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THE RESTORATION INTERVENTIONS OF “FORTE MARGHERA” IN VENICE

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Abstract. *In the framework of the Strategic Masterplan Cultural Heritage 2014-2018 of the Italian Ministry of Culture, a specific attention for the strengthening and constitution of relevant urban cultural centers is sought through the restoration and re-use of structural complexes of great architectural and historic value such as the case of Forte Marghera (Marghera Fort) of Venice. The need to build a fortress at the point where the mainland approached Venice was understood, after the fall of the “Serenissima” Republic (1797), by the Austrian Empire. The fort was therefore built in a marshy area on the edge of the Venice lagoon, crossed by a maze of canals. The works started in 1805. On the area there was already the old village of Malghera, home to warehouses and customs, which was incorporated into the Fort. However, the return of Napoleon's troops in 1806 surprised the works still in a early stage. The fortified work was then revised according to the plans of the French architect Marescò and conducted under the guidance of the general and military engineer François-Joseph Chaussegros de Léry and later the Chasseloup. The most significant buildings still present in the fortress – object of the current restoration works - are the two French barracks (1805-1814), located on the front near the dock. They are two-storey brickwork masonry structures with a 83x15 m rectangular plan and perimeter walls reaching a 3 m thickness, provided with decorative elements made of Istria stone. Visible decay is present in both two massive buildings, due to differential settlements mainly visible the long sides of both buildings, especially affecting the West one, also partially subjected to local collapse. A wide investigation campaign, aiming to the adequate characterization of the constituting materials and building techniques, was carried out in order to properly feed the design of conservative restoration interventions. Results indicate the use of good quality materials and proper layout also in the foundation system, indicating in the poor soil mechanical characteristics the main structural deficiency leading to the visible settlements. To date, the detailed design stage was reached for just one of the three buildings involved in the restoration, while the two remaining buildings are still in a preliminary design phase.*

1 FOREWORD

Within the Strategic Masterplan “Grandi Progetti Beni Culturali” (*Large Projects Cultural Heritage*) 2017-2018, the MIBACT (Italian Ministry for Cultural Heritage and Tourism) financed the intervention: “*Marghera Fort - museum recovery in the environmental crisis area*" [1]. As the beneficiary of the financing, the Municipality of Venice assigned the development of the project and the site engineering to the in-house company Insula spa [2].

The military fort, acquired from the state by the Municipality of Venice since 2010, houses 78 buildings on a territorial surface of 24 acres, and it is being progressively restored with public funding for cultural purposes and recreational activities (museum / exhibition - Venice Biennale, Civic Museums), and related services. The Municipality of Venice has a strong interest in this location given the central position between Venice and Mestre, between water and land (**Figure 1**, left). The project allocates the overall budget (7M Euro) on the recovery of three buildings: the two 19th century "Austrian" barracks, heritage buildings of considerable historical and monumental interest, facing the marina, besides an early twentieth century ruined building, raised next to the main axis of the *Ridotto Island*, the heart of the Fort, to be possibly reused as exhibition spaces.

2 SITE HISTORY, FORTE MARGHERA

Forte Marghera was conceived and built in different stages from 1797 to 1814. Its construction began in July 1805 on the area of the small village of Marghera, at that time also called Malghera.

Consisting of a church, refreshment venues and storage of goods and served by a bridge, it was the nearest embarkation point to Venice in the communication with the mainland, located between Venice and Mestre. The village and the Marzenego, Osellino and Bottenigo canals (which connected Venice to Liza Fusina) flowed into Marghera between marshes and sandbanks. The conformation of the territory, where the fortress was built was far different from the present one (**Figure 1**, right).

