The Medieval Grange of Cuna – Siena (Italy)-Interdisciplinary Studies on Masonry Structures

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Abstract. A team of specialist in different subject worked together with a multidisciplinary approach for the conservation of the complex of the Grange of Cuna, the administrative and storage center of the bigger farm of Santa Maria della Scala Hospital in Siena (Italy) in Middle Ages. Laser scanner surveys, archival and bibliographic researches, stratigraphic surveys, structural surveys were carried on and studied by the members of the team on the complex of 167 rooms. The results obtained by specialist approach was frequently discussed and compared in order to obtain a deeper knowledge of the complex of buildings. Structural engineer studies concerned the identification of different typologies of masonry and the structural diagnostics to mechanical characterization. Double flat jack and sonic inspection were performed on tapial adobe, brick masonry with lime and mud mortar.

Keywords: Grancia di cuna · Masonry · Adobe · Structural diagnostic Double flat jack · Sonic inspection · Santa maria della scala · Tuscany Pisèe · Tapial · Brick · Interdisciplinary study

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1 Working Group and Work Method

The Grange of Cuna was the granary of the bigger farm of Santa Maria della Scala Hospital in Siena. Built starting from the early 14th century, the complex increased till the second half of the 18th century [1]. For its extraordinary state of preservation, its size and internal organization of individual buildings, it is one of the biggest and most beautiful examples of fortified farm in Italian and European Middle Ages context. The masonry complex consists of a small village surrounded by walls with gates and towers. Within the walls is the actual farm and four-story granary, accessible through a monumental ramp (Fig. 1).

Fig. 1. View from Google earth of the complex

Starting from 2012, a lot of studies, funded by the municipality of Monteroni d'Arbia and involving a team of specialists, have been carried out aiming at developing a conservation project of the complex.

In the team, architects (F. Randazzo and A. Magrini) were responsible for the overall coordination of the research and of the architectural survey. Laser scanner technology has been used: five horizontal sections, twenty-four vertical sections and a number of details were done. The survey was the base for all the spatial and geometrical data and provided a model useful to control the articulate shape of complex and helpful to identify structural instabilities and deformations in order to plan the diagnostic phase and the following phase of study of vulnerabilities.

E. Giorgi and S. Dandria carried out archival and bibliographic researches in order to collect information and to cross check them with stratigraphic data; M. Giamello characterized 48 samples of bedding mortar to confirm hypotheses about the construction phases [2]; F. Gabbrielli investigated the main buildings to determine a relative chronology and, based on historical information, an absolute chronology using stratigraphic and archeological methods. Structural engineers (E. Manzoni, A. Dusi) were responsible for structural survey and investigated typologies, joints and the state of conservation in order to define structural units and their mutual interactions; furthermore, they planned the diagnostic that was carried out by F. Casarin.

2 Structural Surveys

Structural engineers firstly concentrated on a review of all the existing studies on the Grancia di Cuna complex's structure, without any useful findings. Subsequently, detailed structural surveys were done, concentrating in particular on the collection of material data and state of conservation. Huge efforts have been devoted to these surveys, given the number of the rooms (167 rooms) and the security conditions of some areas.

Campaign surveys were conducted by drafting a campaign notebook, in which all the information about each wall of every room, including floor and ceiling, were collected and catalogued along with notes on material survey, 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. An extensive photographic documentation has been made and catalogued to complete the notebook. Finally, the connections between structural elements were investigated and the presence of joints and their amplitude were reported.

After this phase, a full mapping of construction techniques, architectonical detail and structural schemes was realized by on-site identification.

3 Multi-disciplinary Interactive Study Development

A lot of brainstorming meetings were held within the working group with the aim of defining a set of hypotheses, related to the historical construction phases, to be investigated. The different competences present in the team and the multidisciplinary approach adopted allowed to have a deeper knowledge, otherwise difficulty achievable, of the masonry structures. The results obtained by specialist approach was frequently discussed and compared in order to obtain a deeper knowledge of the complex of buildings. For instance, direct observation of joints on site permitted to locate (or relocate) historical phases limits found on archival document.

