1 Sampling and characterization of the Torricella Peligna War Memorials

1.1 Information on the monument

The climate in Abruzzo, Italy, is strongly influenced by the Central Apennine Mountain range. The sub-mountainous area has a continental climate, with frequent frosts in winter and high temperatures, even above 30 °C, during summer. Rainfall is strongly affected by the presence of the Apennine mountain ridges, resulting in an annual precipitation average of 1500 mm. Frequent snowfall is caused by cold air arriving from the Balkans. The monuments selected for this study are located in the town of Torricella Peligna, in high foothills region. This site has no significant concentration of anthropogenic nor atmospheric pollutants.

In Torricella Peligna, two war memorials were chosen as case studies: The Tower and The Angel.

THE TOWER

The Tower was designed in 1950 by Walter Sibona to commemorate 120 civilian victims of the Second World War and was completed in 1961. It is about 20 meters high and the base is in chiselled stone surrounded by an iron railing decorated with depictions of the coat of arms of the village of Torricella Peligna. Located at the highest point of the town, the tower does not have surrounding buildings and is fully exposed to weather conditions.

The monument is a truncated pyramid with a squared base. The load-bearing structure is made of a reinforced concrete frame with four decks formed by beams and pillars and 4 round reinforcement rods of 14 cm in diameter at the corners of the pillars and round brackets of 8 cm in diameter with a pitch of 15 cm. The infill walls are also made of in-situ concrete blocks, with dimensions of 15x15x30 cm, laid on horizontal courses with alternating joints in the adjacent rows (Fig. 4.1). The interior is bordered by a series of walkway floors connected by stairs.

a)  b) 

Figure 4.1. The Tower War Memorial monument: a) a panoramic view and b) the internal zone.

THE ANGEL

The "Angel" War Memorial is dedicated to those lost during the First World War. This War Memorial is located at the centre of the Remembrance Park, on the top of a hill close to the Historic Town. The centrally-located monument is at the highest point and acts as the main element of the park, with its monumental dimensions (Fig. 4.2).

The Angel stands on steps made of stone, it has a quadrangular base with four littori bundles at the corners and an obelisk surmounts it, listing the names of the fallen from Torricella during the Wars. The Angel sculpture in concrete is placed against the obelisk at the front-side looking towards the town. The figure, with classical style female features, has hair that is worn tied back from the face and a wreath of laurel leaves. A strong sense of power is associated with the kindness of the winged figure, depicted while writing the names of the fallen into a golden book. At the same time, she use her left foot to pin down a large eagle, the symbol of the Hapsburg empire, which is struggling to free itself. The monument is the work of N. Lucci from Pennadomo, and was built in 1922. Only a few

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years later, the monument was firstly damaged by a hurricane and, in a second time, by bombardments during the Second World War.

Renovation and reconstruction work was carried out in the early 1950s by local administrative committees.

a) b)

Figure 4.2. The Angel War Memorial monument: a) panoramic view and b) the detail of the Angel.

1.2 Sampling activities

Samples from the monuments were taken according to mainly non-invasive criteria in those areas considered to be of interest due to the materials composition and the state of conservation.

THE TOWER

In the table 4.1 and in the figure 4.3 are reported the collected samples.

In the Tower, two samples were taken from the outer band that showed problems of cracking and disintegration. Internally, 4 samples of concrete were taken at different levels of the structure, considering the surfaces characteristics and differences in composition which emerged from visual observation. In addition, in order to plan the removal of previous conservation interventions, the finishing layer present on the surface was collected and analysed.

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Table 4.1. List of the collected samples.

External TOWER	- TPT1 - sample of concrete collected from the outer frontal zone band - TPT2 - sample of concrete collected from the outer band upper side in contact with the rebar
Internal TOWER	- TPT3 - sample of concrete collected from the left-sided pillar at the second stairs level - TPT4 - sample of concrete collected from the right-sided pillar at the second stairs level - TPT5 - sample of concrete collected from the wall between the pillars at the first floor - TPT6 - sample of concrete collected from the beam below the stairs at the ground floor

Sample TPT1 – The sample was taken from the external projecting band that showed deep cracks and detachment of material. This area is made of two different cements with different compositional characteristics due to previous maintenance work of the monument. This difference in composition, as well as the microclimate created by the outer metal coating of the bands, probably led to the penetration of moisture into the concrete material, promoting the corrosion process of rebar with the subsequent formation of cracks and detachments.

Sample TPT2 - The material sampled had considerable cracking with partial detachment, leaving the rebars exposed. The reinforcements were highly oxidized and presented swellings, formation of corrosion products and detachment of material splinters.

Samples TPT3/TPT4/TPT5/TPT6 – The concrete samples were taken inside the tower from the deck-frame, the beams and the pillars showing critical conservation conditions. Both areas characterised by rising humidity and areas considered not compromised were chosen in order to check for any differences in the conservation of the cement material.

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Figure 4.3. The photos show the samples collected and their position.

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THE ANGEL

In table 4.3 and in the figure 4.4 are reported some information and the position of the samples collected.

Table 4.2. List of the samples collected from the Angel.

ANGEL	- TPA1- sample from the side of the book with reinforcements - TPA2 - sample from the dress - TPA3 - sample from the second head of the eagle - TPA4 - sample from the element on the side of the base

Regarding the Angel War Memorial, samples (see figures 4.4 and 4.5) were taken from areas showing advanced degradation processes and according with the different material features observed during visual examination.

Sample TPA1 - The book presents the most advanced conservation problems, with deep cracks and detachment of the cement material. The rebars are exposed to the environment with intense corrosion products formations. The corrosion, with the consequent increase in volume of the rebars, may be considered to be the main cause of the detachments and deep lesions.

Sample TPA2 - The sample was taken from an area of minimum thickness characterized by widespread micro-cracks and small detachments of material, with deposits of detached surface particles and stagnation of water, without internal metal reinforcement.

Sample TPA3 – The sample was taken from an exposed area characterized by deep micro- and macro-cracks and suffering from leaching from the upper areas. The rebar is exposed and its corrosion has probably contributed to the formation of cracks. The concrete material is disjointed, being devoid of modelling and very badly eroded.

TPA4 sample - The material of the "bundles" is different from that used for the statue, being finer in composition and with better structural conservation characteristics. It is compact and free of cracks.

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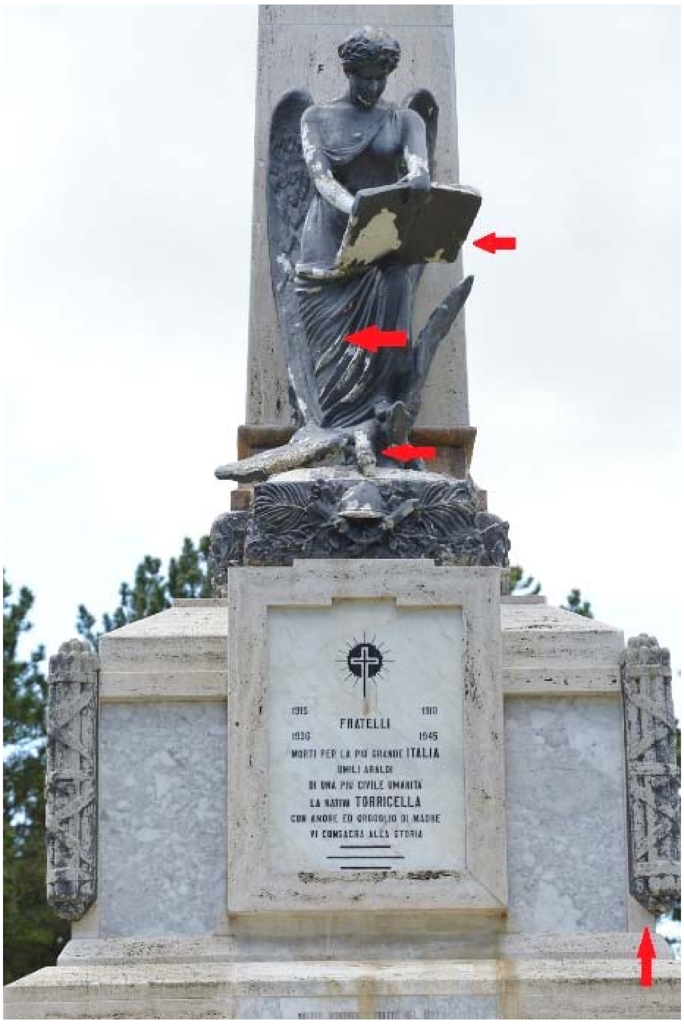

Figure 4.4. Angel monument: the arrows indicate the positions of the collection of the samples.