Figure 1: location of Forte Marghera area (left) and historical map of the settlement of “Marghera” (right)

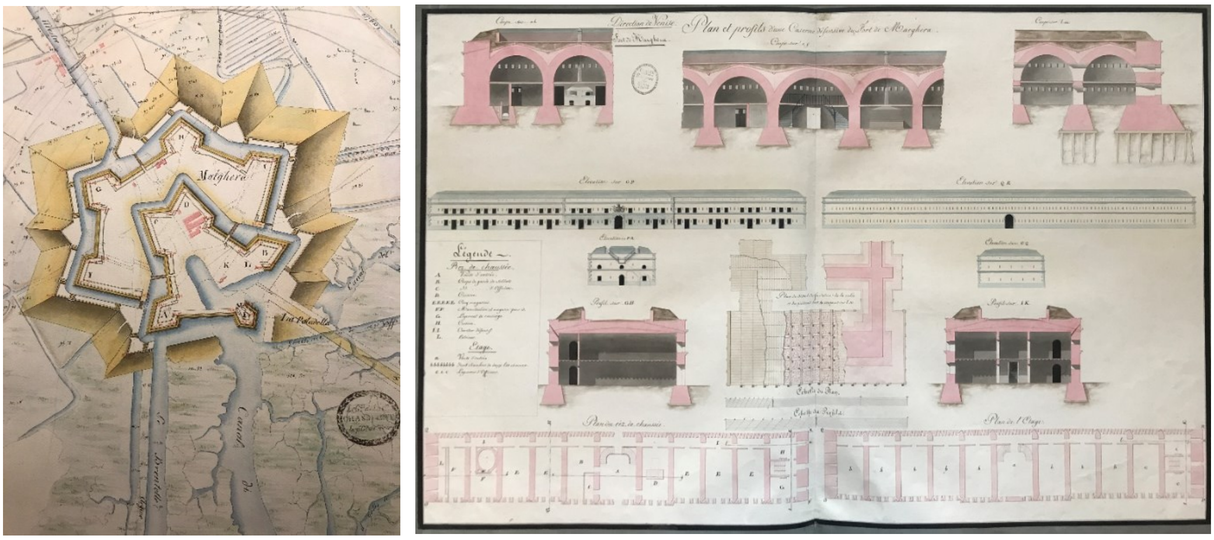

Figure 2: general plan of the Fort (left) and of the French barracks (right)

Following the Salso Canal from the mainland to the lagoon, after the village of Marghera, there was the Anconetta bridge and then the island of San Giuliano. Both in Marghera and San Giuliano there were watchtowers.

The Republic of Venice made the lagoon the main element of defence from its enemies, controlling the most important communication canals linked with the hinterland by blocking them with chains, fences and palisades and a flotilla of armed vessels. Historically, the first line of defence for Venice was on the coast (towers, fortresses), then on the inner islands of the lagoon. Forte Marghera was the first "mainland" garrison to defend the harbour of the city and its very important arsenal was destined to become, in the course of a century, the core of the Campo Trincerato di Mestre (Entrenched Field of Mestre).

The construction of the entrenched field started by the Austrians in the early nineteenth century was completed by the French during the Napoleonic occupation. Its origin dates to the historical period of the fall of the Venetian Republic, when on May 12, 1797, under the force of the Republican armies led by Bonaparte, a pro-French popular government was formed. The French were the first to take a census of the fortifications and to design the Fortress of Marghera above the village. The Austrians, in 1805, began the construction with some requisitions and the construction of some ramparts, and subsequently the French completed it with the construction of the most imposing fortification to defend the city and the consequent disappearance of the ancient village of Marghera.

With the First World War, Forte Marghera, together with the other fortresses of Mestre, was not part of the strategic line of defence, and the weaponry was dismantled and transferred to the front. In recent times, it became an ammunition storage and a weapon repair site, as shown by the buildings used as workshops. Its military function ended on June 30, 1995.

2 STRUCTURAL & GEOTECHNICAL INVESTIGATIONS

A thorough structural investigation campaign was conceived and executed in order to achieve an adequate knowledge level for the design of the interventions for the recovery and restoration of the three historic buildings of Forte Marghera object of intervention (**Figure 3**).

Figure 3: the three buildings object of the intervention: building nr. 8, 9 and 29

These are the two Napoleonic "barracks" located on the lagoon side, called "Building 8" (west) and "Building 9" (east), and a building that has not been covered for years following the collapse of the roof due to deterioration, called "Building 29", located in the center of the islet of the fortress. Tests aimed at the definition of the structural elements' composition (walls and vaults inner arrangement), the geometrical and crack pattern detailed survey (hidden structural portions, foundations) and material characterization (mechanical characteristics). A relevant part of the diagnostic effort was directed to the geotechnical characterization of the soil, being this the obvious suspect of the evident differential settlements pattern resulting in visible structural distortion and masonry walls cracking, especially in the west barrack.

