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A job and study site: A decade of studies and interventions on ROCCA DE Terzi of Sissa

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Abstract

The present paper is related to the structure of Rocca di Sissa, also known as Rocca de' Terzi, a castle near Parma in the north of Italy. The building construction started in the eleventh century and found its modern appearance in the nineteenth century. Studies on the building started in 2007 and went going on until 2020, also during several job sites and survey campaigns. In the present paper, the path of knowledge on the structure and related interventions on the castle is presented as a case of study.

Key words: historical structure, masonry, Parma, non-destructive Inspection, interdisciplinary studies

1 Introduction

Documents attest to the presence of the building in the 11th century. It became a fortress at the beginning of the fourteenth century and partially destroyed from the Republic of Venice in 1424. In 1440 the castle was remodelled as a residence and other modifications occurred in 1551.
Much of the current appearance of the fortress is the result of an eighteenth-century renovation that connected the ancient tower with the side residential buildings, developed around a central court. A small intervention occurred during the XX century, as the access ladders. Nowadays the building is a square court with a central dungeon in the north arm.
The castle has a masonry structure with lime-based mortar or mud mortar and bricks. The building has 3 levels of masonry vaults, the first and the second levels of the court building have masonry vaults, upper level has timber slabs and timber roofs. the dungeon has 3 more levels. The first level of the court is filled by an embankment. At the first level, the masonry wall has a scarp.
In 2008 and in 2012 the castle was slightly affected by the earthquake in the north of Italy and the town hall that was housed there had to move away.

2 2007-2012 Early studies

In 2007 the study of the building began aimed at the seismic analysis of the complex. The data on the building was very poor. The geometrical survey was not so detailed, there was no information about buildings material and construction detailed and historical archival and bibliographic researches were very old.
The first survey campaign was carried on. Detailed structural surveys were done by the author's team, concentrating in particular on the collection of materic data and state of conservation. Huge efforts have been devoted to these surveys, given the security conditions of some areas and the lack of existing data.
Surveys campaigns were conducted collecting information about each wall of every room, including floor and ceiling: notes on material survey (both structural and finishes data), deterioration and instability, construction details, records of tests carried out, corner wall connections, types of architraves as well as notes on the construction techniques used obtained by visual survey or small essays. Extensive photographic documentation has been collected and catalogued. Moreover, the connections between structural elements were investigated and the presence of joints and their amplitude were reported. After the campaign, all the horizontal structures were identified in geometry and material.