Three different typologies of walls are present in the complex of Grancia di Cuna: brick masonry and lime mortar, brick masonry and mud mortar, adobe (tapial). Thanks to the multidisciplinary approach, brick masonries with mud mortars were located in the medieval buildings, while adobe masonries plastered with lime mortar are present in some post-medieval additions.

Based on the inspections carried out and the shared knowledge, the hypothesis to be confirmed was set and it consisted in 7 historical phases. The diagnostic plan was drawn up in order to validate the above-mentioned hypothesis.

4 Diagnostic on Masonry Structures

Some preliminary essays on small portion of wall were performed in order to remove plaster and obtain information about texture, thickness of layers and on information that could help in defining different structural typologies. Some controlled disassembles were also performed to collect information about the core of the walls.

The instrumental campaign was aimed at determining the main mechanical characteristics of masonry. The position of the tests was defined for collecting data on masonry on each historical phase.

Nine double flat jack tests, at least one for each phase, were finally performed. Sonic tests were planned on the same position of flat jacks as well as in other walls, in order to extend the elastic modulus information on other areas with similar sonic response. Overall, 14 sonic tests were done.

Since one phase, indicated as phase 6, presented different typology of masonries in the same wall, use was made of termocamera in order to try to map the distribution of adobe and solid bricks in these walls.

4.1 Double Flat Jack on Adobe Wall (Tapial)

One double flat jack was realized on tapial adobe wall, showing. during the final test phases, many vertical cracks and sub-horizontal cracks close to the jacks. It has to be underlined that these types of tests are seldom carried out on tapial. Results are reported in the following (Figs. 2 and 3, Table 1).

Maximum measured stress was equal to 0,60 N/mm^2, being cycle load increased at a rate of 0,20 N/mm^2.

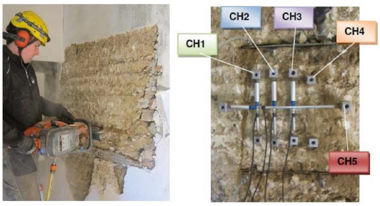

Fig. 2. Double flat jack on adobe set-up

Table 1. Tangential elastic modulus vs. stress variation

E tan [N/mm2]	Δ (σ) [N/mm2]
202	0,00–0,20
183	0,20–0,40
89	0,40–0,60

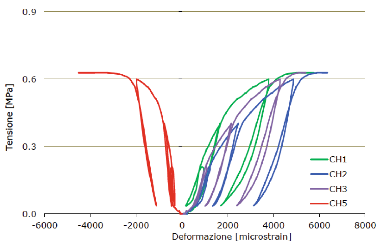

Fig. 3. Tension-deformation of single channel for double flat jack on adobe

4.2 Data from Instrumental Analysis and Interpretation

Main results on double flat jacks and sonic inspection are reported in Table 2 in which the number of phases is not reported in chronological order. In Figs. 4, 5, 6, 7 and 8 the mapping of each phase is represented in different colors.

The following remarks can be made. Sonic tests 1a and 1b performed on the first two levels showed a slightly increase of speeds with height; the area of test 1c has an outer facing in solid brick with lime mortar and a higher speed was recorded, while in the other points investigated the joints are made with mud mortar, therefore these walls do not seem belonging to same construction phases to which construction phases 1a and 1b area belongs.

The results on phase 3 showed good speeds on both panels investigated with slight differences probably due to the possible presence of bondstones (diatoni).

Phases 4 and phase 5 showed similar results to phase 1.

In phase 6, SON-6a and SON-6bis-a sonic analysis gave similar speed, therefore it can be assumed to be representative of the same type of masonry (e.g. solid bricks and mud mortar with inner adobe core wall), whilst double flat jack test 6b (MPD6b) did not give useful results because of the rotation of the inner core. SON6bis-b recorded higher speeds due to the presence of lime mortar. The lower speeds of the entire investigation and registration campaign was found for adobe (tests MDP6c and SON6c). As already mentioned, phase 6 presents different typologies of masonry, also within the same wall. An attempt of using termocamera was done in order to map of the distribution of adobe and solid bricks in the wall. Unfortunately, thermography was not able to give expected results; phase 7 showed good quality walls, actually the best in the complex.