2.1 The investigation campaign

Building nr. 8 has an extensive cracking and deformation pattern, attributable to foundations' differential settlements. From the available documentation, it is noted that buildings 8 and 9 have very large masonry foundations, with the presence of wooden poles to intercept the deeper load-bearing layers (**Figure 4**, left). The study of historical hydrography has however shown that part of building 8 appears to have been partially built over a palaeochannel, subsequently filled with soil for the construction of the fort (**Figure 4**, left). A series of investigations were therefore executed to investigate the nature of the foundation soil in a widespread manner, in order to highlight any difference in the soil capacity or critical issues. A series of electrical piezocone penetration tests CPTu (n. 4 on the North side and n. 4 on the South side of bldg. nr. 8, plus nr. 4 tests along building nr. 9) were performed with depth variable between 15 and 30 meters, together with nr. 5 soil boring at a depth of 20 meters with undisturbed sampling for laboratory tests. Several excavations aimed at highlighting the foundations were also carried out, with execution of sub-vertical surveys aimed at the interception of wooden poles to a depth of 5 meters.

From a structural point of view, different investigation procedures were considered for the two older buildings and the newer one. The two barracks, composed by massive walls and vaults, were subjected to the following structural tests: single and double flat jack tests to obtain information on the local state of stress and the mechanical characteristics of masonry, carried out in the head and inner walls; micro-core drillings with video-endoscopic inspection, for the evaluation of the internal composition of the walls (head, side and internal walls) and vaults (at the key and at ¼ of the span of two vaults); sonic tests on walls, to identify the compositional characteristics of masonry by measuring the velocity of mechanical waves propagating within the structural elements, especially in the thicker walls; collection of mortar samples for characterization and mineralogical-petrographic study, performed on samples extracted from the core drillings; excavation trenches on the roof, after dismantling the existing cover, to check the exact stratigraphy and state of conservation of the vaults on the extrados; crack pattern survey of the buildings. The more recent building – nr. 29 – already heavily damaged from previous collapse of the roof, was object of the following structural tests: collection of undisturbed samples of single-leaf thick panels for performing nr. 2 diagonal-compression and nr. 2 simple compression tests in the laboratory; micro-core drillings with video-endoscopic inspection, for the evaluation of the internal composition of the pillars; collection of mortar samples for characterization and mineralogical-petrographic study, performed on samples extracted from the core drillings; crack pattern survey of the building.

2.2 Obtained results

The analysis of the crack and deformation pattern of the structures, together with the material decay assessment allowed to identify and map the structural deterioration related to the different pathologies encountered. Besides the identification of the visible cracking of the west barrack, not only in the façade but also in the transverse walls (**Figure 5**), it was indeed possible to appreciate a diffuse material decay (severe degradation of mortars, missing brick units, spalling, pulverization, erosion, rising phenomena and presence of biological attacks), mostly due to the environmental conditions (seaside).

From a mechanical and compositional point of view, the brickwork masonry walls result – notwithstanding the encountered deterioration – sound and properly built, coherently with its military intended robustness.

