in few actual cases, whose structure deeply differs from its often only formal type. The battlements of the medieval architecture offer a significant example of these contradictions.

An overhanging battlements is a *chemin de ronde* on top of the walls protected by a parapet with merlons built on the extremity of brick or stone corbels, between which machicolations are realized; they originate from the necessity of making the vertical flanking – or plunging fire – easier. Overhanging battlements characterized many Italian fortifications between the end of the 13^{th} and the middle of the 15^{th} century, when artillery progress made this type of defence obsolete. The construction – an overhanging wall on thin corbels – is intrinsically vulnerable. Its duration in time depends on the cohesion of mortar, porosity of bricks and compactness of stones: the decay of materials due to the ravages of weather affected structural efficiency. Horizontal surfaces were protected from water with hydraulic mortar of lime made hydrophobic with the addition of protein materials as testified by so numerous 19^{th} century manuals in all European languages that one reference in Italian can be enough [1]. Where machicolations were not protected, they let rainwater leak on the top of the walls and even between the corbels. Especially in harshest climates, it was preferred to cover the battlement with a roof. Under the entry for *Mâchicoulis* in his *Dictionnaire* [2], Viollet-le-Duc emphatically underlined the difference between the overhanging battlement of Avignon walls – lacking a roof – and the covered one in Pierrefonds. Thanks to his surveys of the construction details in Piedmontese fortifications of the 13^{th}-14^{th} centuries, Alfredo d'Andrade drew up a documentation that was unparalleled in the rest of Italy [3]; he himself began to write a *Dictionnaire* and carefully covered numerous towers which he repaired or entirely rebuilt. Owing to these maintenance issues, nowadays almost all existing overhanging battlements date back to late 19^{th} and 20^{th} century. Where they have not been rebuilt entirely, the lack of homogeneity between ancient and added parts may determine significant behavioural differences: being often more fragile than their prototypes, over time they have required continuous maintenance and further substitutions.

The recent studies focused on the two principal failure mechanisms: either the out-of-plane overturning of merlons around a hinge at the top of the parapet or of the whole battlement around a hinge at the top of corbels; the cross-cracking of merlons that mainly occurred when they were hold – but also loaded – by a roof, widespread in the XIV-XV^{th} century examples.

2 STRUCTURAL BEHAVIOUR OF OVERHANGING BATTLEMENTS

The copious specialist bibliography on medieval fortifications, published during the 19^{th} century in various European languages, thoroughly illustrates the origins, evolution, and characteristics of the battlements, merlons and crenels. Printed monuments, such as the work by Otto Piper (1895) [4] for the German-speaking area, or erudite syntheses, such as the text in Italian by Enrico Rocchi (1908) [5], are only two, but reliable examples. Even the general works on medieval architecture are rich in references. Among these, the earliest ones are the most reliable: they describe still preserved, ancient examples, but the culture of their time influenced the observations. A subsequent generation of studies dates back to the post-World War II period, while parallel developments in postclassical archaeology introduced stricter truth criteria. The use of this literature requires a critical comparison of almost two centuries' publications, up to the most recent syntheses of archaeologists and medievalists.

Two different construction techniques were commonly used to build the corbels which had to support these overhanging structures (fig. 1): the former involved the insertion of several superimposed orders of large stone corbels into the masonry: the latter had to realize a brick or stone masonry that protruded gradually from the vertical plane below. If we do not consider the friction in the contact surfaces, when stone cantilevers are used, each element is subjected to bending independently of the upper and lower ones, and there are tensile (in the upper fibres) and compression (in the lower fibres) stresses in its cross section. When we take friction into account, axial compression is generated in the lower cantilevers and traction in the upper ones. To support the weight of the parapet and merlons at their external ends, the stone cantilevers are to be considered as fixed in the masonry; they should be loaded by a weight at their internal end (for example a back wall), held downwards by a metal bracket anchored in the masonry, or balanced inwards with a significant load. In all cases it is necessary to use stones with a high tensile strength and compactness, to avoid a rapid decay caused by rainwater absorption. It was possible to create a considerable overhang with corbels of reduced height using a very resistant stone. To achieve the same overhang, masonry corbels should necessarily be higher. Given the significant height in relation to the projection, on their upper surface fewer tensile stresses are generated than in the previous case; however these stresses can hardly be balanced by the tensile strength of the masonry, which in this case is essentially given by the adhesion of mortar. It was therefore common to insert a wooden beam at the top of the corbels which adhered to the masonry thanks to friction, thus allowing to provide it with the necessary tensile strength; at the same time, owing to its bending stiffness this beam contributed to directly transfer part of the load to the masonry behind. For this reason – especially in the fortifications of the middle Adriatic area – another beam was often inserted at half height of the corbels (e.g. Gradara, Jesi, Acquaviva Picena, Canzano). Alternatively – or together with the wooden beams – a more expensive iron tie rod could be inserted, equipped with an external anchor: it could guarantee a greater tensile strength. Although initially it produced a greater resistance, later the presence of wooden elements within the masonry often became a source of vulnerability: not adequately protected from atmospheric agents, timber gradually decayed, losing contact with the adjacent masonry, therefore generating a discontinuity within it.

