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THE "GRADELLE" BRIDGE ON ST. MASSIMO CHANNEL IN PADOVA

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Abstract. *This paper describes the "Gradelle" bridge, which belongs to the Venetian circle of walls of Padua, Italy, crossing the St. Massimo water channel. The transformations suffered by the bridge during its history are presented, and the actual state of conservation and the forms of damage due to the age and to the pollution are analyzed. On the basis of the observed crack pattern, a hypothesis is formulated on the causes of the mechanism detected, which has been verified by means of a numerical simulation.*

1 INTRODUCTION

This three-span masonry arch bridge belongs to the XVI century urban walls of the city of Padova, which for many centuries was part of the Venetian Republic (also known as "Serenissima"), belonging to the mainland of Venice. The town of Padova was considered the ultimate inland protection of the sea-city, so it had to be strong. After the victory over Maximilian of Augsburg, in 1509, the Venetians started the construction of the new city walls around Padova to defend the town against the artillery shots. The "Gradelle" bridge, built around 1521, served as a fortified connection of the wall circle over the St. Massimo channel.

It is made by three barrel vaults of equal span,the central one of higher rise; two small buildings lean against the South parapet. It appears sober, rigorous and solid, but elegant in its simplicity. The construction is made of solid brick masonry and *trachite euganea* stone, without any covering. It is situated near an arterial road, but it is surrounded by the nature: the St. Massimo channel still flows under two of its vaults and two green areas surround it both at East and at West. The zone, one of the most evocative and characteristic of the town, is waiting for years for the realization of the "Parco delle acque e delle mura", the project of the city council which aims to connect all the green areas that has survived near the renaissance city walls and the water ways that cross or surround the town.

Figure 1: South view of the bridge

Figure 2: North view of the bridge

2 HISTORICAL OVERVIEW

2.1 Building phases

The current aspect of the bridge is mainly the result of to two different phases: the original construction of XVI century and a re-adaptation intervention that goes back to the end of XVIII century.

The "Serenissima" Republic built the new bastioned walls after the attack launched from the Augsburgical troops to the town of Padua. Comparing two ancient maps reported by Portenari[1], we can see that, before the Venetian intervention, the bridge's zone was in correspondence of the "Portello Vecchio" (one of the old harbours of the town), in a non-built area (fig. 3). The St. Massimo channel flews outside the Municipal Age walls and after the Venetian work it was included in the town limits by the new walls (fig. 4). The *Gradelle* bridge was built in order to cross the channel, and two bastions beside it defended the break made in the continuity of the wall.

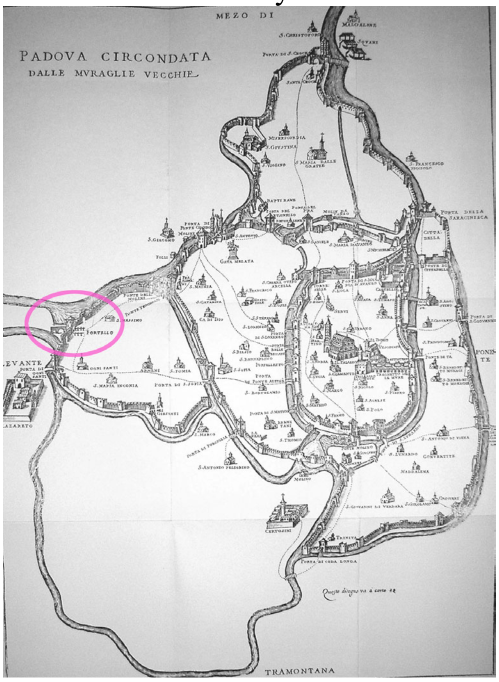

Figure 3: View of Padova (from Portenari[1]) with the Municipal Age walls.