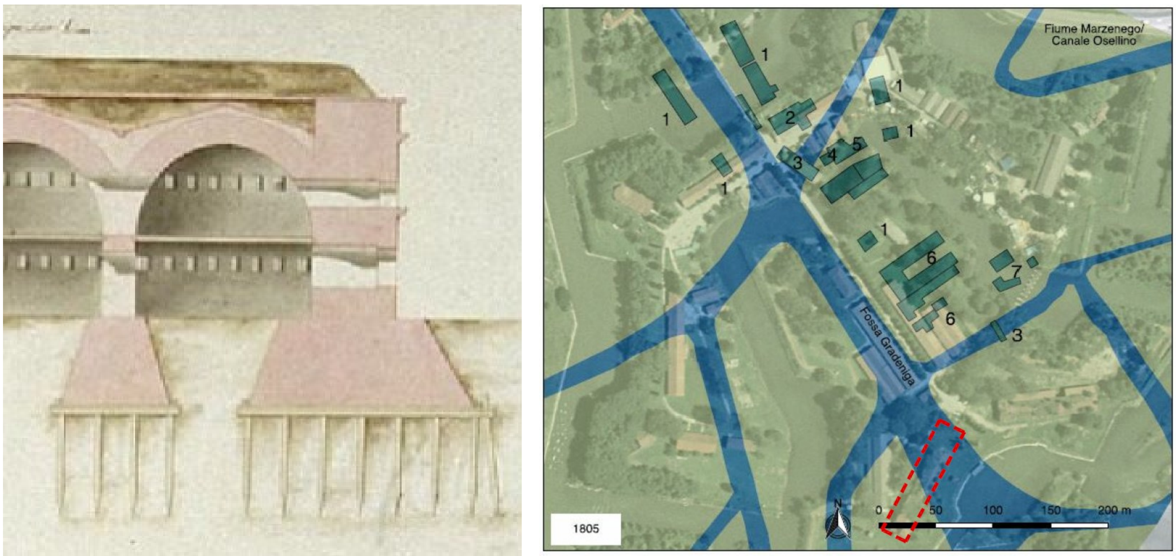

Figure 4: layout of the original French blueprint of the foundation of the head and inner transverse walls (left); map with indication of the palaeochannels in the area of Forte Marghera (right): highlighted in red building nr. 8

Figure 5: crack pattern in building nr. 8: it is highly visible a well-defined differential settlements trend

The inspection of the inner sections of both walls and vaults indicated a properly arranged core, without any loose infill, even for the thicker walls (2,80 m).

Stiffness values emerged from the flat jack tests carried out are compared with those reported in the Italian Standards for the type of masonry observed (brickwork masonry with lime-based mortar). According to Italian Standards [3], the Elastic modulus E is in the range 1.200 – 1.800 N/mm^2 (with reference strength between 2,6 and 4,3 N/mm^2). The comparison with the obtained results shows that the moduli of elasticity obtained onsite match the standard figures. The compressive tests carried out on the wallets extracted from the single-leaf perimeter walls of building nr. 29, being a XX c. building, shown a higher stiffness (and resistance) masonry, equal on average to 7.370 and 5,40 N/mm^2 respectively (**Table 1**).

The sampled mortars composition reflects indeed the constructive periods of the three buildings. Cementitious binder was only found in the sampled material from building 29, dating XX c. the two older buildings, nr. 8 and 9, present mortars using non-hydraulic lime as binder.

Sonic tests carried out widely on the two older buildings (a total of 6+6=12 tests) indicated good to very good values for the sonic velocity through the masonry walls, with relatively homogeneous figures (avg. max/min equal to 1.852 / 2.820 m/s). Higher values were found in building nr. 9 (overall average value of 2.440 m/s) than in building nr. 8, (2.150 m/s), possibly also for the different state of conservation of the two buildings.

The investigations on the foundations and on the soil allowed to confirm the layout as represented in the historical blueprints, with some minor differences (e.g. the foundation width for the massive perimeter walls).

Informative results emerged both from the CPTu and the borehole tests. These last depicted a typical soil stratigraphy of the lagoon of Venice, composed by superficial layers of clayey silt to a depth of -3,00 m, then an alternance of soft layers of silt clay and sand (and a mix between the three) down to a depth of approx. -9,00 m, then the so called “caranto” layer (over consolidated silty clay) with a thickness of 2 – 2,50 m. below this depth and down to the end of the perforation (-20 m), alternance of sandy silt and again more or less compact silty clay.

The penetrometric tests explained the differential settlements trend encountered in building nr. 9, given the visible change in the soil resistance between -2,0 ÷ -4,0 m, where the foundations / poles find support, between tests nr. 1, 2, 8 (denoting a certain capacity) and 3 to 7, remarkably weaker, approximately located in correspondence of the filled channel.

Table 1: mechanical tests on masonry, on site (flat jack tests) and in laboratory (compressive tests).