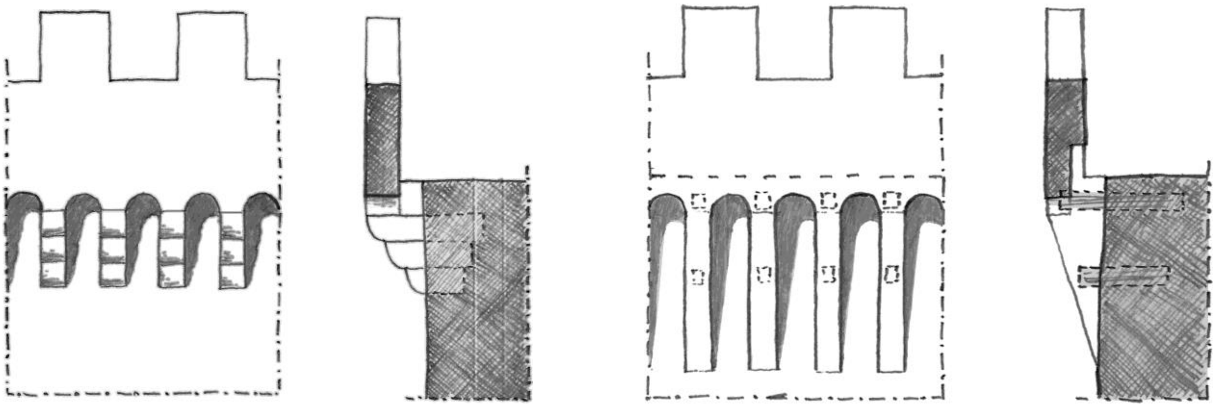

Figure 1: Overhanging battlement with corbels made of stone cantilevers (on the left) or of brick or stone masonry reinforced with timber cantilevers (on the right) (drawings by E. Zamperini).

3 *RESTAURARE EST REFICERE*: EARLY 20TH CENTURY WORKS IN THE STRONGHOLD OF ARQUATA DEL TRONTO

The stronghold of Arquata del Tronto, already subject to at least two expeditious interpretations [6, 7] of the damage following the earthquakes of August 24th and October 30th, 2016, is halfway the result of restoration works carried out during the 20th century (from

1903-06 till 1991-94). The earthquake damaged all inadequate additions, repairs and prevention systems; the only few ancient parts to be damaged were those whose maintenance was omitted and waterproofing had not been realised, seriously weakening the walls.

The quadrilateral donjon is probably the most ancient part of the fortress. It may date back to the mid-14th century, but no documents citing its existence allow us to distinctively identify the still preserved remains; there are not even ancient construction elements that can be compared with others having a firm date in the same geographic area. A curtain wall was connected to the donjon to define a protected area. By the 15th century, two minor towers were added to reinforce the wall. The first has a pentagonal plan and it's still existing; the second was approximately circular and had a triangular buttress; between 1903 and 1950, without proper consolidation it gradually collapsed and it was finally demolished. Works were documented in the seventh decade of the century, [8, pp. 135-137] [9, p. 30] and the upper part might have been in ruins in 1525 [9, p. 30, n. 63]. In 1655 the fortress – abandoned for over fifty years – laid in ruins and was not suitable for hosting the castellan [10]: the situation was acknowledged in a decree issued by Pope Alexander VII on February 9th, 1657. The earthquake of L'Aquila in 1703 [11, 12] and that of Valnerina in 1730 [11, 13] caused serious damage to the town. The fortress also needed repairs, which were contracted for the remarkable amount of four hundred *scudi* in five years [14]. Subsequently, till the end of 18th century, it's very doubtful that the Community spent other funds to maintain the building [15]. Still in 1815 [16], it's documented that a newly appointed castellan took over the stronghold, but there is no information about its conditions.