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Figure 4.5. The pictures show the details of sampling.

1.3 Results of the characterization

According to the scheduled activities, the War Memorials in Torricella Peligna were characterized to achieve information for example on their composition and state of conservation. In particular, the characterizations of the samples extracted from the monuments and in situ measurements were carried out by using complementary techniques. Details on the results of the characterizations are reported hereafter.

Petrographic study of thin sections

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The samples collected from the two monuments are characterized by some differences in terms of composition and morphology of the aggregate, and in some cases of binder too. The main characteristics observed under optical microscope with transmitted light are reported in the table below.

The results obtained for the Tower monument will be first discussed. By considering the binder, aggregate and pores of the tower's samples, it is possible to indicate a binder/aggregate ratio that is 1:3 (in vol.) approximately. The binder shows all the characteristics of a cementitious binder and the porosity (10-15% in abundance) is characterized by rounded pores, with the exception of one sample (TPT6 in which they are lengthened). It is a typical hydraulic binder with an amorphous texture and grey in color. As observed in figure 4.6, the samples are characterized by an uniformly distributed very high presence of micrite and very abundant presence of small opaque grains (around 25 micron in size) dark in color The micrite could derive from the use of carbonatic filler (that means a very fine powder added to the ground clinker) but it is also the results of carbonation of calcium hydroxide deriving from the partial hydration of C3S during the setting phase. The dark grains could be interpreted as residual clinker (Fig. 4.7).

The aggregate is made of carbonate and silicate grains. The last, less in abundance, is mainly constituted by mono- and poly- crystalline quartz grains, plagioclase, K-feldspars, and flint fragments. The carbonate component is more variable in terms of nature origin; it deals with granules of micrites, bioclasts such as biomicrites, biosparite, biopelmicrites and intramicrites (Fig. 4.8).

Though the dimensions of the aggregate's grains vary from the sample to other, a grain-size range between 0,25 to 1,5 millimeters can be defined. In one sample the carbonate grains are up to 6 mm. The roundness of the grains varies from sub-angular to angular, also inside the same sample.

The two samples TPT1 and TPT2 show a finishing layer that covers the concrete surface (Fig. 4.9). This layer was also analyzed and it results composed by two single layers; the external one is green in color (TPTG) and the more internal, directly in contact with the concrete surface, is a fine stuff (TPTW). The analyses were performed in order to determine their real nature and composition and so in order to plan the future interventions of removing. The TPTG, more external layer, is characterized by a total extinction (maybe made of an organic material); the layer covering the cementitious paste, TPTW, is 1-2 mm thick and it seems to be made of a mixture of lime and mono and poly- crystalline quartz grains.

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The Angel monument was also characterized. The samples extracted from this monument are quite different to each other under optical polarized microscope. It is difficult to indicate a single type of cement, because in two samples TPA2 and TPA4, there is the contemporary presence of two types of binder: a typical cementitious binder and a mixed binder (Fig.4.10). This last is composed by air lime and cement and it is recognizable by the presence of a lot of quantity of fine powder of micrite in the matrix. Usually the air lime fraction prevails on the cementitious one and the two components are well blended. The sample TPA1 shows a typical cementitious matrix with amorphous texture in which micrite and rests of fired clinker with alite and belite are present (Fig. 4.11). The sample TPA3 is a mortar based on mixed binder. The cement and air lime fractions are not well blended, as suggested by the alternation of calcite-rich and calcite-poor parts. Opaque particles dark in color are uniformly distributed in all the samples (Fig. 4.12).

In all the investigated samples the aggregate is also made of both carbonate and silicate grains. Usually the first prevails on the second one. The carbonate fraction consists of micrite and microspartite fragments, bioclasts, biosparites and biomicrites. The silicate fraction is represented by mono and poly- crystalline quartz grains, flints, plagioclases and K-feldspars, whose abundance varies from one sample to another. As regards the binder/aggregate ratio, it is 1:1.5 approx. with the exception of the sample TPA3 characterized by a supremacy of the binder on the aggregate (2:1).

The percentage and the type of the pores are also quite different in the four samples, especially when two mortars are present.

In detail, the absence of a discontinuity between the two mortars in the sample TPA2 seems to indicate that they were applied together, meaning that the mixed binder was set up over a yet raw cementitious one. This hypothesis is supported by the different dimensions of the aggregate in the two mortars that exclude the use of an only one mortar not well blended. A clear and sharp discontinuity is evident between the two mortars. In the sample TPA4, so that the application of mixed binder occurred after hardening of cementitious one.

By comparing the two groups of samples from the Tower and Angel, the main clear difference is due to the dimensions of residues of fired clinker. In the samples from Angel the sizes vary from 50 microns to 150 microns, while in the samples of Tower the grains are under 50 microns in size. This difference could be connected with a different production process of the clicker. The cement used to make the Angel seems to be the result of a soft grinding process, in some way typical of a handicraft approach. The small dimensions of the particles of clinker in Tower samples could be instead the result of a grinding industrial process that gives more homogeneity in terms of grainsize.

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In general, the cements used in the two monuments seem to be scarce in quality and probably the aggregate came from the alluvium of the confluence of the Sangro and Aventino Rivers. It deals with crushed fluvial gravels and sands, these last preserve the original dimensions and morphology.

However, it is more difficult to explain the coupling of cement and mortar. In our opinion it can be the results of technical trick in order to obtain a higher flexibility of the products during the molding. It rests to understand if this trick was used for all the monument or for the superficial layers only.

Table 4.3. Torricella Peligna's samples: main optical characteristics by observations on thin sections.

Monument	Sample	Binder/Aggregate ratio	Matrix	Clinker grainsize (μm)	Aggregate	Note
Tower	TPT1	1:2.5	cementitious binder	25 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
	TPT2	1:3	cementitious binder	30 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
	TPT3	1:3	cementitious binder	20 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
	TPT4	1:2.5	cementitious binder	30 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
	TPT6	1:3	cementitious binder	30 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
Angel	TPA1	1:1.5-2	cementitious binder	75 approx.	Carbonate and silicate grains	carbonates >> silicates. Organogenic carbonates
	TPA2	1:2 1:1.5	cements air lime + cement	35 approx.	silicate and carbonate grains	silicates ≈ carbonates. Organogenic carbonates
	TPA3	2:1	air lime + cement	120 approx.	silicate and carbonate grains	silicates ≈ carbonates.
	TPA4	1:2 1:1.5	cements air lime + cement	50 approx.	Carbonate and silicate grains	carbonates > silicates. Organogenic carbonates