Test ID	location	Local stress [N/mm^2]	"Elastic" limit stress [N/mm^2]	Max stress [N/mm^2]	E [N/mm^2]
DFJ 1/8	Head wall, bldg. 8	0,19	3,28	4,22	1.941
DFJ 2/8	Internal wall, blgd. 8	0,64	3,75	4,22	1.408
DFJ 1/9	Head wall, bldg. 9	0,44	2,78	3,25	1.424
DFJ 2/9	Internal wall, blgd. 9	0,41	1,85	3,42	1.072
PM2	Perimeter wall bldg 29	--	--	5,56 [strength]	8.797
PM4	Perimeter wall bldg 29	--	--	5,25 [strength]	5.952

3 STRUCTURAL MODELING – SAFETY CONDITIONS

The two French barracks nr. 8 and 9 have a rectangular plan, 85x15 m in size, and are made by transversal thick walls (about 110 cm thickness the internal walls, more than 280 cm the head walls), which support the barrel vaults (**Figure 6**). The longitudinal facades, also in brick masonry about 110 cm thick, are simply juxtaposed to the vaults, and not clamped to the transverse walls, as highlighted by some cracks visible on site. Walls and vaults are all made in solid bricks masonry, with lime mortar joints.

The buildings are 7 m tall, and originally, they had a roof terrace with perimetral ramparts; nowadays there is a pitched roof made with wooden beams and rooftiles, and the space between the original pavement and the roof is filled with soil.

Building 8 differs from Building 9 for the absence of the central staircase, which is positioned on the East side, where there are intermediate floors that divide the first two vaulted rooms. Barrack 8 presents also a lower part in the north-west corner, due to the collapse of a portion of the barrel vault, currently covered with a wooden roof.