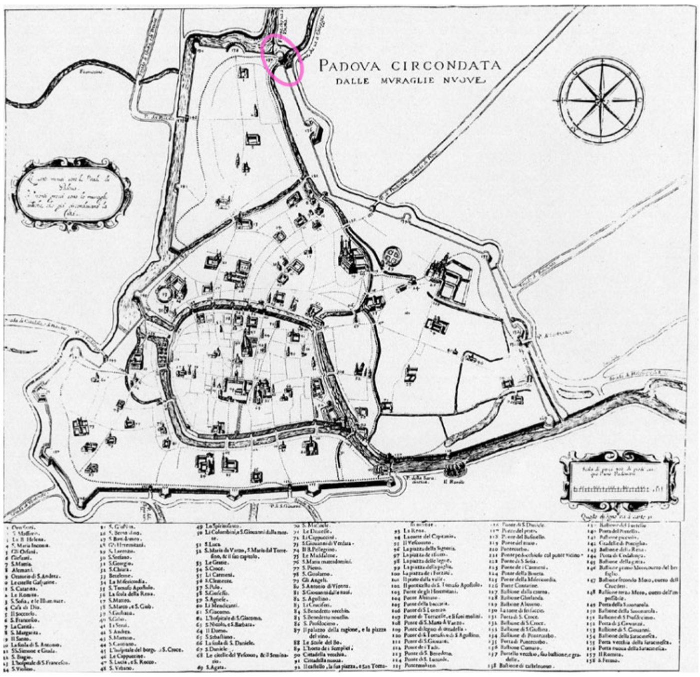

Figure 4: View of Padova (from Portenari[1]) representing the city walls after the Venetian works

The openings were protected by means of sliding iron gates (in ancient Italian "gradelle") also used in peacetime as tollgates for the nearby salt harbour[2]. These devices could be lifted or lowered as needed, causing the passage on the water to be opened or closed, allowing in the same time the water flow also when completely closed.

When it was built, the bridge appeared with the three barrel-vaults having the same height; there are no documents about the date of construction. It may be built immediately before or after the nearer bastion, the bastion Buovo, which is adjacent to it, and is needed for the military protection of the bridge. Certain data exist about the erection of the bastion Buovo (1513): the designer was Bartolomeo d'Alviano, which, during his absence, was substituted in the fulfilment of the work by the sculptor and architect Sebastiano da Lugano and by the master-builder Agnolo Buovo. This last gave his name to the bastion, therefore he was likely the master-builder both of the fortified tower and also of the adjacent bridge.

An inscription posed over the small central building, that goes back to 1781, testifies that the navigation was re-activated in 1771, after having been suspended for long time (since 1726). The inscription tells also about the restoration of the bridge that was carried out by the public administration so that "the access to the town by boat was possible".

On September 17th, 1771, Giacomo Nani, in front of the Council o Venice, started the process of revaluation of the town of Padova, of its bridges and hydraulic network, and gave back to the town the ownership of the *Gradelle* bridge[3]. The next step, after this conquest, was the restoration of the bridge, testified by the above-mentioned claque and by the words reported by Gennari “In the end of this month (march 1781) we could see the new big arch of *Gradelle* of St. Massimo, which construction was decided by the Town instead of the old one too low by now, in order to let the navigation of any kind of boat along that channel...”[4]. The master Giacon drew the project of restoration, and his drawing is the only written evidence about the interventions underwent by the bridge. The rest of its story, in the lack of documents, has to be derived by the direct observation of the physical evidence itself.