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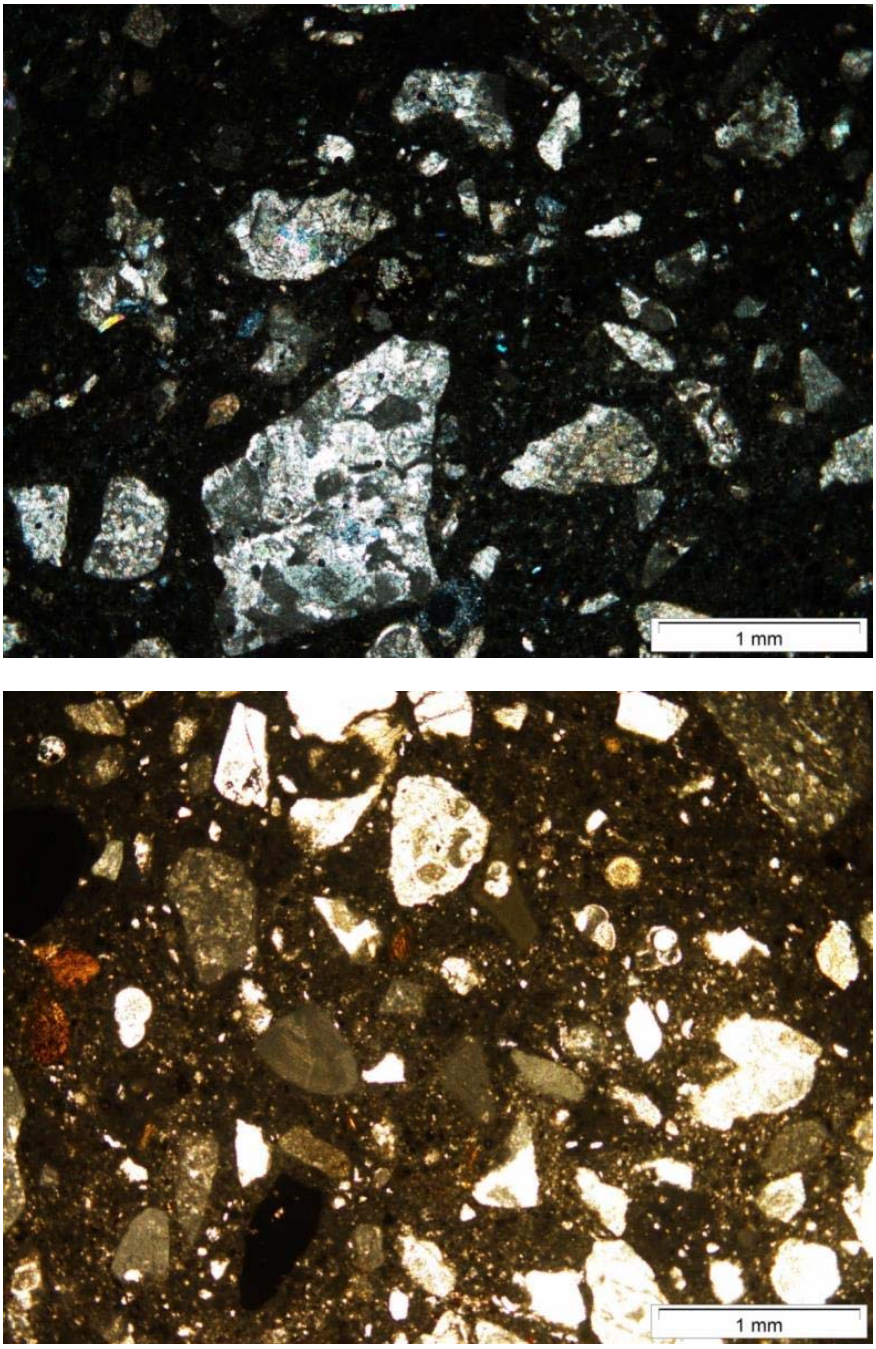

Figure 4.6. Micrographs showing the distribution of the aggregates in the sample TPT1 (crossed and parallel nicols).

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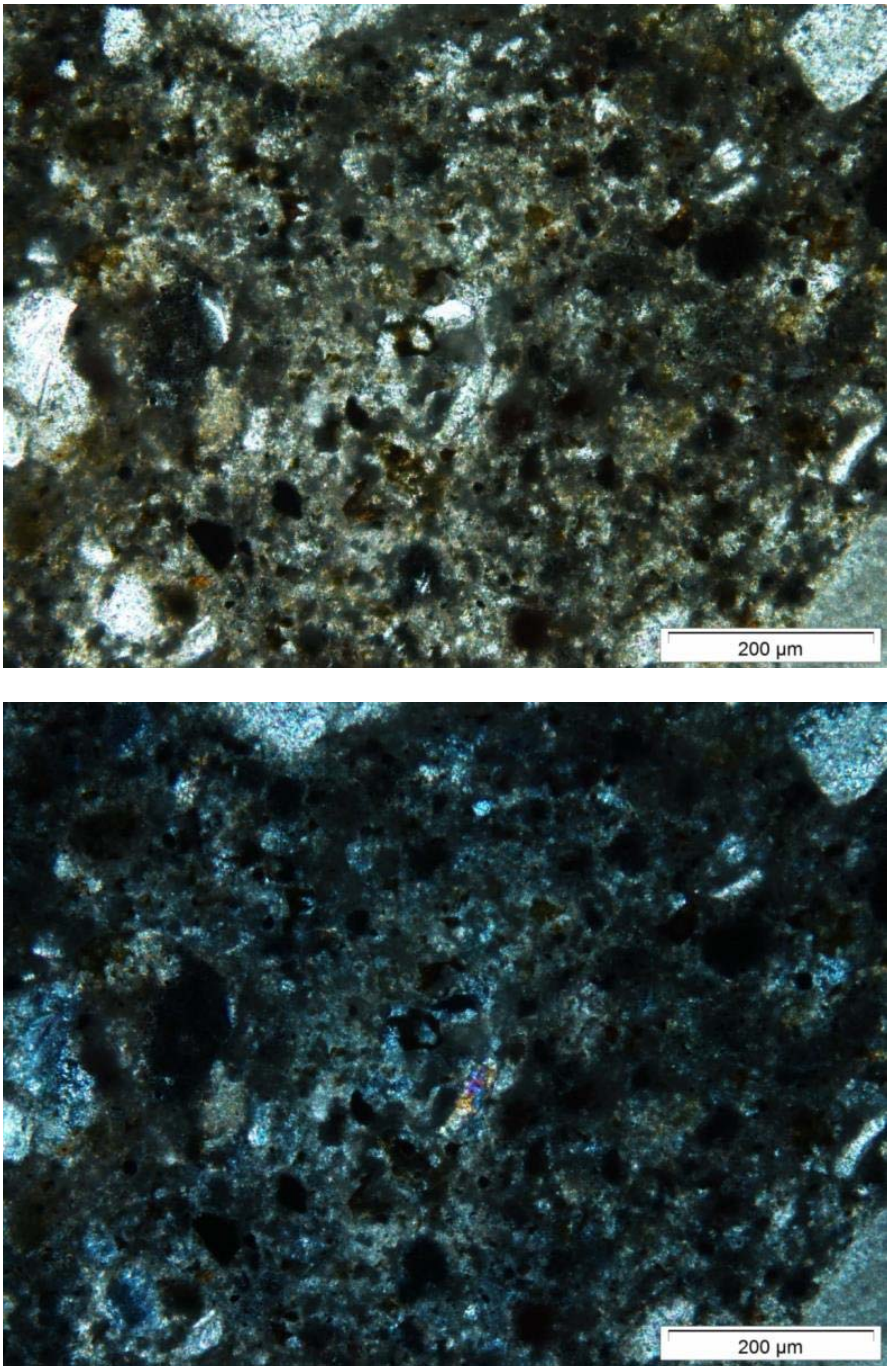

Figure 4.7. Micrographs showing residues of clinker. Belite and alite phases are visible (parallel and crossed nicols).