Starting from the assumption that masonry in the same historical phase should have homogeneous mechanical characteristics, the results of the diagnostic on structures confirmed some of the hypotheses made on the of construction phases. Considering that inside the border of historical phases, masonry with different mechanical characteristics has been find, new phases have to be considered and at the end 10 phases were identified.

Chemical and physical analyses on mortars confirmed this phase hypothesis; results are reported in [3].

Table 2. Comparison of diagnostic results

Phase	Test name	Speed [m/s]	Elastic modulus Average Unloading [N/mm2]	Masonry typology	Color reference in figures
1	MDP1	–	1245	Brick masonry, mud mortar, good wall texture	Orange
	SON1a	550	–		
	SON 1b	669	–	Brick masonry, mud mortar	
X	SON 1c	935	–	Brick masonry, lime mortar	Dark brown
3	MPD3	–	3461	Brick masonry, mud mortar, good mortar layer	Violet
	SON3a	1348	–		
	SON3b	1039	–	Brick masonry, lime mortar	
4	MDP4	–	8268	Brick masonry, lime mortar	Blue
	SON4	776	–	Brick masonry, mud mortar	
5	MPD5	–	1380	Brick masonry, mud mortar	Light green
6	MPD6a	–	x	Brick masonry, mud mortar, inner adobe rubble core wall	Magenta
	SON6a	636	–		
	MPD6b	–	4170	Brick masonry, mud mortar, deep repointing with lime mortar and inner adobe rubble core wall	Grey
	MPD6c		306	Adobe (tapial)	Red
	SON6c	542	–		
	SON6bis a	872	–	Brick masonry, mud mortar and inner rubble core wall	Yellow
	SON6bis b	1006	–	Brick masonry, lime mortar	Light brown
7	MPD7a	–	7874	Brick masonry, lime mortar, good quality mortar	Light blue
	SON7a	1705	–	Brick masonry, lime mortar	
	MPD7b	–	4510	Brick masonry, lime mortar	
	SON7b	1787	–		
	SON7c	1680	–	Brick masonry, lime mortar	
				MPD = Double flat jack SON = sonic inspection	Rose: not investigated tapial Dark green: not investigated brick masonry and lime mortar