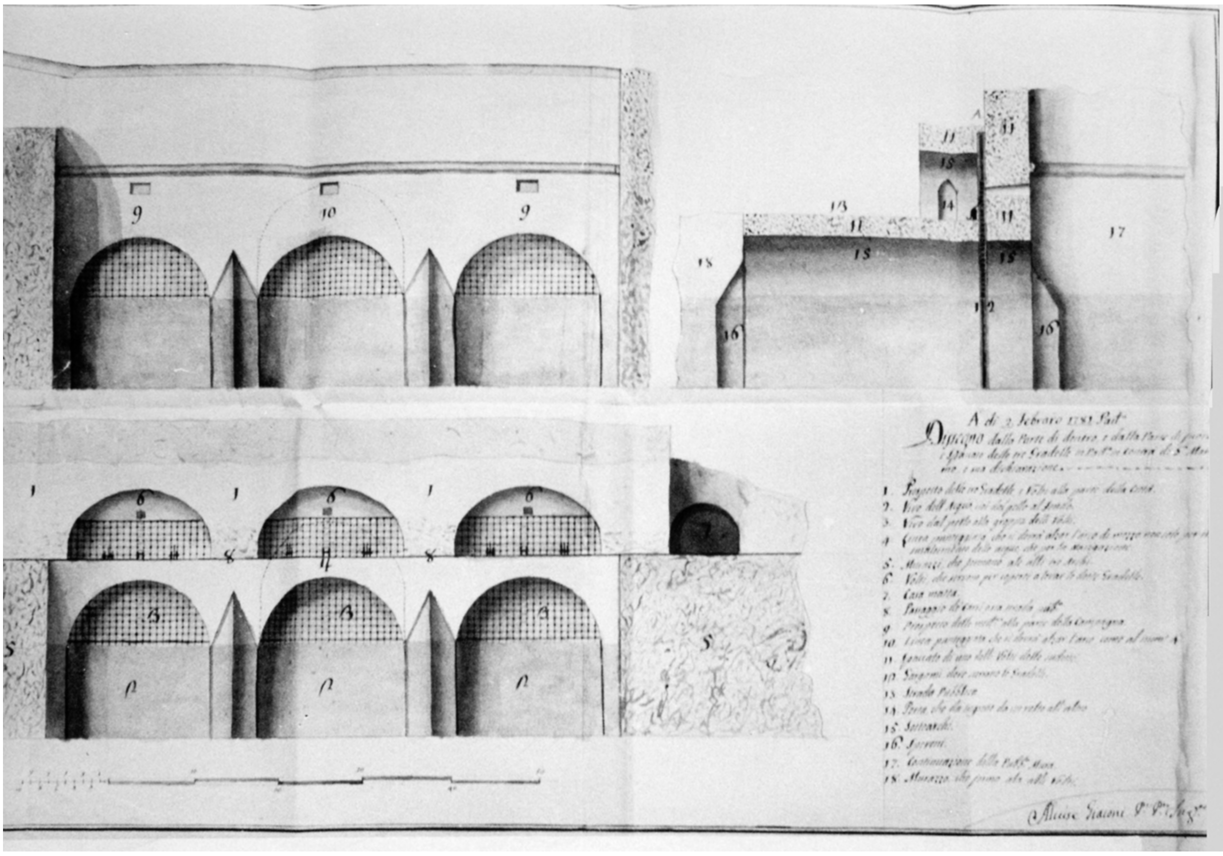

Figure 5. The appearance of the bridge in 1771: the raising of the central arch is indicated in dotted line.

The drawing does not mention the two small buildings over the bridge. Therefore, they were probably erected during the progress of the works. The central one replaced a previous building (visible in some ancient maps) that gave shelter to the mechanism for lifting the gates besides it acted as a house for the custom officers. From the historical land registers, we can see that the other small building was always close to the first one. It acted as powder magazine and was occasionally used as provisional prison for smugglers and contraveners.

2.2 Underground passages

Inside the bridge and in the West area, there are small portions of an underground passage that can still be covered, but have a very difficult access. The first portion is extended toward West under a building near the bridge and is 18m long; the second one, over the East vault of the bridge, is 8m long. Originally the two stretches were connected together and, in the portion over the bridge, the path was opened towards the internal side of the walls (see Fig 6). After the raising of the central vault, and consequently of the trampling floor, and the erection of the toll house, the soil filling had to be carried over the new vault, and the two surviving arches of the ancient way had to be closed with earth-containing walls towards North-West. The rooms have barrel masonry vaults, and very irregular earth floors.