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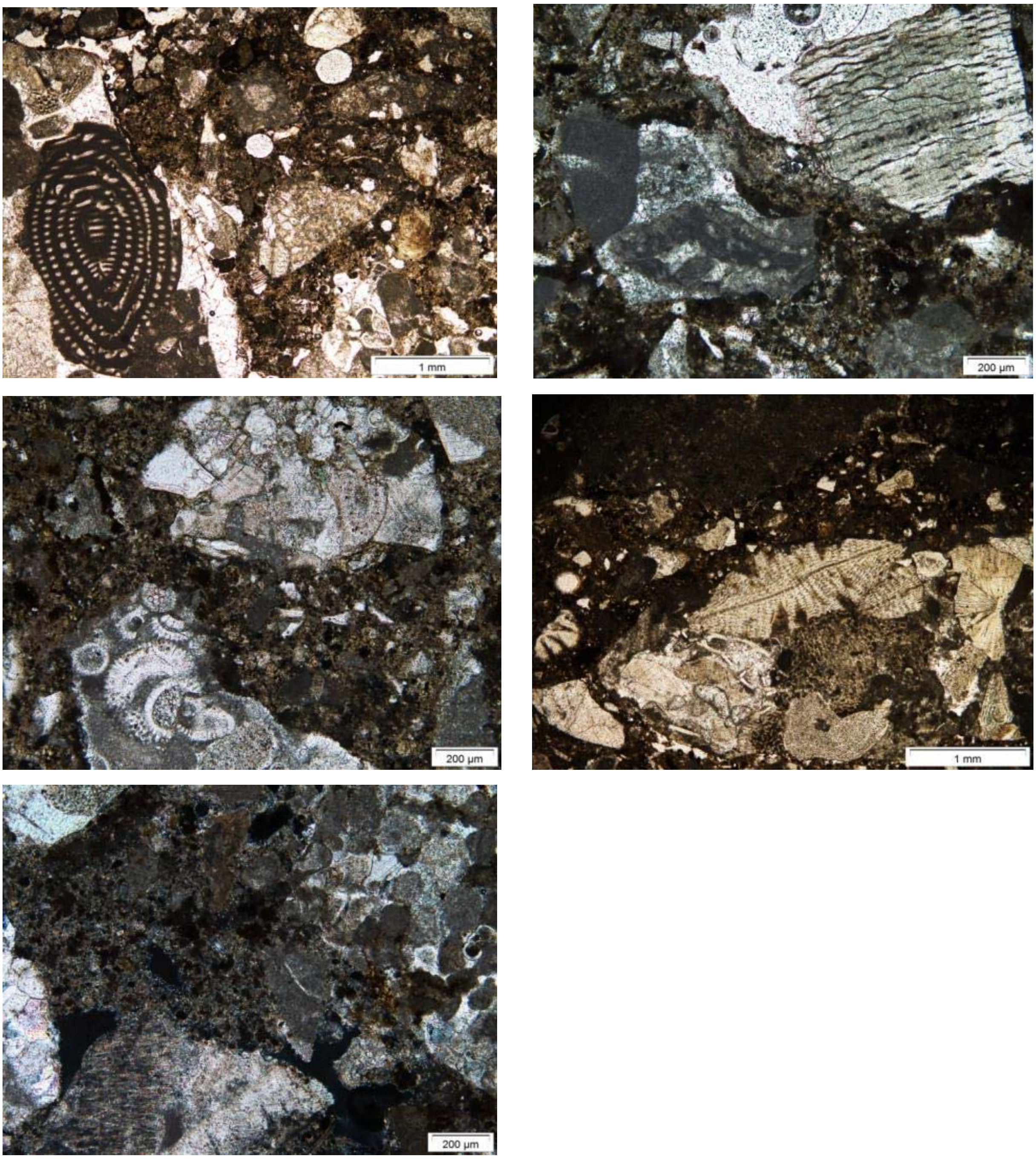

Figure 4.8. Slideshow of different types of organogenic carbonate aggregates present in TPT samples.

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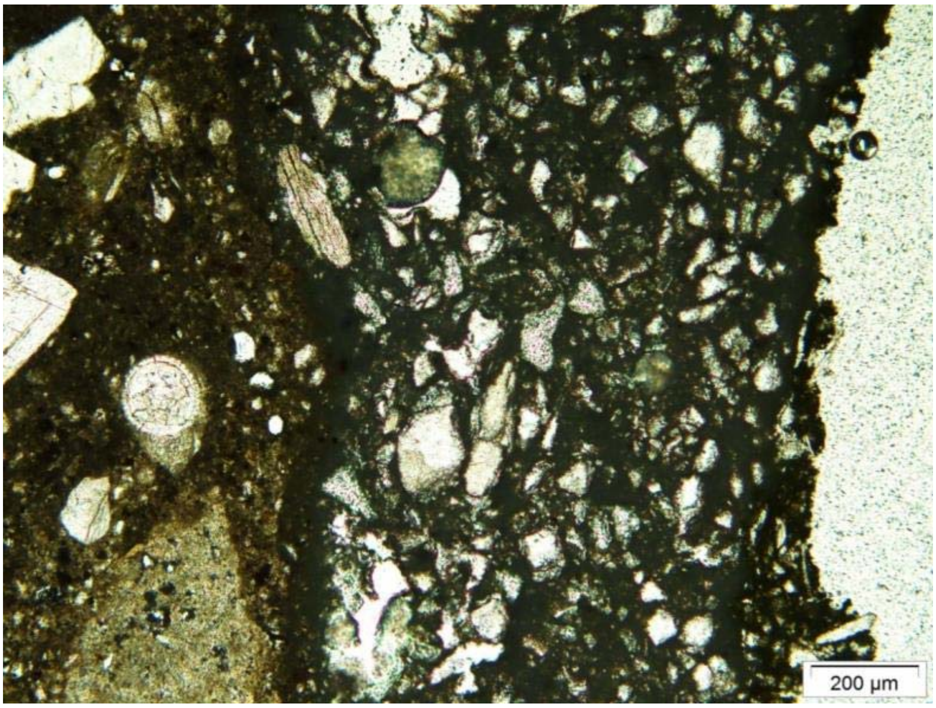

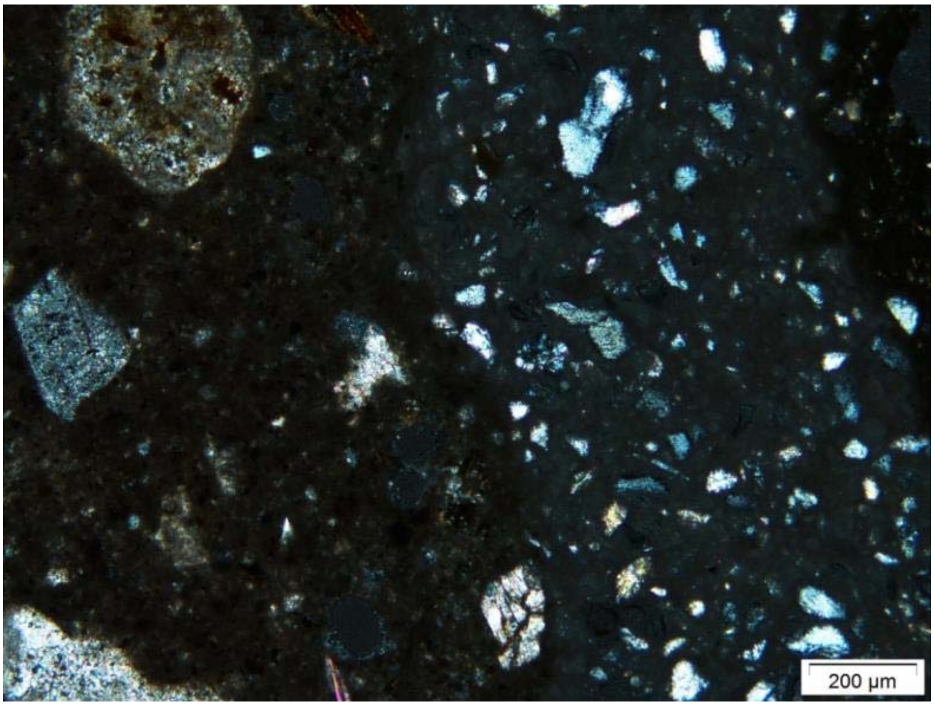

Figure 4.9. Micrographs showing the surface finishing layer on the TPT1 sample.