The divestment by the State coincided with the drafting of a summary restoration project by Vincenzo Pascucci of the Provincial Finance Office (*Intendenza di Finanza*) of Ascoli (May 7th, 1883) [17], which gives a summary idea of the state of the building in that moment. After the transfer to the Municipality of Arquata in 1890 [18] – following a decade of negotiations [19] – the State's commitment to the restoration involved the direct intervention of the Provincial Commission for the Protection of Monuments, and in particular of its more active member Giulio Gabrielli, an amateur gentleman; through reports and writings he offered many useful elements to document the state of the building [20]. The problematic financing of the works by the Ministry of Education directly brought into question the General Directorate of Antiquities and Fine Arts, whose fonds has preserved some preliminary material, including a first series of photographs [18] (fig. 3). In 1901 the Regional Office for the Protection of Monuments – then directed by Count Giuseppe Sacconi, the architect of the Vittoriano [21, 22] – was charged with drafting the project on which to quantify the funding. His illness and death (1905) almost coincided with the establishment of the Superintendencies (1907). The first superintendent of the Marche region was Icilio Bocci [23], who had previously worked at the Lombard Regional Office.

It may be asked whether this mobility between offices had determined conventional restoration solutions, as a result of common references. The answer is difficult, both for the intrinsic diversity of the buildings and contexts, and because – especially in places that are difficult to reach – the project gives only rough indications referred to shared rules of art, and it was managed by local people such as contractors and municipal technicians.

4 RECONSTRUCTION OF THE DONJON'S OVERHANGING BATTLEMENT

In 1901 the project was drafted by Guglielmo Giustiniani, on behalf of the Regional Office [17]: the costs envisaged by the previous appraisal of the Provincial Finance Office of Ascoli were considered excessive. According to the project report, the donjon was reduced to the perimeter walls and even the existence of the upper vault (at the level of the battlement) is doubtful; however «traces of ancient wooden ties with anchor rods to support the overhanging merlons were still visible». The appraisal instead provided for the construction of a masonry staircase on rampant vaults to access the top, and for the "restoration" of the vault: the term is ambiguous, indeed it's used even for large reconstructions in correspondence of fragments or simple traces. As the photos [24] show, on the north wall the corbels had collapsed to a level incompatible with the existence of the vault, however the existing round barrel vault – made in large irregular sandstone ashlars – suggests that on the other sides at least the springers were still remaining. The reconstruction of the overhanging battlement needed an «Iron frame around, to support the overhang of the merlons», defining an encircling tie about 10 m long on each side. The appraisal enumerates also eight tie rods, however their position is not described. To protect the underlying vault, a square room of about 4.30 m on each side was designed; its perimeter walls were 60 cm thick built in continuity with the internal side of the tower walls: therefore a large terrace difficult to maintain was avoided. The pavilion roof was set on 3.50 m high walls, and had to protrude to protect the *chemin de ronde*. A schematic drawing shows the eaves leaving Guelph merlons (about 1.2 m high over the parapet) uncovered (on the left in fig. 2) and remaining about 40 cm above their upper face, on the contrary a dimensioned sketch suggests a bigger protrusion of the eaves to cover the entire overhanging battlement (on the right in fig. 2), as already designed by Pascucci [17]. However, the wooden eaves included «struts with iron connection to the frame of the merlons». Giustiniani recognized the function – even static – of the roof, and he suggested an essential, hardly visible version of it, based on presumptive dimensions; indeed there was no means of climbing to the top of the donjon.

Figure 2: From the left: design drawing and dimensioned sketch of the donjon battlement by Guglielmo Giustiniani; design sketch by Dante Viviani [15].