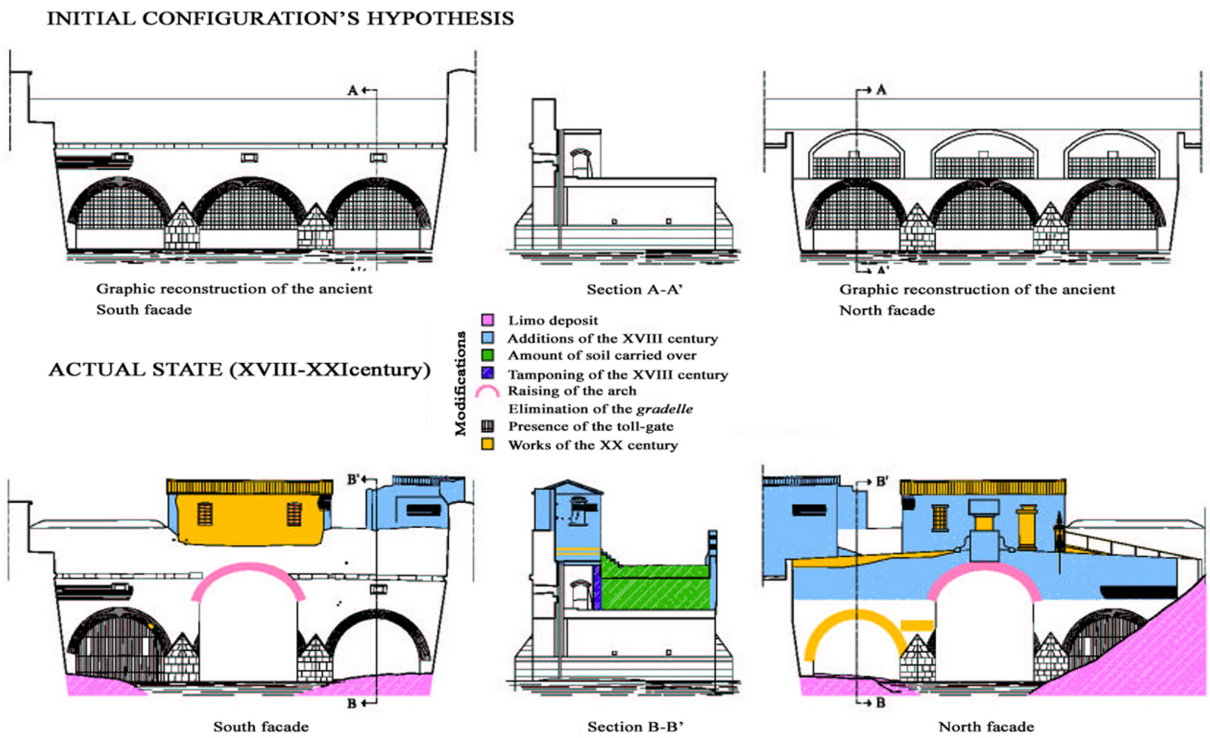

Figure 6: Modifications between XVIII and XXI century

2.3 Recent facts

At the beginning of the last century, the slaughterhouse of Padova was built in the area East of the bridge. A big water tank was built which was placed high on the bastion Buovo (West of the bridge), to obtain strong pressure of water, for the slaughterhouse needs. The bridge becomes a secondary exit of the slaughterhouse that connected it to the water tank, carrying over it the pipeline path; moreover, the West side was closed by a big iron gate, still existing. In the area of the bastion a kennel was installed.

During the functioning of these two activities, the area upon the bridge underwent various fates and changes, all tied to the works in the neighbourhood. When the two activities were dismissed, all the area was abandoned and saw dark years.

By the ‘80s, the ex-tollhouse was occasionally used as classroom by a cultural association, for showing to children the bread making, but by now the bridge lives only in the sporadic spring visits organized by cultural associations to re-discover the past. It is now in a state of semi-disrepair. Some openings are walled up, big cracks appeared; lime deposits obstructed the lateral vaults and the walls are colonized by the ivy and other vegetation hanging on the water of the central arch.

Figure 7: The central barrel with a detail of the abutment of the ancient vault

3 MATERIAL DESCRIPTION AND DETERIORATION

Among the structures of the bridge, the piers are in *trachite euganea* (a local strong effusive rock, coming from Euganei hills, still used a lot in Padova and Venice), the rest is in brickwork masonry. The filling of the vaults is made of *trachite euganea*, too, broken in small irregular pieces; it is visible in the intrados were the central vault was raised, here you can also see the beginning of the ring of the ancient arch. The same stone has been used also for the framing of the external side of the walls. The presence of original plasters is limited to two circumscribed areas. An important role were played by the iron, which is used for the surviving *gradella* and in the remains of the accessories of navigations, the gates over the bridge and the parts of a possible lifting mechanism (on the North parapet of the bridge) probably used to weigh out the goods passing the custom.