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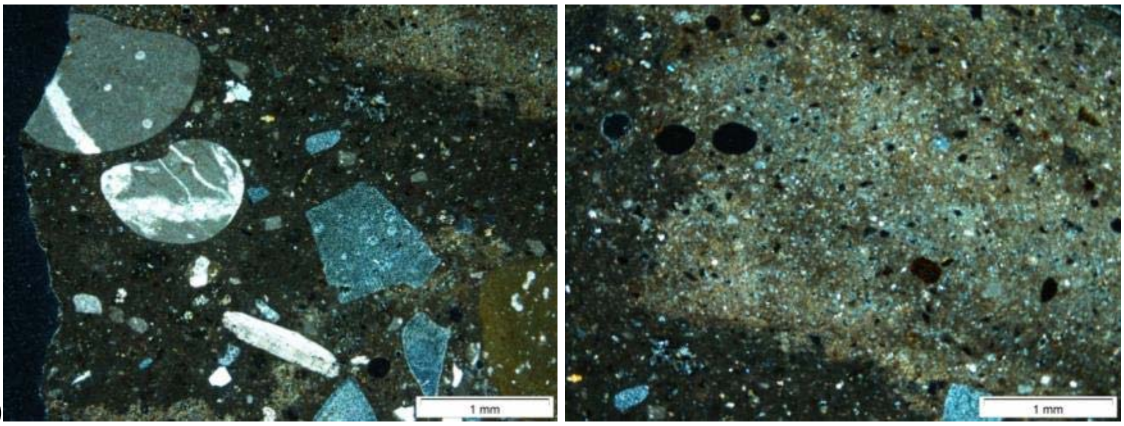

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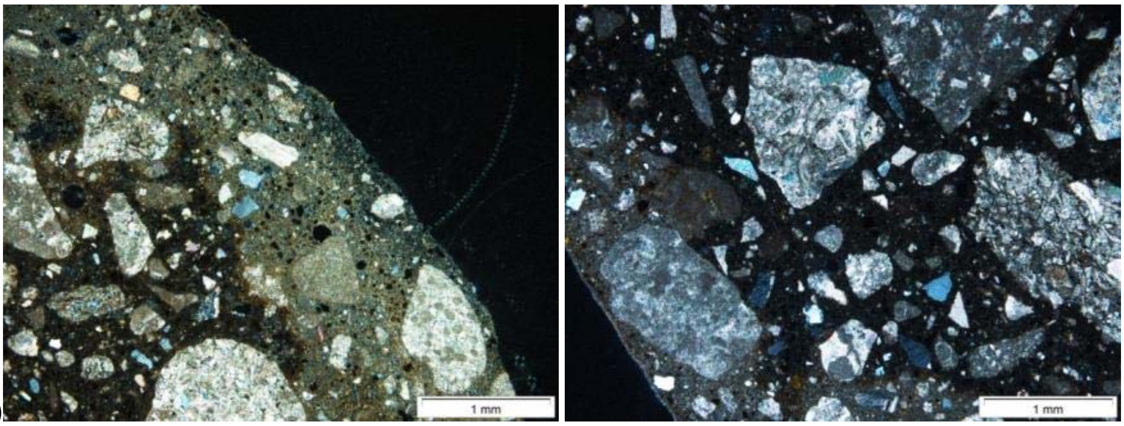

Figure 4.10. Micrographs showing a) Interaction (TPA2) and b) contact point (TPA4) between two types of mortar: cements – dark part and mixed binder (air lime+ cement) – light part.

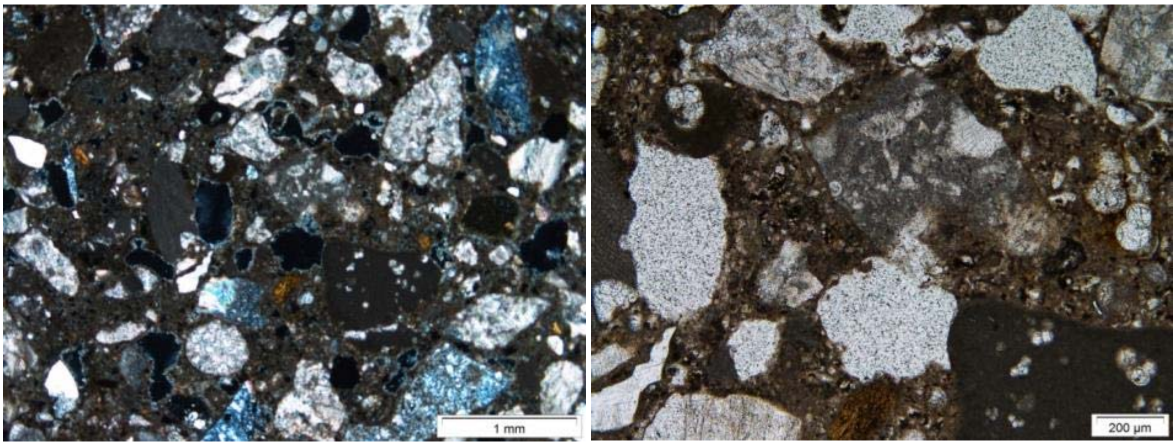

Figure 4.11. Example of cementitious binder in sample TPA1 (crossed and parallel nicols).

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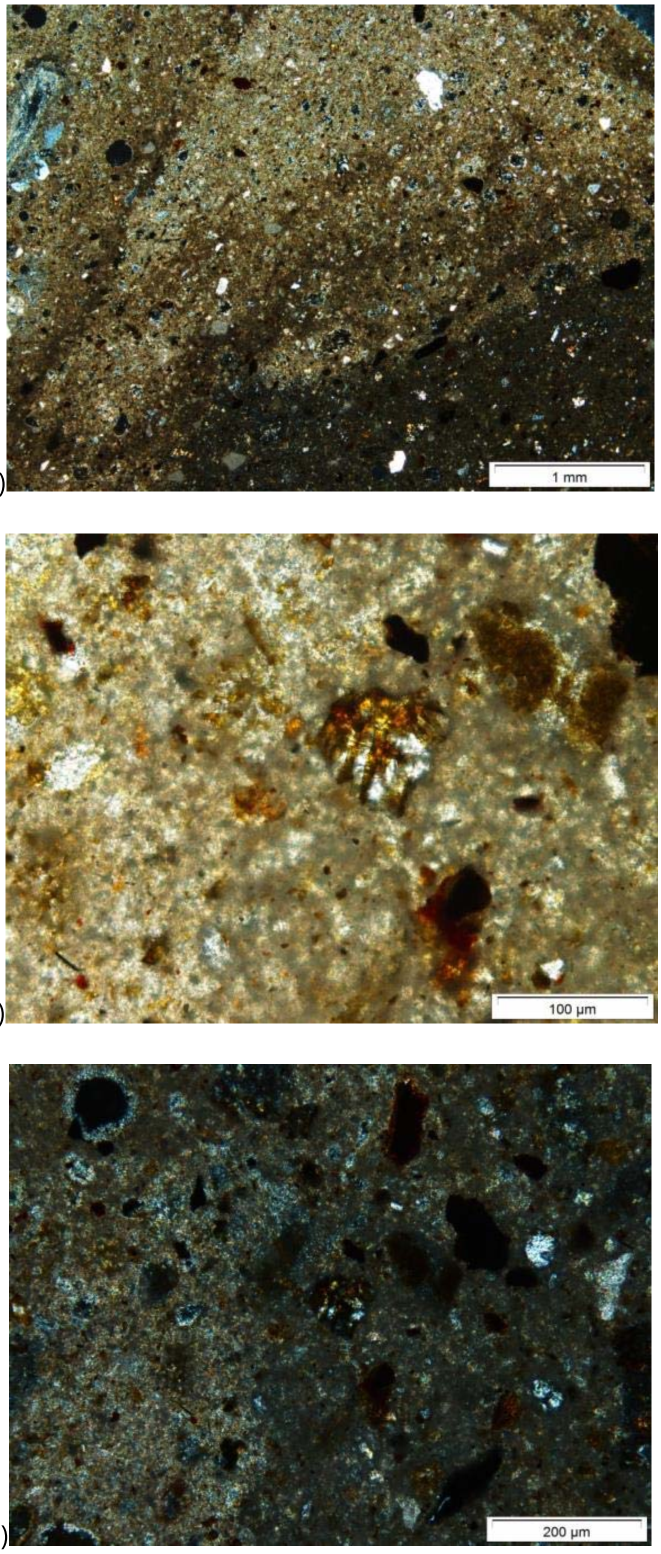