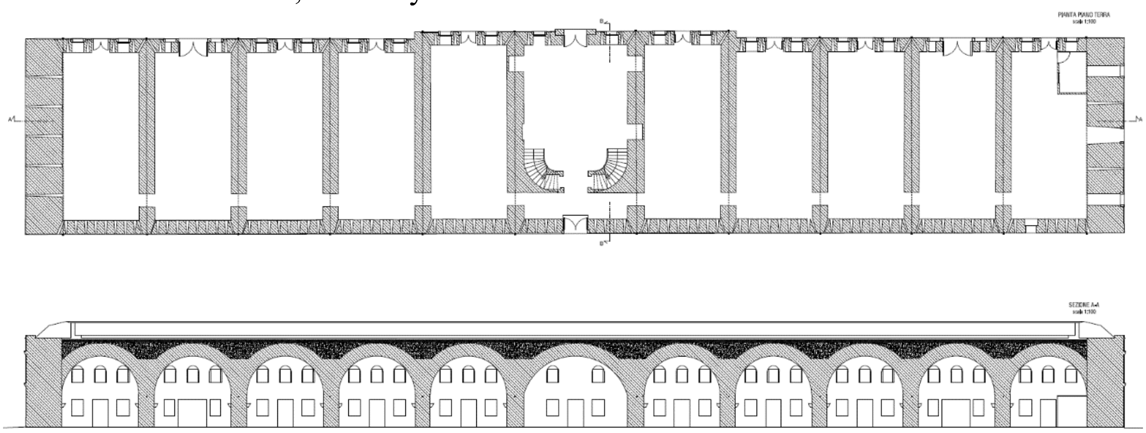

Figure 6: building nr. 9 – plan and cross section

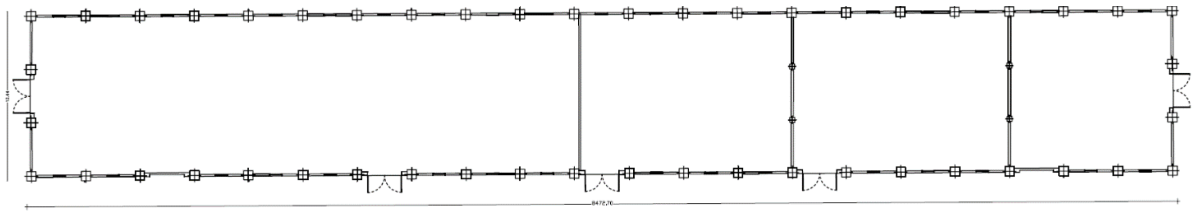

Figure 7: building nr. 29, plan view

The current situation of both buildings highlights a significant state of decay; the external facades are damaged by the growth of vegetation, especially on the top cornices, where some stone pieces are fallen. Vertical walls present cracks in correspondences of the chimneys and diagonal cracks near the entrance portals. There are also systematic cracks between the vaults and the facade walls, due to the absence of connections between facades and transversal walls. Furthermore, the building nr. 8 presents several and evident deformations, with wide cracks on facades and inner walls, remarkably in the central portion which appears lowered than the north-west corner, as described earlier.

The depot building nr. 29, built in the early twentieth century, has completely different structural characteristics (**Figure 7**). This building is made by squared masonry pillars (0.65x0.65m) spaced 4 meters, with bricks masonry single-leaf spandrel walls. It has an elongated rectangular shape, 12.5x85 m, one storey, with pillars high 3,30 m; the roof, currently collapsed, was a wooden pitched roof, with wooden trusses supported by masonry pillars.

3.1 The modelling strategy

Considering the different constructive typologies of the three buildings, different analysis approaches have been chosen.

The two French barracks have been studied using a finite element model, which has been created to define the stress distribution on vertical walls and on foundation soil. The model of each building was processed by the commercial software MIDAS and it is composed by 351’417 tetrahedral 3D elements. The typical size of the tetrahedral 3D element is 0,5m.

Dynamic linear analysis has been used to simulate the seismic behaviour of the massive buildings, considering different level of connection between longitudinal and transversal walls: the two barracks are indeed built with the facades simply juxtaposed to the transversal walls and to the vaults, as often encountered in Venetian historical buildings. Therefore, the facades have been modelled separated from inner walls and vaults, connected to them only by unidirectional (horizontal) springs. This detail also allowed an accurate study of the stresses on foundation soil, avoiding stress distribution on walls that are not directly loaded by the vaults.

The interaction between soil and foundations has been analysed using elastic Winkler springs, calculated according to the geotechnical investigation results. Differences on soil characteristics have been considered using different stiffness value on the springs. Limit analysis was finally used to evaluate the seismic behaviour of vertical walls, in order to check their vulnerability to out-of-plane collapse, including the high horizontal thrust of vaults.

The depot building (nr. 29) was instead analysed with a non-linear equivalent frame model, performing a static non-linear (pushover) analysis and considering the seismic contribution of the longitudinal single-leaf walls between the masonry pillars. Such walls were eventually reinforced by design in order to consider them as effective bracing elements. The horizontal rigid plane -necessary to distribute the seismic actions to the resistant walls- is ensured by the new steel structures of the roof, with an out-of-context architectural hint. Limit analysis has been used also in this case in order to check the out-of-plane collapse of the vertical walls and to calculate the retaining force which has been applied to the roof structures.

3.2 Obtained results

The global FE models of the barrack buildings (nr. 8 and 9) have been used to perform both static and seismic (dynamic) analysis (**Figure 8**).

The self-weight analysis – carried out according the current Italian Construction Standard NTC2018 – has confirmed the soundness of the vertical structures, built to resist to cannon attacks. The great thickness of vaults and of vertical walls can distribute easily the heavy loads from the roof, made with large layers of soil and with perimetral ramparts.

Results obtained in terms of σ_{ZZ} stress (compression) indicate that the average value of compressive stress at the ground level corresponds to approximately 0,4-0,5 N/mm^2 (**Figure 9**). Average compression stress on vaults is lower than 0,2-0,45 N/mm^2.The seismic behaviour of the building is characterized by the large thickness of masonry walls, which can easily absorb the seismic actions. The main vulnerability is due to the construction method of the facades, which are juxtaposed to the transversal walls and to the barrel vaults and may be subject to hammering effects. Out-of-plane vulnerability is connected only to non-structural elements, such as chimneys or stone cornices. Regarding the interaction between soil and foundation, considering only gravity loads, the inner walls, which are loaded by the vaults, present an average stress about 0,25 N/mm^2, instead in the longitudinal facades, which are loaded only by their self-weight, the calculated stress at the ground level is about 0,18 N/mm^2. This difference in soil stresses, due to the constructive discontinuity between facades and inner walls that do not allow any stress distribution, may have caused differential settlements, which may partially explain the actual crack pattern.