Figure 1. Rocca of Sissa, North view

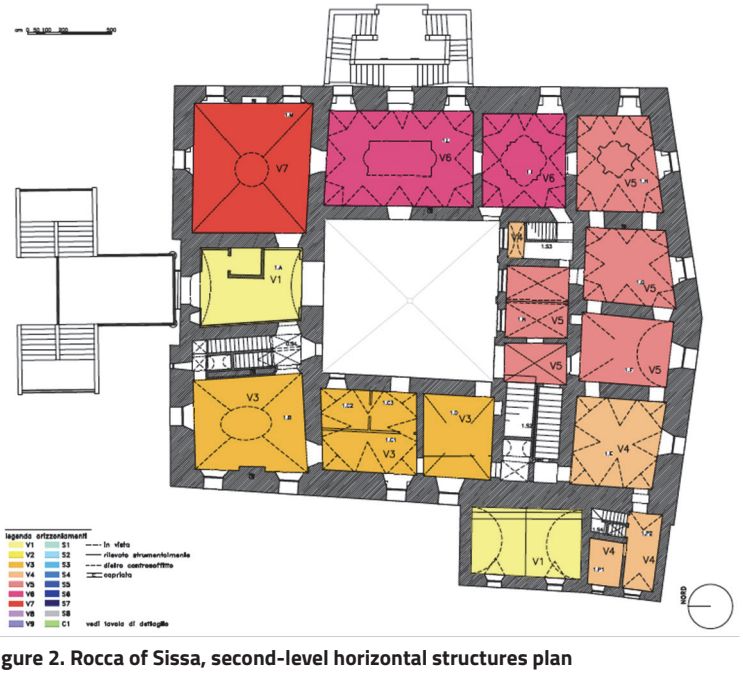

Figure 2. Rocca of Sissa, second-level horizontal structures plan

In 2008 a general plan for the conservation and reuse of the whole castle was drawn up and the authors were in charge of dealing with the structural aspects. Hypothesis damage mechanisms acting and its causes were made. In the same period, the first historical study on documents was carried on by the architectonical designer, arch. C. Dusi and his team.
In 2011-2012 a second survey campaign was realized. Continuous monitoring of the major cracks was installed on the building. The purpose of the monitoring campaign was to verify the movement of the southwest portion of the Rocca complex, in the area surrounding the mail staircase and any movement of the vaults on the first floor. 17 tools have been installed: 14 electronic joint meters (crack meters), stroke length 50 mm, 2 thermocouples (thermometers), 1 electric pressure transducer (piezometer) and a Geologic RTU data acquisition unit which samples the electrical data every 8 hours. After 16 months, it can be concluded that the instrumentation has detected movements, although small, which indicates a mechanism is in place at the southwest angle of the Rocca. On the other hand, it is possible to say that the repeated series of seismic events in the first half of 2012 has changed the extensions and trends observed on any cracks present in the Rocca. This could be due to a change in the behavior of the structures following earthquakes.
Geological surveys were carried on evaluating the geological, hydrogeological and environmental characteristics and geotechnical aspects of the foundations of the Rocca dei Terzi of Sissa. To this end, a campaign of geognostic investigations was carried out which involved the execution of one drilling with continuous coring, 2 penetrometric tests and a geoelectric survey with tomographic interpretation. Furthermore, for the measurement of Vs30 and the determination of the seismic category of underground, seismic prospecting was performed with the MASW method.
The lot looks like a sub-flat and morphologically stable surface. These are mainly sandy and silty sandy soils. Based on the seismic survey carried out, the value of the propagation speed of the cutting waves within 30 m of depth (Vs30) in the soils affected by the intervention in question is equal to 263 m / sec, therefore the category of belonging of the equivalent lithotype is the C, according to Italian code. Moreover, the presence of moat around the castle, as pictured in some XIX century illustrations, were excluded.
In 2015 the first intervention on the building was designed and realized. The batch interested the tower building. Several FEM models was carried on in order to study the behavior of the part on the complex under static loads and in seismic conditions. The main problem of the modeling was the connection between the dungeon and the rest of the building.
The intervention remodeled the roof with a new non-thrust timber roof, preserving the precious timber bell castle. Moreover, the vaults in the tower were strengthened with small reinforcement walls and steel tie rods.

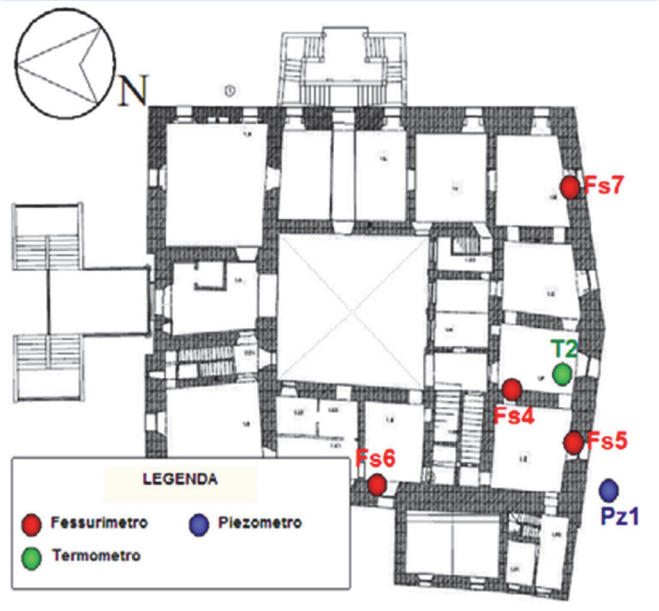

Figure 3. Rocca of Sissa, instrument map on level 1

The presence of the scaffolding during the works permitted a better knowledge of the masonry of the tower. The corbels details could be seen and the texture of the upper external part of the 27m tower was finally studied.
After the first job-site, a second one has allowed the museum to be set up on the tower and visits are now organized regularly.