a) b) c)

Figure 4.12. TPA3: Mixed binder; a) the dark part is a cement and the light part is air lime; b) and c) examples of alite and belite crystals (parallel and crossed nicols).

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Analysis of mineralogical composition and structural properties by X-ray Diffraction, FTIR and SEM-EDS measurements

The results of XRD analyses performed on all the samples collected in Totticella Peligna, show as main mineral phases: calcite and quartz and secondly some calcium aluminum hydrate mineral phases typical of cement, such as ettringite, and another phase belonging to the C-A-H family. In addition, at traces level, some anhydrous silicate calcium mineral phases, such as belite ($Ca2SiO4$) and celite (C3S), are also detected. In two samples traces of gypsum are recognized. This component was added to favor the setting process.

Taken into account the table 4.4, it is possible to note that the samples from the Tower are characterized by the presence of C3S and C3S3 mineral phases, and gypsum. This mineralogical paragenesis indicates that the reaction among the elements constituting the cementitious mixture was not completed during the setting and hardening process (Fig. 4.13). In only one sample (TPT4) traces of ettringite are detected meaning that the reaction was complete.

Regarding the sample from the Angel, the mineralogical composition is characterized by the presence in all the samples of ettringite and belite (C2S). This last could be referred to the residues of fired clinker seen at optical observation. Gypsum is absent. These differences are the result of different firing process of the cementitious mixture. The C2S phases indicate a less firing temperature than the C3S. The presence gypsum seems to indicate a not perfect mix design.

Concerning the finishing layer, the two components were also analyzed, after detaching with scalpel. In both samples TPTW and TPTG are present quartz and calcite as main mineral phases and rutile, gypsum and ettringite in traces (Fig. 4.13 d-e).

Table 4.4. Torricella Peligna's samples: mineral phases composition.

	Sample	**calcite**	**quartz**	**gypsum**	**belite (C2S)**	**celite (C3S)**	**pseudo-wollastonite (C3S3)**	**Ettringite**
Tower	TPT1*	xxx	x				x	
	TPT2*	xxx	x				x	
	TPT3**	xxxxx	x	x		x		
	TPT4	xxxx	x			x	x	x
	TPT6	xxxx	x	x			x	
Angel	TPA1	xx	x		x			x
	TPA2	xx	x±		x			x±
	TPA3***	xxx	x		tr.			x
	TPA4**	xxx	xx		x			x

* traces of wairakite; ** traces of plagioclase; *** traces of brownmillerite.
Legend: xxxxx – very very abundant; xxxx – very abundant; xxx – abundant; xx – discrete; x – scarce; tr. - traces

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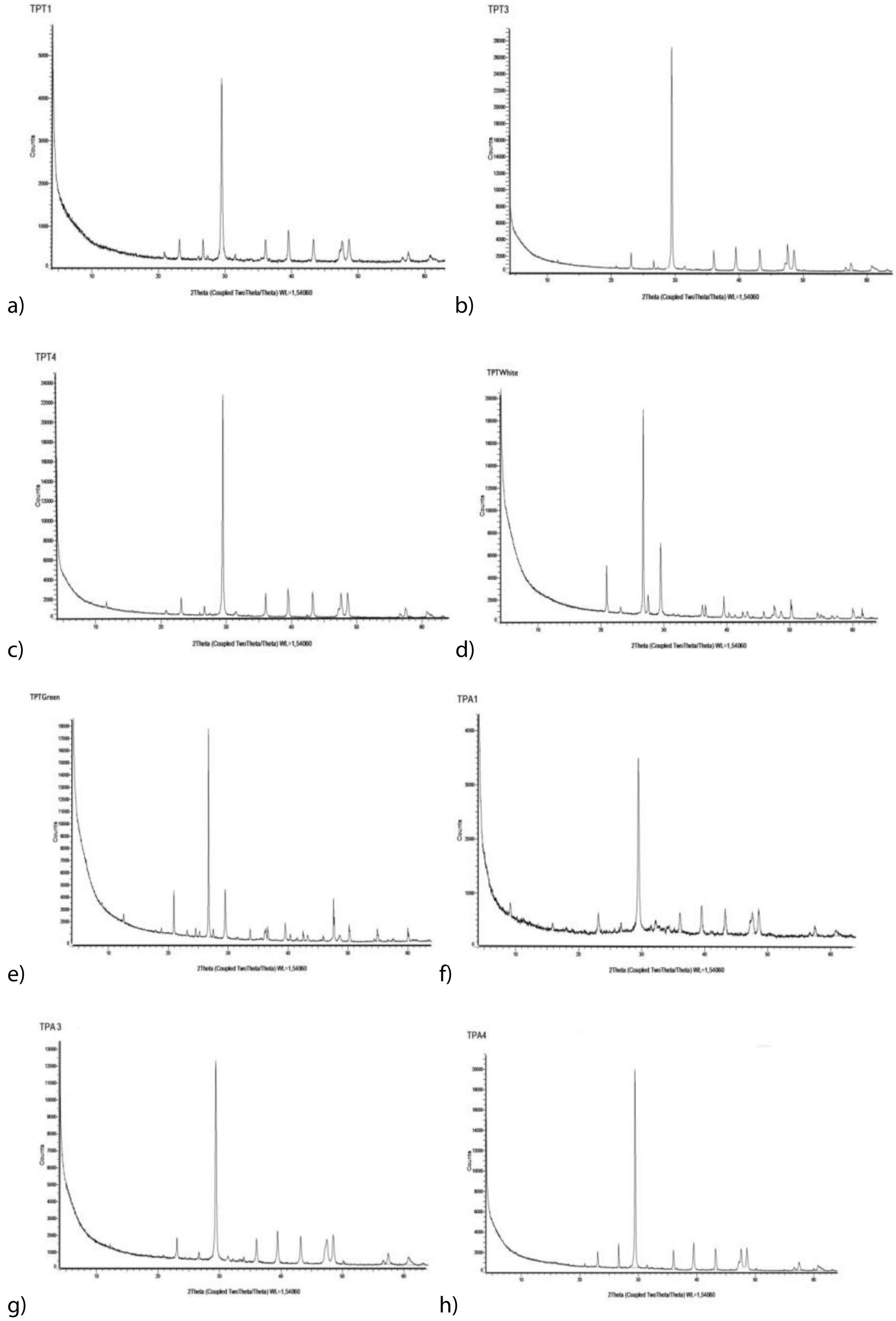

Figure 4.13. XRD spectra of all the samples from Tower and Angel monuments.