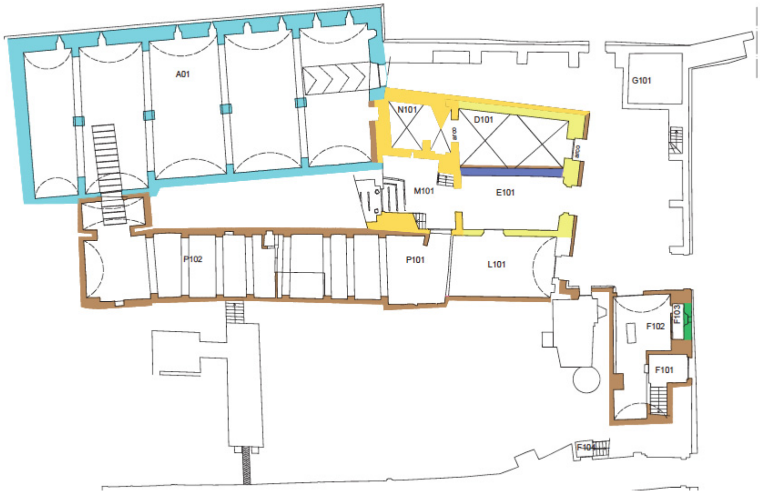

Fig. 4. Level 0

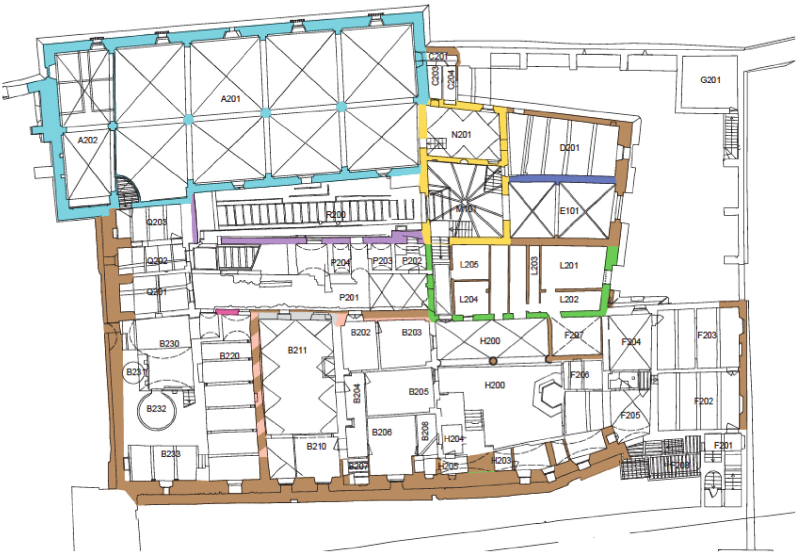

Fig. 5. Level 1

Fig. 6. Level 2

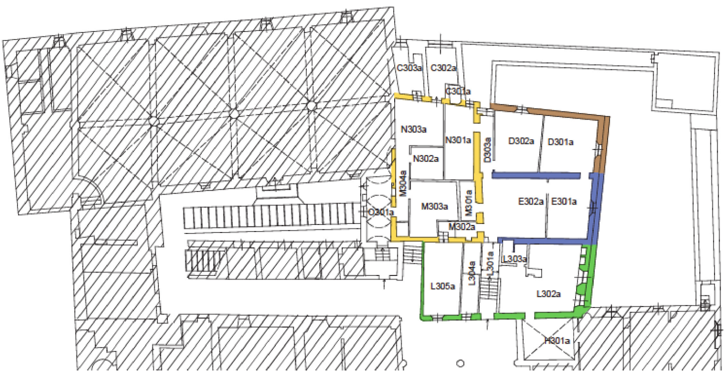

Fig. 7. Level 3

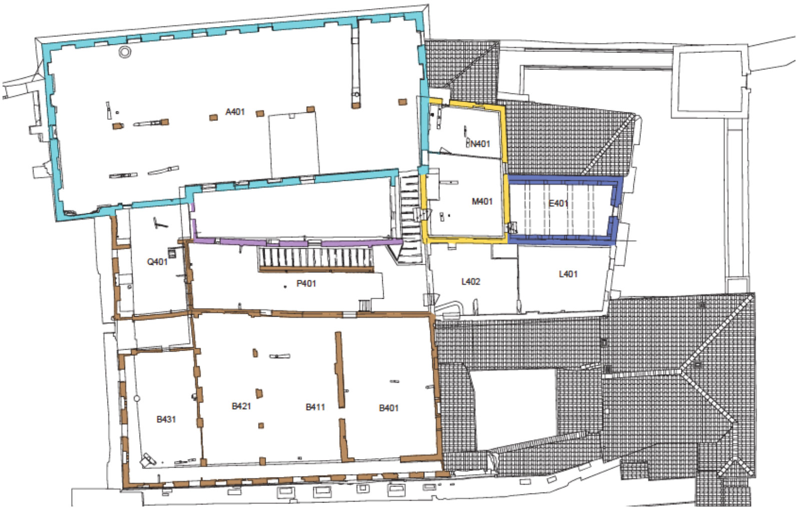

Fig. 8. Level 4

5 Conclusions

The importance of multidisciplinary approach has been demonstrated. In the Grancia of Cuna case study the multidisciplinary approach allowed for a better and deeper comprehension of the structure of the building, that would have not been possible by resorting to singular specialist approach.

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