3 2016-2017 Second campaign and new job-sites

In 2016 a new campaign started. Laser scanner surveys, structural surveys, non-destructive and semi destructive tests were carried on.
Laser scanner survey was carried on by Ianus (Verona, Italy) architects. After that, an accurate geometrical model of the building was finally available and structural analysis could have a strong base to be performed.
The authors updated cracks surveys and defined a structural diagnostic plan. Non-destructive and semi destructive tests were carried by ExPin (Padua, Italy). The campaign was aimed to determine the main characteristics of the walls, such as the type and texture of the walls, materials and construction techniques, the mechanical characteristics of the walls. The tests carried out were weakly destructive (flat jack tests, video endoscopic investigations).
The following tests were performed: 2 tests with double flat jack in order to obtain information about the mechanical characteristics of the masonry investigated in terms of elastic modulus, 42 videoendoscopic investigations aimed at defining the textural

characteristics, the materials and the possible presence of cavities or internal cracks. The tests were carried out on some walls and all the vaults.

Figure 4. Rocca of Sissa, diagnostic map on level 1

After the campaign, the knowledge of geometry and many material physical characteristics in the castle was known, so the structural identification could be carried on. Furthermore, the lack of documentary information also made impossible any enhance on archival and bibliographic researches. Unfortunately, it was not still possible to define all the constructive phases of the building. This is a strong lack of knowledge, because it was not possible to define a plane where each wall could be assigned on a construction phase of the building and assign structural characteristics to each different masonry type, as texture, mortar, kind of bricks, elastic modulus.

All the walls are made of properly cooked bricks. Different sizes are available. Moreover, lime mortar and earthen mortar are found together, also in the same wall or in the thickness of the same portion of the wall. Frequently in the core part of the wall earthen mortar can be found and outer part lime mortar is more present. In some point, rubble masonry was found, especially in the dungeon where the thickness of the wall is about 80cm.

In 2017 accelerometers were placed on the tower to detect the modal behavior. The instruments were "low noise" Force Balance Triton accelerometers by Lunitek. The signals were processed and were compared with the FEM analysis conducted for the 2015 construction site and the results can be defined as coincident.

In 2018 a new job site opened and it close in February 2020. This intervention involved a bigger economical effort and a big area of the castle was repaired and strengthened. The vault was repaired by traditional techniques with lime mortar and hardwood wedg-

es. After that, they were strengthened against earthquake by small diaphragms walls. UHTSS steel nets were use as modern extrados tie roads.
Cracks were repaired with cuci-scuci technique and helicoidal steel bars.
The upper gallery was closed during the long history of the building. In this job-site the lower and upper galleries were reopened, stairs and timber slabs were reinforced with steel profiles. The reopening of the galleries involved intervention in the masonry pillar, but overall it lightens the masses above the pillars of the courtyard. The columns were reinforced with UHTSS steel net and lime mortar.

Figure 5. Rocca of Sissa, Inner prospect on the galleries, before (left) and after (right),