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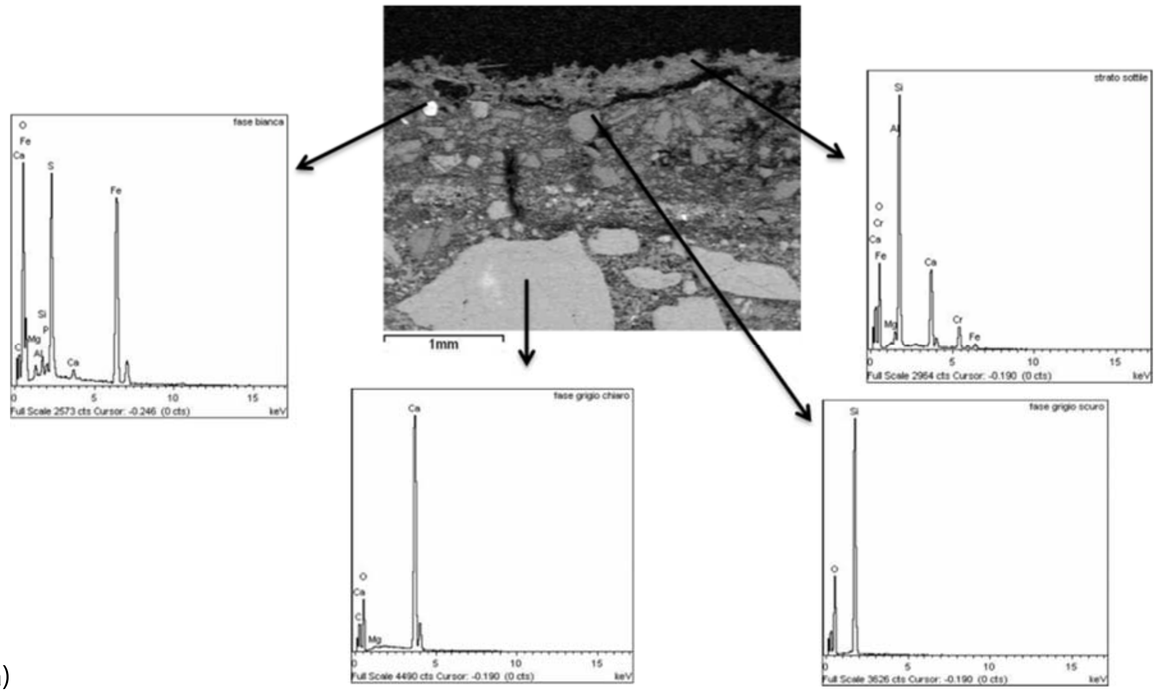
The samples extracted from the Tower and Angel were also investigated by FT-IR spectroscopy using an ATR accessory and by SEM-EDS to obtain complementary information on the composition, structure and morphology.

The most representative data are reported hereafter by talking into account the sampling area and state of conservation.

The SEM-EDS analyses reported in the figure 4.14 were conducted on the cross section of the TPT2 sample (Tower). The sample consists of structural cement covered by a surface finishing layer. The SEM-EDS and FTIR measurements confirm the presence of calcium, aluminum, silicon, iron and sulphur, typical elements of cementitious matrix and permit to sustain that the aggregates mainly consist of calcite and quartz. Moreover, the EDS analysis also reveals the presence of Cr in the green finishing layer.



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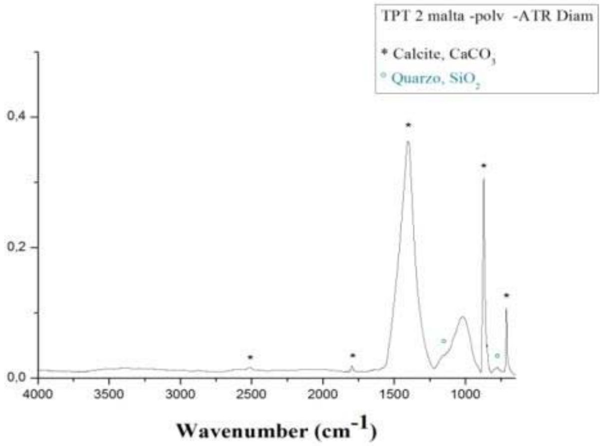
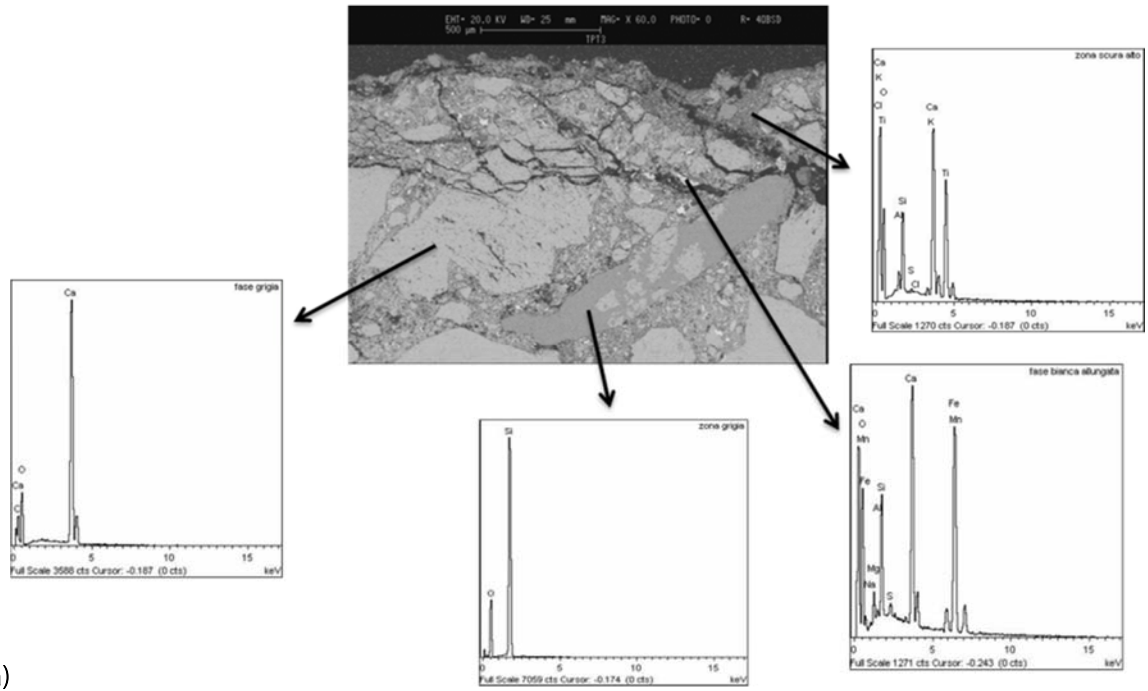


b)

Figure 4.14. Results of a) SEM observations and EDS spectra and b) FTIR spectrum of TPT-2.

The TPT3 sample comes from an internal pillar of the Tower that does not show evident degradation problems. The SEM observations on cross section of the structural cement matrix and finishing layer are reported in the figure 4.15 together with the EDS results. It is evident that the results are very close to those obtained for the sample TPT2.