The various kind of deterioration and decay have been analyzed and summarized in the maps of the deterioration, using the terms suggested by *Normal 1/88*, which represent a standard reference in Italy for the conservation project.

3.1 *Trachite euganea*

The blocks made of *trachite* stone are still working well in the piers, after almost five centuries, and they do not show any effects of the elapsed time. They only show lime incrustation, organic patina near the water level and incrustation due to the presence of vegetation; these deteriorations produce damage only to the surface of the stone, because of its hardness and limited porosity.

On the contrary, the frame of the South facade has more problems. It is cracked in its East side, as well as the rest of the brickwork of the same part of the bridge. This kind of damage, as explained later, is mainly due to a phenomenon of differential settlement extended to all the East zone.

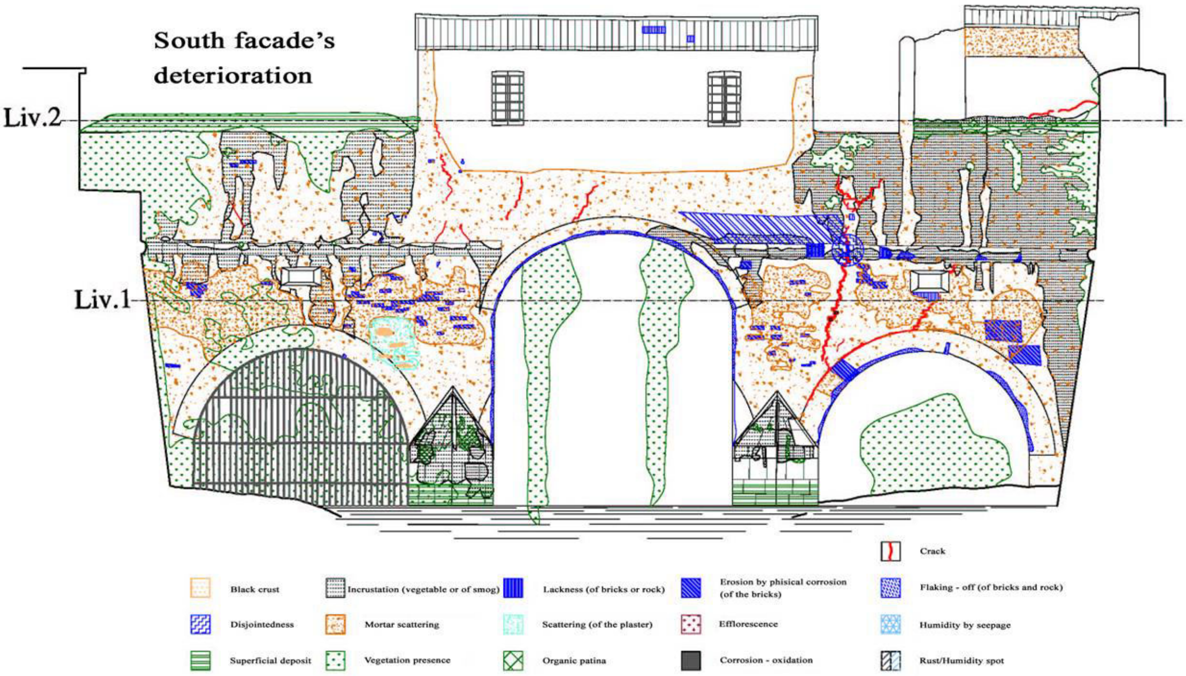

Figure 8: Map of the decay in southern façade.

3.2 Brickwork

Bricks generally belong to the two building phases (XVI and XVIII century); some limited portions are of the XX century. The most ancient ones have all similar characteristics: dimensions, colour, and also similar deterioration. The XVIII cent. bricks contain probably more piece of broken crockery, in fact they are more orange.

Modern bricks, more uniform, were used in the South wall of the central building over the bridge, for walling up windows and doors openings, and in the North ring of the East vault. These bricks, differently from the others, are often flaked.