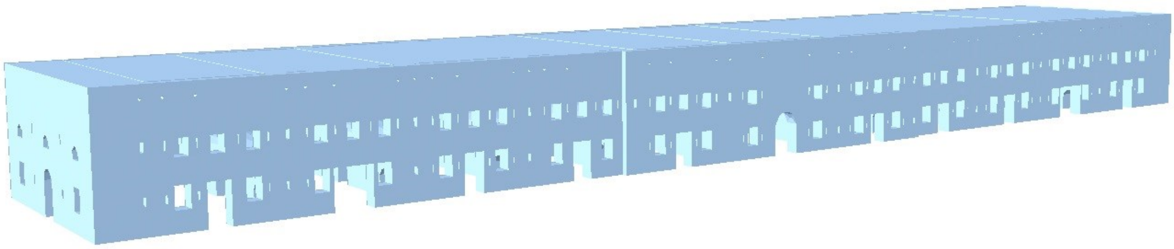

Figure 8: 3D FE model of the barrack buildings

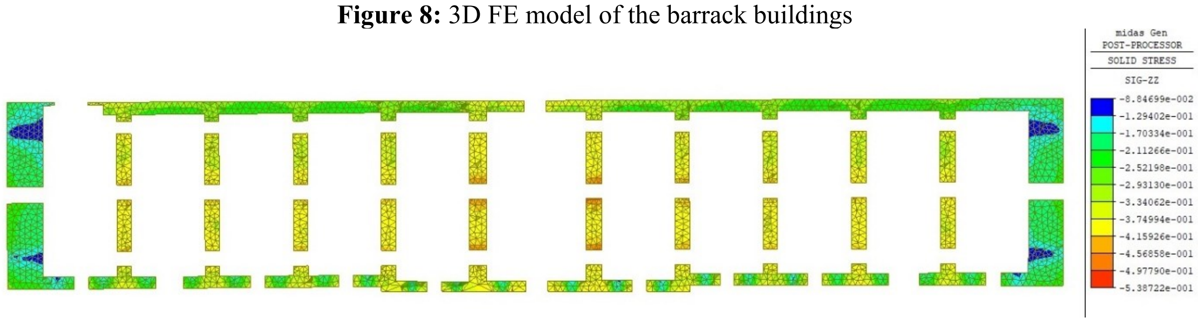

Figure 9: compression stress on masonry walls at the ground level

The depot building (nr. 29) has very different structural characteristics: low thickness walls, one principal resistance direction, collapsed roof. The seismic analysis highlighted a good longitudinal behavior, thanks to very long and regular walls, but a high vulnerability in transversal direction. The limit analysis approach, implemented to define the stability of the masonry panels under the seismic actions, indicated a general unsafe situation, mainly for the very low thickness of the walls that are not retained by the roof structures.

4 THE REHABILITATION AND STRENGTHENING INTERVENTIONS

In agreement with the concerned entities (Municipality of Venice, Ministry of Cultural Heritage central and local offices) and in consideration of the financial resources, the objectives and priorities of the interventions to be performed have been defined:

- Full and functional restoration of the east barrack (nr. 9), for expositions and services;
- Structural strengthening of the west barrack (nr. 8);
- Full and functional restoration of the Depot Building (nr. 29), for expositions use.

Considering the great cultural value of all the buildings, all interventions have been oriented to the maximum conservation of the original characteristics, especially for the two barracks.