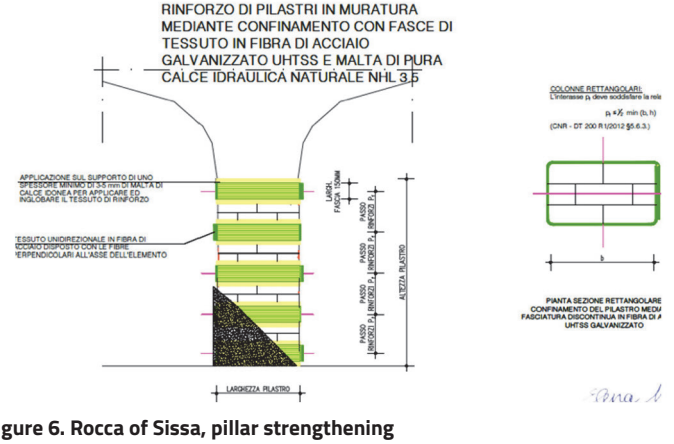

Figure 6. Rocca of Sissa, pillar strengthening

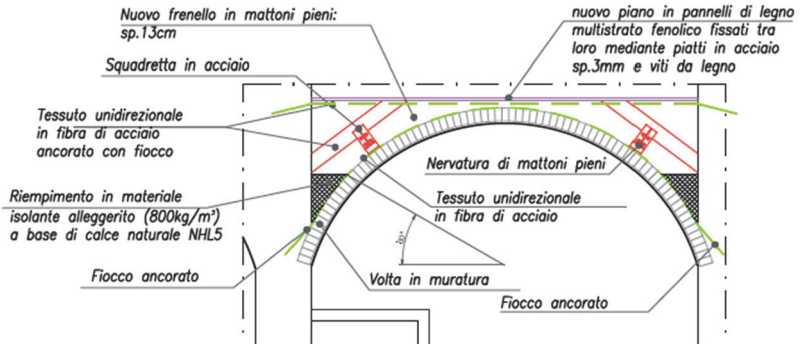

Figure 7. Rocca of Sissa Diaphragm walls on vaults-design

Figure 8. Rocca of Sissa cuci scuci with brick and lime mortar

Figure 9. UHTSS steel net and lime mortar on the vault

The controlling body was afraid that the general behavior of the complex could suffer because the vault intervention would not be realized on the whole building. Analysis was carried on in order to show that the works would not change the global behavior of the building, but strengthening would act on local behavior of the vaults [1, 2].
All the floors were removed, and the extrados part of the vault was visible and could be repaired. In spite of the number of diagnostics carried on the building, only after the opening of the job site it was possible to learn about the copious presence of cracks in the vault that had been repaired in the past. Some of them is impressive for the dimension of the crack, in some cases more than 7 cm, that had been repaired with uncut stones. The clue that permitted to imagine that something had occurred on the vault was the deformation on the vault that cannot be seen without precise and detailed survey as laser scanner can give. The vault texture is mainly at 45° with thicknesses of 12 cm, but sometimes they have different geometries, with weaving parallel to the generatrix. On the vault only lime mortar was found.

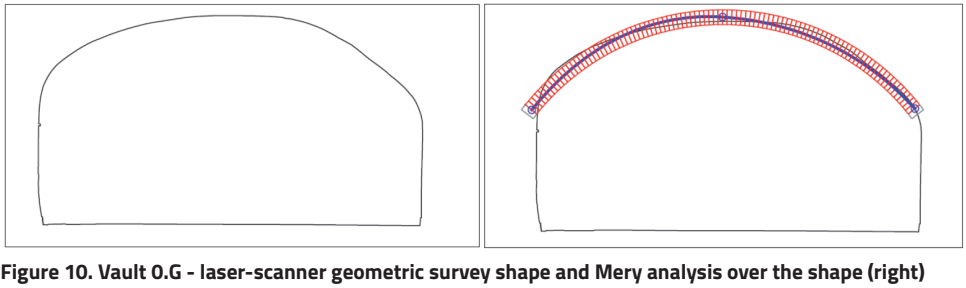

Figure 10. Vault 0.G - laser-scanner geometric survey shape and Mery analysis over the shape (right)

Figure 11. Rocca of Sissa Cracks in the extrados of 0.G vault

Once the floors had been removed, inspection of perimeter wall could be done. On the hidden part of the masonry, Middle age decorations were found. Moreover, numerous joints were found on the vertical wall. Diaphragm walls on vaults were found out as a strengthening technique carried out after the construction of the vault. It was clear that vault always had problems and during the centuries many times they had been the object of repairing and remodeling intervention. Stratigraphic and archaeological methods had been applied to the wall. The most impressive fact is that there is a strong lack of corner wall connections. A detailed photographic campaign and orthophotos were taken by Ianus.