Again this project was rejected because it was too expensive. Dante Viviani [25] – from Arezzo, but trained in Rome, later first Superintendent of the Monuments of Umbria – was commissioned to scale it down. His succinct elaborations [26] were developed by the municipal surveyor according to his indications. All the correspondence that replaced the inspections, the quoted sketches (which Viviani recommended to follow faithfully), and the construction accounting documents clarify the nature of the project and are confirmed by the existing tower. According to ancient – or at least supposed to be so – traces, instead of the masonry stair designed by Giustiniani, Viviani designed a brick vault at one third of the internal height and two timber floors, connected by subsequent timber stair flights. Against Viviani's instructions, the mayor ordered the master masons to build a vault corresponding to the entrance floor. Thus providing an access to the top of the tower, the reconstruction of the overhanging battlement began, using a suspended scaffold. Viviani reduced the height of the central room to 2,40 m, but he increased its side, placing its perimeter walls aligned with the axis of the underlying masonry; furthermore he reduced the protrusion of the eaves to 60 cm. They therefore covered the last part of the access stair which entered the thickness of the wall and turned parallel to it. Corbels were rebuilt «from the most resistant part of the [clay brick] base», so almost completely, although photographs taken before 1903 show that they were largely preserved, except on the southern side. Arguably, due to long exposure to weather mortar became incohesive and bricks splintered, thus leaving no alternative. The scaffolding allowed accurate surveys, and Viviani's sketches provide significant indications, although it is difficult to distinguish the existing parts, its interpretation and the project.

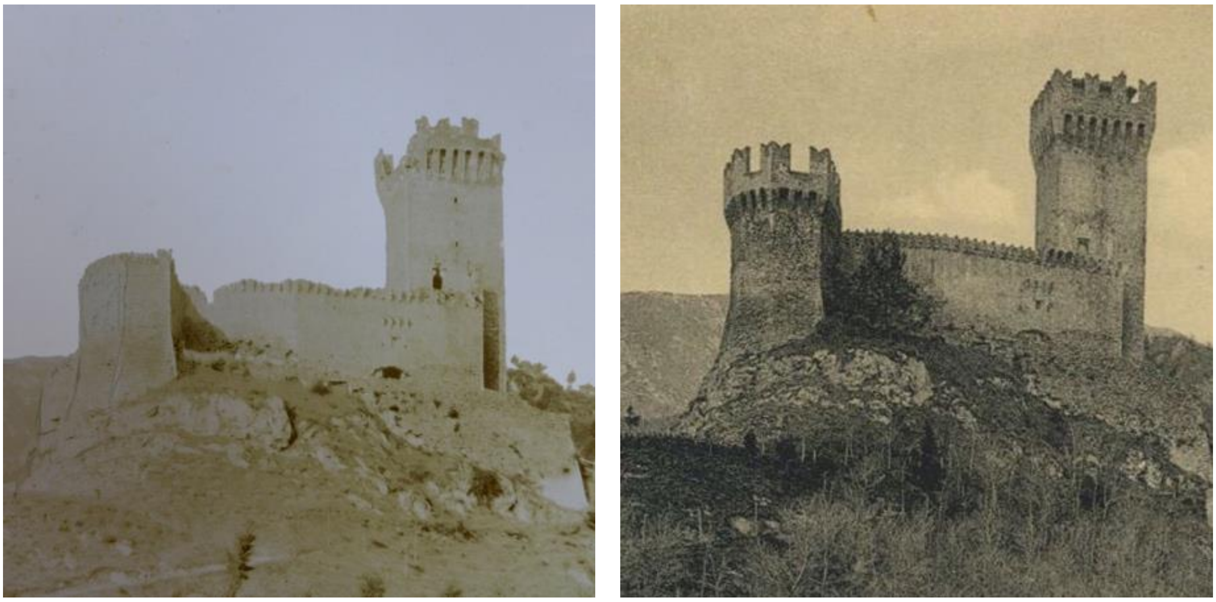

Figure 3: Views of the stronghold of Arquata before [18] and after the restoration works.