The east barrack (nr. 9) intervention will consist in the structural strengthening of the vertical and horizontal elements with seismic upgrading and the realization of new systems (HVAC, electrical, hydraulic). Masonry restoration techniques will be also carried out to achieve a consolidation of the materials in compliance with the historical conservation criteria. The original configuration of the roof will be sought, restoring the roof terrace with perimetral ramparts. The terrace will be accessible by external staircase and lift, in a new steel-made volume separated from the original building. From the structural point-of-view, minimum intervention criteria have been followed; masonry walls and vaults will be restored by traditional interventions, such as structural repointing and cracks sewing by grouting, using natural hydraulic lime mortar. Considered the satisfactory seismic behaviour of the building, the seismic retrofitting will be obtained solving the main vulnerability emerged from the structural analysis, that is the disconnection between façades and inner walls. New stainless steel tie-rods will be inserted in order to connect horizontally the façades, avoiding overturning and hammering effects in case of earthquake; these tie-rods will anyway allow for any vertical displacement between facades and transversal walls, in order to maintain the current static behaviour.

For the west barrack (nr. 8), considered the wide crack pattern and the marked trend of differential settlements, it is planned a strengthening intervention at the foundations level, in order to restore the safety conditions without considering the successive architectural restoration as for building nr. 9. Intervention will consist either on the improvement of the soil mechanic characteristics (e.g. jet grouting) or the insertion of a series of micropiles through the existing masonry foundations in order to connect them to the deeper and stiffer soil layer (over consolidated silty clay) named “caranto”. At the present time, the design outcome is still open: structural and geotechnical modeling will drive the intervention type.

For the depot building (nr. 29), the complete collapse of the roof allowed to propose a new steel roof structure which contribute to the seismic retrofitting of the building at the same time leaving the internal space completely free and unitary so as to promote flexibility of use for temporary exhibitions. The steel structure is made by welded IPE profiles creating a global reticular beam, acting in its plane as bracing system for the roof and for the masonry walls. Ten new steel columns act as static support for the roof structures and as seismic-resistant elements: the triangular shape columns are connected to the roof profiles by inclined branches, forming seismic portals, fixed at their basis, which can absorb both horizontal and seismic actions.

Figure 10: rendered view of the new steel roof structure

As for the original wooden roof, the structural function of the existing masonry pillars is maintained, using them as vertical support for the steel roof; the connection system is studied in order to transfer only vertical actions, avoiding horizontal thrust on masonry, using the original holes of the wooden trusses to center the roof load.

Roof steel elements collaborate with existing masonry walls for the seismic resistance, both in the transverse direction, through the façade walls which are enlarged and connected to the roofing structures, and in the longitudinal direction where the panels between pillars will be reinforced and will become bracing elements. These panels are therefore reinforced by:

- Connections to masonry pillars by the insertion of stainless steel rebars, completely hidden inside the mortar joints;
- Reconstruction of the upper part of the walls, currently collapsed, with reinforced masonry (steel rebars inserted inside the mortar joints);
- Application of steel reinforced strips (FRCM) on the internal side of the panels, using lime mortar, in order to confer tensile resistance to the masonry.

4.1 Future actions

The final design is currently completed for the Building nr. 29 and the approval by Superintendence and Firefighters is pending. For barracks nr. 8 and 9, considering the historical value of the buildings and the interactions between structural requirements and cultural protection needs, a more demanding design phase in terms of restoration is still on-going.

5 CONCLUSIONS

- A very iconic former military area is progressively being reconverted with success to cultural and leisure use at the doors of Venice and its lagoon;
- In this process, in the framework of the Strategic Masterplan Cultural Heritage 2014-2018 of the Italian Ministry of Culture, relevant funding was given for the structural and architectural restoration of two massive historical CH buildings corresponding to Austrian barracks, and a partially collapsed more recent Italian depot building;
- A relevant study was carried out to define the structural safety level of the three buildings, based on thorough structural and geotechnical investigation, in order to design the requested strengthening interventions;
- Structural tests carried out described buildings lacking maintenance with the related problems, however properly built, whit compositional and mechanical good characteristics;
- Geotechnical tests were able to characterize the soil main parameters, stratigraphy and mechanical capacity, also explaining the visible differential settlements of the west barrack, most likely due to unsatisfactory soil compaction in the works of channel filling;
- Interventions were and still are being defined following two different approaches: substantially conservative (with seismic and structural upgrading) for the two seaside barracks, more relevant from a cultural heritage point of view, and introducing a new architectural sign (roof substituting the original one, completely lost) for the more recent Italian depot building.

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