The greatest problems for the bricks under the vaults and in the underground passages are due to the saline efflorescence (because of the very wet condition) and to the water infiltrations coming from the layer of soil posed in the XVIII century behind or over the walls. The salt crystallization, associated with the dimensional dilatation inside the bricks pores, causes erosion and superficial flaking of the bricks.

Very diffused are also different forms of incrustation: on the bridge there is a spread presence of black concretion due to the amassing of atmospheric polluting particles over the washed surfaces of the walls or over the areas covered by the vegetation, which implies a water veil. When a certain thickness and certain hardness are reached, the incrustation creates internal stresses, rises and comes off. This causes the deterioration called erosion due to corrosion (or rather to physical and not chemical reasons) and the scattering of the mortar.

In addition, the ivy forms organic incrustation with the remaining of its clinging roots.

3.3 Plasters

It seems they had been laid over well circumscribed and limited areas, to use them as bases for inscriptions. On the external side of the wall, there could have been a reprimand for the smugglers and over the parapet between the small buildings a sort of price list. However, these are only hypothesis, only more accurate investigations could detect if there was some painting over the plasters or not.

3.4 Iron

The iron is the material used for the *gradelle*. The metallic elements of the sixteenth century were probably substituted during the XVIII century. Now only their rests are visible.

Also the rings under the vaults used for the boats mooring were iron made, as well as one of the two doors of the lateral building and many other pivots or rings, which function is unknown. The gate of the beginning of the XX century which closed the secondary exit of the slaughter-house was made of iron too. Due to lack of maintenance, every iron made object is corroded, tarnished, broken or has some missing part.

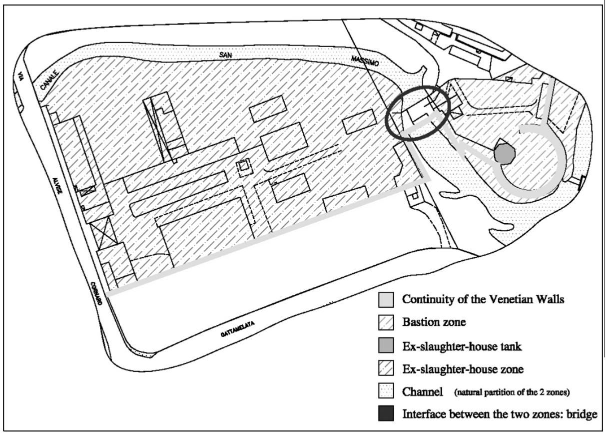

Figure 9: Map of the area involved in the cracking mechanism

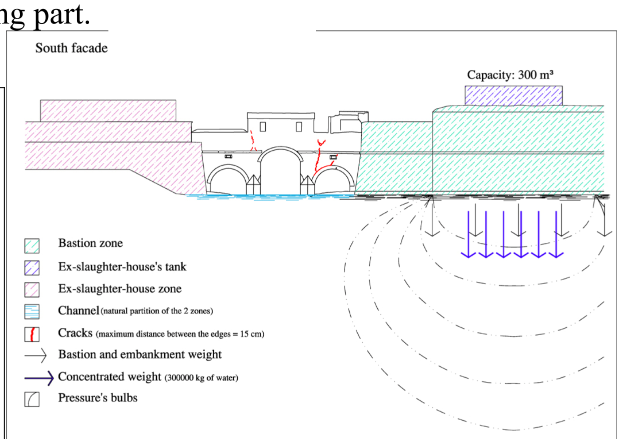

Figure 10: Cracking mechanism as effect of soil settlement

4 STRUCTURAL DETERIORATIONS

The entire building has enormous cracks, mainly developed in its East part and due to the differential subsidence. This phenomenon was caused by the presence of the bastion next to bridge, necessary for the protection of the discontinuity of the walls. With its embankment, the bastion immediately became an enormous weight in that zone and was after increased by the construction of the water tank on its top for the slaughter-house. The two combined weights probably determined an increase of the soil settlement, which imposed a rotation to the East pier, causing cracking of the south front and on the intrados of the vault nearest the bastion.