Parapet and merlons are 40 cm thick, but rectangular niches (about 40 cm high, 50 cm wide, 13÷15 cm deep) were obtained in the thickness of the parapet itself to reduce corbelled masonry protrusion (in the middle, fig. 4); this allowed to widen machicolations without reducing the net passage within a *chemin de ronde*, that did not exceed 1.60 m in width. Therefore for about half of its length the thickness of the parapet was reduced to 25 cm, while the external face of the tower wall tilted inwards to increase the width of the machicolations. In this way the overall protrusion of corbels was no more than 60 cm, with a height of about 2.4 m. Although modified several times, the construction of the parapet and merlons is revealed by the damage they suffered: they consist of two external wythes made of brick and tuff stones and a nucleus built with less carefully, mainly in probably reused bricks; some larger tuff blocks act as headers. Above the machicolations, masonry was supported by single tuff ashlars worked in segmental arches; each of them lays for about 10 cm on the corbels, which are 42 cm large like three brick headers. The large remains – equal to one third of the masonry according to Giustiniani – in 1901 included the two corner merlons on the west side, the two central ones on the north side and, at least in part, the two central ones on the east side; however the merlons of the northern side collapsed in December 1903 and subsequently the right corner had to be demolished. The surviving specimens allowed a substantially faithful reconstruction, at least in size and in the use of materials.

Figure 4: From the left: battlement of the donjon and one of niche above the machicolations in 2012 (user: interminatispazi - wikimedia commons); view of the stronghold of Arquata after the earthquakes of 2016 (courtesy of the Arquata del Tronto Municipality).

The bricks were either recovered or similar in size to the existing ones, measuring 26 cm x 13 cm x 5.5 cm, as Viviani had insistently requested. It's possible that the mixed masonry of the parapet and the merlons didn't reproduce the original construction, but the result of subsequent repairs in which the most versatile brick had gradually replaced the stone. Iron tie-rods had been placed inside the parapet masonry, crossing each other in the corners, thus hooping the wall that supported the merlons. Unlike the underlying sandstone masonry, the top part of the tower has a brick face; the corbels protrude from it. Ten to twelve brick courses constitute the lower part of them, while above there were limestone tuff blocks – of different heights and with horizontal laying surfaces – up to the maximum protrusion. A sketch suggests that there are wooden cantilevers inserted in the masonry. They are located at the height of the arches that support the parapet and are testified by the presence of bricks between the springs of the tuff ashlars, to allow a reduction of the thickness of the external wythe; in the south-eastern corner other two timber cantilevers can be seen at the height where tuff ashlars begin and at an intermediate level, but it is impossible to know if there are similar cantilevers in the other corbels (on the left in fig. 5). At each corbel, wrought iron tie-rods were placed 15÷20 cm above the timber cantilevers, as shown by the anchor rods still present or by the grooves in the masonry that housed them before their removal. The presence of timber cantilevers and iron tie-rods is confirmed by the booklets of measures. Merlons were 1.3 m high over the parapet; in the drawings appeared the dovetail of the ghibelline merlons (on the right in fig. 2), an interpretation of the discontinuous top plane of the remaining elements and probably of some iconographic references: probably a low relief depicting a small castle with a tower, on the Sant'Agata Gate of Arquata [27], and a painted ex voto existing in the sanctuary of the Icona Passatora about 30 km from Arquata [28]. Despite the care dedicated to the bricks, however the materials used for the additions to the donjon battlement were the same commonly used at the time, including machine-made bricks, and the undifferentiated use of hydraulic lime, pozzolana or even cement in mortar. As the documents relating to the supply of materials testify, the works continued until the summer 1909. Owing to the changes to the design of the upper room, Viviani renounced to provide the battlement with effective weather protection. Even before the earthquakes of 2016, bricks above all, but also stones had extensive cracks and splintering, and the joints were often lacking mortar; favoured by percolation of rainwater, in the machicolations vegetation could grow. Wind is another significant pathogenic factor, since it strongly erodes mortar joints and the sandstone of the masonry below the battlement, especially in the corners of the tower.

Figure 5: From the left: the damaged battlement (courtesy of the Municipality of Arquata); the bars for reinforced concrete without anchors inserted to replace the old tie-rods; the collapsed south merlons of the donjon, in which we can see the x-crossing reinforcing bars.