The walls seem intact above the level of the floor but show numerous closings and openings below the level extrados of the vaults. Further advances in knowledge can be implemented, perhaps with the aid of a thermographic campaign. The continuous remodeling of the building is evident: windows, doors and many reopening and closure were clearly identified on the walls. Moreover, different levels of vault had found a place on the building during centuries and the presence is still shown in the small space between the extrados of the vault and the present floor. The discovery was surprising also because on the outer perimeter the appearance of the building is unitary.

The presence of the scaffolding during the works permitted to investigate this aspect. Also on the outer wall, stratigraphical surveys techniques had been applied and some hypothesis had been made, so new input for further studies was found.

At the present point, it seems that an external masonry counter wall was applied in many points, in order to give homogeneous apparel to the complex. The dating of the intervention will be one of the next study topics.

In February 2020 the survey's campaign went on and stratigraphical survey techniques had been applied to the inner court.

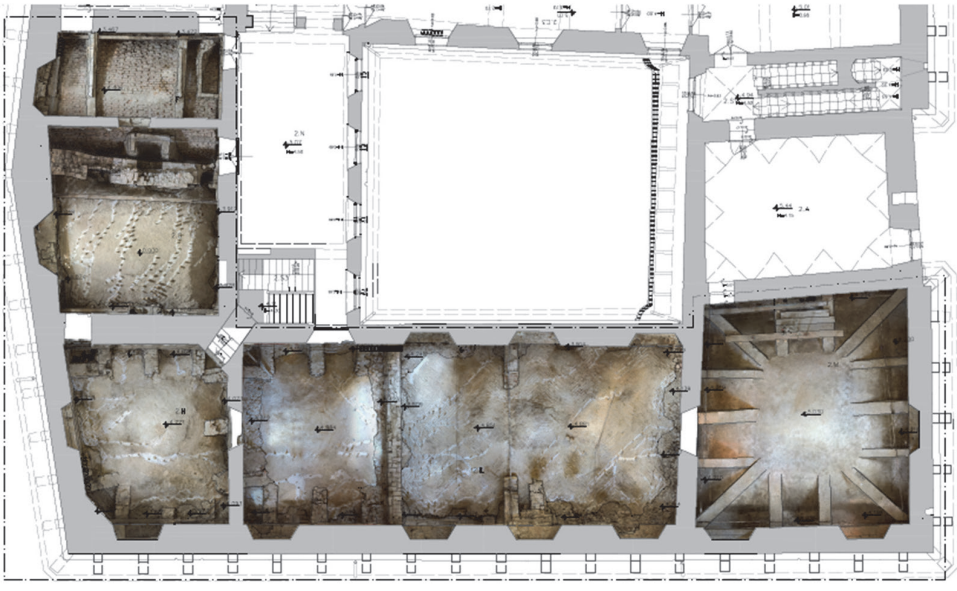

Figure 12. Rocca of Sissa orthophoto vault 2nd level (Courtesy of Ianus)

4 Conclusions

More a decade of studies was carried on Rocca of Sissa. The initial investment of the properties in drafting a global project that is implemented from time to time the necessary resources are found. The study campaigns have followed over the years alternating with job sites. The job sites also were an opportunity to deepen the knowledge of the construction techniques and materials used in the building and an impulse to improve the planned interventions. After more than a decade of studies and interventions on Rocca de Terzi of Sissa can be defined as a real job and study site.

Acknowledgements

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References

[1] Girardello, P., da Porto, F., Modena, C., Valluzzi, R. Comportamento sperimentale di volte in muratura rinforzate con materiali compositi a matrice inorganica, *Anidis Conference* (2013), Padua, Italy

[2] Cattari, S., Lagomarsino, S., Resemini, S. Il ruolo delle volte nella risposta sismica degli edifici in muratura in XXXX (2007) pp211-270.