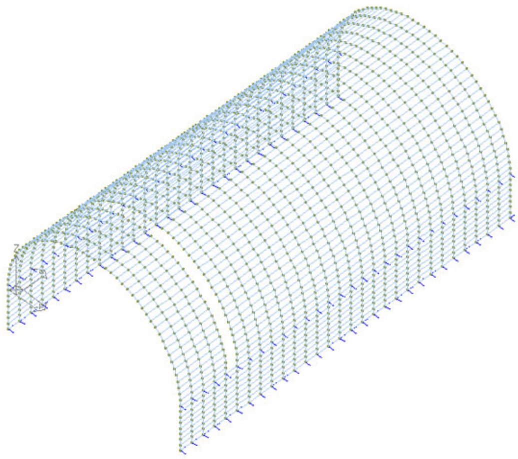

Figure 11: Model of the barrel vault

A study has been performed with a FEM numerical modelling technique, in order to verify the hypothesis on the collapse mechanism of the East vault. Only the eastern vault with the *gradella*'s slit has been modelled, using four nodes shell elements. The restraint associated to the pier bases were to vertical and horizontal displacements, instead the ones associated to the imposts' level were only to horizontal movement (these bonds simulated the lateral thrust of earth on the East side, and the thrust of the adjacent vault on the other side).

The study has been led about three loading combinations:

- vault's own weight plus the filling;
- vault's own weight plus subsidence (simulated as imposed displacements, increasing from North to South, applied to the East pier base);
- vault's own weight plus filling plus subsidence.

The first combination does not involve considerable value of principal stress in tension, and the possible addition of the upper layer of earth should only increase the stability.

The second combination shows the trend of the principal stresses in tension, which reflects the path of the real crack. It also shows that stresses are bigger in the south part of the vault (the part of the *gradella*'s slit), where in fact the crack opening is greater.

The third combination confirms the trend of the second one, with increasing values.

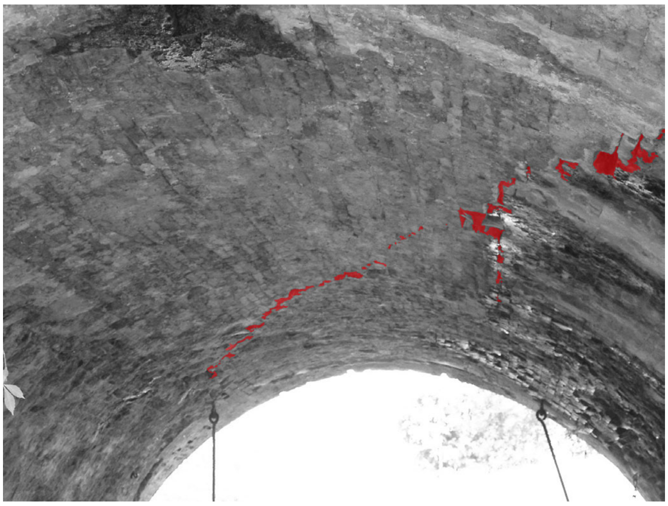

Figure 12: View of the crack on the intrados of eastern barrel

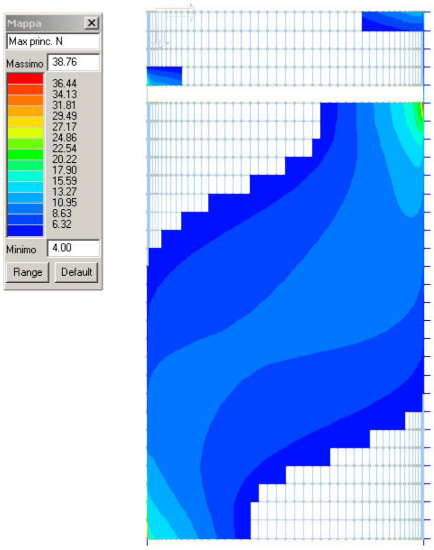

Figure 13: Contour map of principal tensile stress

CONCLUSIONS

A small bridge, belonging to the renaissance city walls of Padova, has been descript and analyzed, showing the probable reasons of its cracking pattern. The particular interest of this bridge relays in the fact that it documents a close connection of the town with the water paths that still cross and surround its territory, so that also the city walls had to take into account the needs of the navigation. The conservation of this building in the future could be foreseen also in connection with a general intervention of protection and revitalization of the network of water channels and green areas around the city walls.

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