4.1 One hundred years of replacements.

The construction was fragile and already in 1922 a series of partial renovations began, but they were of little use, since an appraisal of 1932 states that crenellation was «in total ruin» [29]. Following the 1943 earthquake, three of the donjon merlons collapsed and were rebuilt in 1946 [29]. After the 1979 earthquake, an extensive renovation of the battlement followed in 1982 [29]. However the most problematic intervention was the removal of the parapet hoop made in the early 20th century, replaced with bars for reinforced concrete without terminal anchor bars (in the middle in fig. 5); to put them in place, deep chases were cut in the already slender section of the parapets, then filled with a cement grout that only partially adhered to the masonry. The merlons were subject to a nominal strengthening realised by perforating them and inserting a couple of inclined reinforcement bars. These were placed in the barycentric plane of the merlon, parallel to the parapet below; at the base of the merlon they crossed exactly at the centre of gravity of the section (on the right, fig. 5). In 1992-93 the timber structure of the roof – already rebuilt in 1960-61 [30, 31] and resting on a reinforced concrete ring beam – was replaced by a reinforced concrete slab and six out of twelve merlons were rebuilt. Very little of the ancient remains existing in 1903-04 survived till the earthquakes of August 24th and October 30th 2016.

The collapse of parapets and crenellation on the two sides perpendicular to the seismic wave can be easily explained: the battlement had been weakened by the chases made at its base and the lack of anchor bars made the new tie-rods totally unable to provide any connection with the perpendicular walls. The significant seismic force induced by the mass of the roof slab caused the collapse of the upper room on itself, further contributing to the failure of the southern side of the battlement, towards which it ruined. On the eastern side, only the central merlons remained, the corner ones collapsed with northern and southern parapets. On the western side, only the parapet is preserved; the two central merlons suffered in plane failure due to shear: the reinforcement bars were not only useless – due to their position – but also harmful, since the perforation for their insertion weakened the masonry; moreover the masonry at the base of the merlons was probably decayed by the stagnation of water in the crenel. Given their significant width compared to the height, merlons generally collapse by out-of-plane overturning if they don't have a roof loading them. However, material decay and incorrect strengthening interventions play an essential role in the activation of the out-of-plane collapse mechanism and can also cause an in-plane shear failure; nonetheless it's very difficult to translate their influence into a numerical parameter.

5 THE OVERHANGING BATTLEMENT OF THE EASTERN CURTAIN WALL

In the works of the first two decades of the 20th century two other overhanging battlements were rebuilt, using techniques very different from the one that has already been examined. On the eastern curtain, the building site was active between 1908 and 1909 [26]. The corbels of the external façade (on the left in fig. 6), towards the town, are made up of four rectangular-shaped sandstone cantilevers which – fixed in the core conglomerate – cross the external wythes and progressively protrude. The free end of each cantilever is rounded to form a quarter of an ellipse, which originates at the end of the cantilever below; the corbel has the shape of a scalene right triangle in which height is about 1 m and protrusion about 60 cm. The spacing of the corbels is about 60÷75 cm, while their width is 20 cm. To prevent stone cantilevers overturning, wrought iron straps were placed to connect them to the masonry. Parapet and merlons were never rebuilt. The cantilevers are still largely ancient as documented by the photos of the early 20th century. The additions are recognisable by workmanship and decay.

Figure 6: From the left: stone cantilevers in the corbels of eastern curtain wall; stone cantilevers supporting brick arches; I-beam with L shaped anchor bar in one of the brick masonry corbels of the polygonal tower.

The greatest damage, up to the loss of an entire corbel, is due to the sandstone decay: in some cases splintering affects also the internal parts of the material decreasing its strength. On the internal face of the same wall a simpler overhanging structure widens the *chemin de* *ronde*: this has corbels about 30 cm wide, made of two layers of sandstone cantilevers, the lower one is rounded, the upper one has a simple parallelepiped shape; they support brick arches one header thick and three header deep (about 40 cm) (in the middle in fig. 6). In this case the corbel spacing is more than 1 m. Some of the stone cantilevers are ancient, the whole is a probably faithful interpretation of existing traces. Apart from some percolation, due to the cracks produced in the concrete cover that should have waterproofed the top of the wall, this system has not reported any damage.

6 THE OVERHANGING BATTLEMENT OF THE PENTAGONAL TOWER AND ITS STRUCTURAL DISORDER

The reconstruction of the battlement of the pentagonal tower started in 1908-09, but it was later abandoned. Neither the internal space of the tower was covered with the designed vault, nor the stairs were built, nor the *chemin de ronde* was finished. In some photos taken before 1990, the last was covered by a discontinuous layer of soil [29]. No traces of pre-existing structures were left. The overhanging battlement was Viviani's invention. He reinterpreted the crenellation of the donjon: the structure was entirely made of bricks on the discontinuous plane of the perimeter walls. The stepped corbels projected from the vertical masonry; the distances from each other varied – about 30÷60 cm – while their width is uniform and about 40 cm, i.e. three headers. The small arches are made of rowlocks reinforced by headers above, however their out-of-plane depth doesn't exceed half the thickness of the superior parapet: as in the donjon, to widen the machicolations, in correspondence with each of them the parapet had a niche, whose back is aligned to the arch. The top of the niches is horizontal, and the parapet is made of two external wythes between which there is a casting of broken bricks and hydraulic lime or cement. Accentuating a peculiarity of the donjon, in the machicolations the façade masonry tapers inwards with an inclination almost mirroring that of the corbels. In this way the parapet rests only on the corbels, entirely overhanging outside the walls of the tower. On this unstable base, Viviani designed heavy angular merlons loaded with a triple dovetail. This battlement is a sort of autonomous screen: on the curtain walls no battlement was built, which would have partially contributed to the stability of the extreme merlons. Thus some merlons collapsed (and were rebuilt) several times, in particular after the 1943 earthquake; finally all the merlons were reconstructed during the last restoration campaign in 1992 [29]. So it's easy to understand the failure in 2016. The rigid block of merlons and parapet crushed the internal part of the pilasters between the niches, and fell in blocks on the *chemin de ronde*, thanks to its more resistant mortar. The damage suffered by the upper part of the corbels has brought to light various metal elements inside them, in a non-systematic way: tie rods with anchors are positioned at the springs of the arches, just below the parapet; about 30 cm lower, inside the masonry of the corbels, some I-beams show a hole at the end of their web, inside which a circular L-shaped bar is inserted (on the right in fig. 6).

The deterioration of the bricks – probably from the beginning a lower quality material – not sufficiently protected from atmospheric agents gave rise to a significant decrease in the structural strength. The detachment of splinters or entire portions of bricks would have required a constant maintenance effort. Owing to the scarce economic resources and the administrative procedures of a small town, maintenance works were unsustainable and in fact they could not be realized. As on the donjon, also here a part of the damage to bricks might be due to the use of waterproofing substances, described in all the restoration specifications of the second half of the 20th century: they ensure a very discontinuous protection, and they impede evaporation, thus causing the permanence of water in the masonry.

6 CONCLUSIONS

A research susceptible of numerous insights – both on the sources and on the building and its materials – is summarized and simplified here, rather than illustrated; it proves that in a not large construction there are five different overhanging battlements, in which the formal analogies with other buildings do not correspond to the structural ones. The failure occurred in significantly different ways owing to a specific vulnerability, construction methods, repairs and material decay. It would be more useful to investigate in-depth into individual cases, to evaluate the differences between them and to identify future situations of real or potential risk. If such a practice were widely carried out, a sort of abacus would be established, the more valid, the more numerous the cases studied. In particular, it would be possible to establish a catalogue of failure phenomena that occur – especially in seismic events – when certain inadequate ways of building or repairing are employed, facilitating prevention on a territorial scale. Building diagnostics and interventions would be better addressed.

An essential tool is the historical research, particularly referred to the last centuries, carried out in a scientific and rigorous way, on the archival sources and on a selected bibliography, avoiding all texts – principally the most recent ones – that do no mention their sources … It is necessary to start from the present state and gradually go back to all documented interventions, trying to identify their traces in the building. As for instability and decay phenomena, it is necessary to identify not only their nature, but also their duration and try to determine their remote or recent causes. A micro-history of construction, degradation and repairs prevents from falling into generalizations – only briefly above described – paying the utmost attention to every single and real feature of the building, leaving nothing for granted. On the basis of a very detailed diagnosis it is therefore possible to find solutions and respond adequately to the real and peculiar problems that engineers and architects are called to solve.

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