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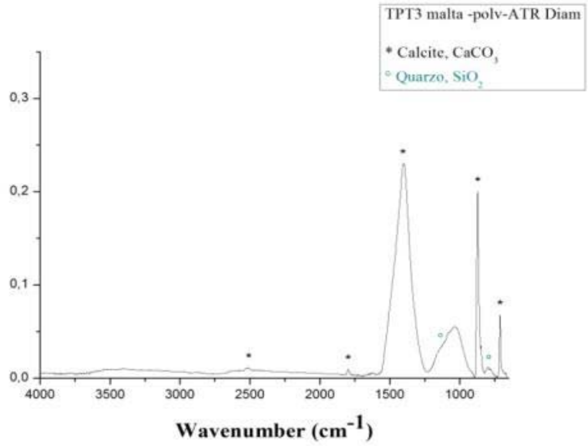
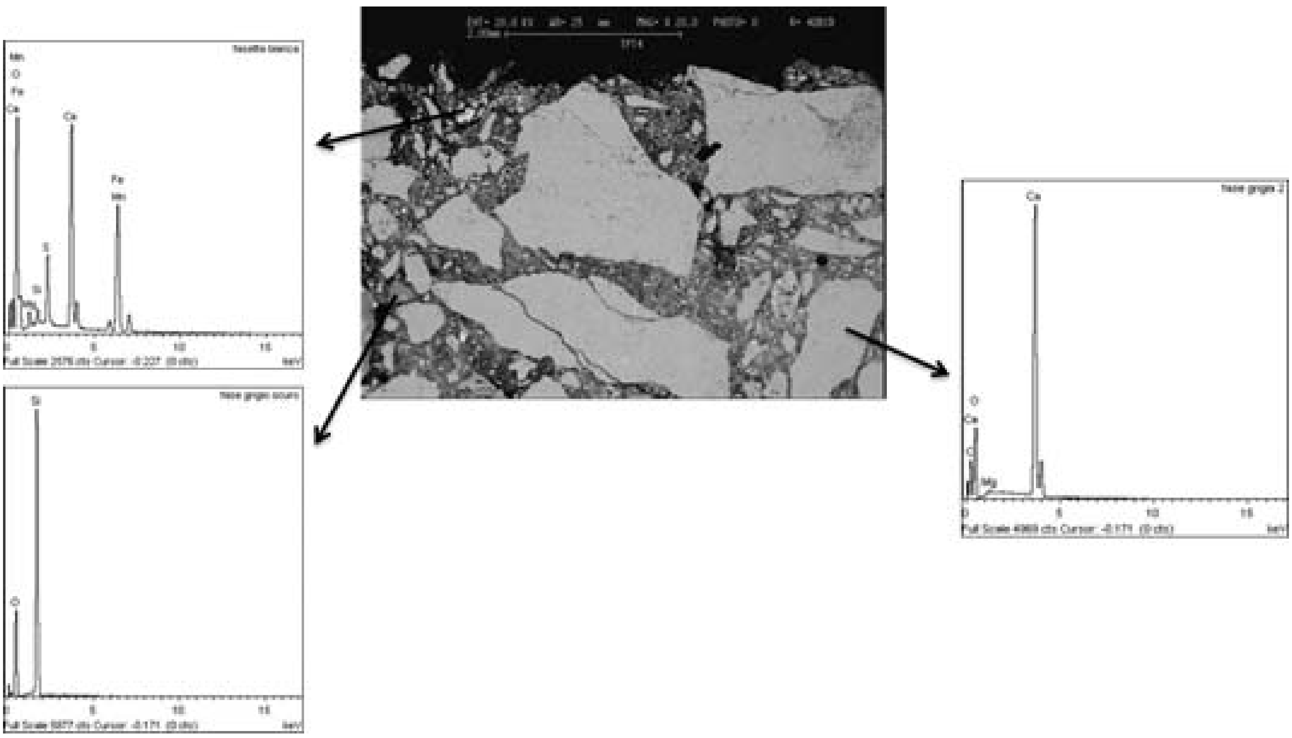


b)

Figure 4.15. TPT3 sample: a) SEM image showing coarse aggregate grains and EDS analyses; b) FTIR spectrum.

The same investigations were carried out on the sample TPT4 from an internal pillar of the Tower with evidences of degradation. The SEM-EDS data in the figure 4.16 show the presence of large aggregates which mainly consist of calcite and quartz. In this case, the EDS analysis on the surface reveals the presence of sulphur and chloride which could be related to the degradation phenomena affecting the concrete structure.

a)



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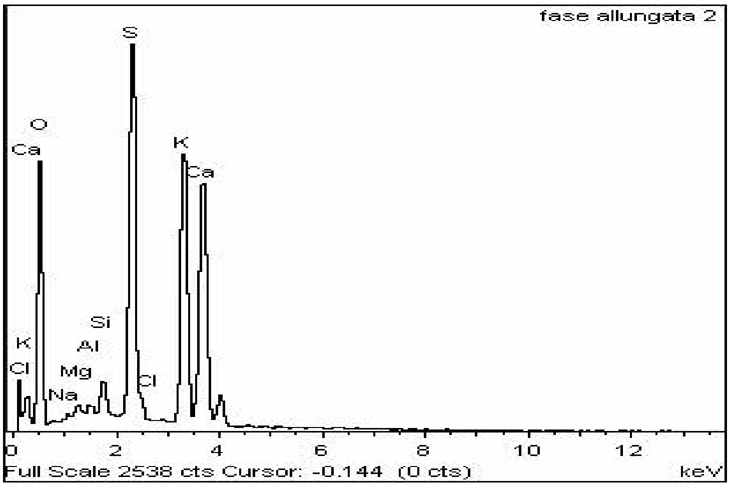
b) 

Figure 4.16. a) SEM-EDS analysis and b) EDS spectrum of concrete surface of TPT4 sample.

The TPT4 sample has also been analyzed by FE-SEM revealing the presence of several voids (shrinkage cracks) around the aggregates that can play a role on the mechanical performance of the material, as well as on its durability. Two representative images are reported in figure 4.17.

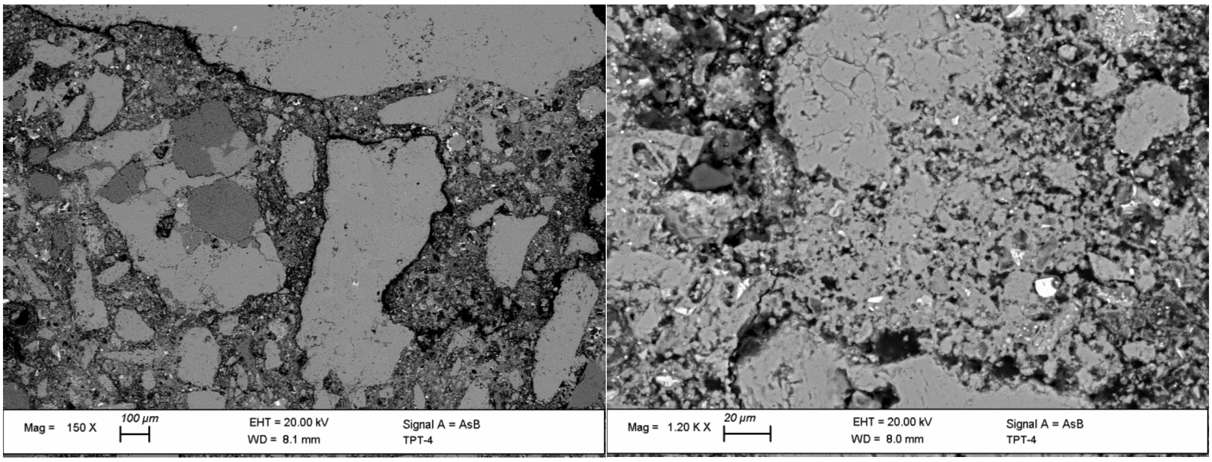


Figure 4.17. FE-SEM images of TPT4. Voids around grains are quite visible.

About the Angel, the results of the SEM-EDS and FTIR characterization of two representative samples from different areas are reported in the figures 4.18 and 4.19. In particular, the TPA1 from the left side of the book, a highly degraded area with cracks, and the TPA2 from upper fold of Angel dress at the right side were analyzed. SEM observations have evidenced the presence of aggregates different in shape and level of roundness. This is probably the result of the use of different sands and/or different grinding level. In terms of composition, the FTIR spectra confirm that mainly consist of

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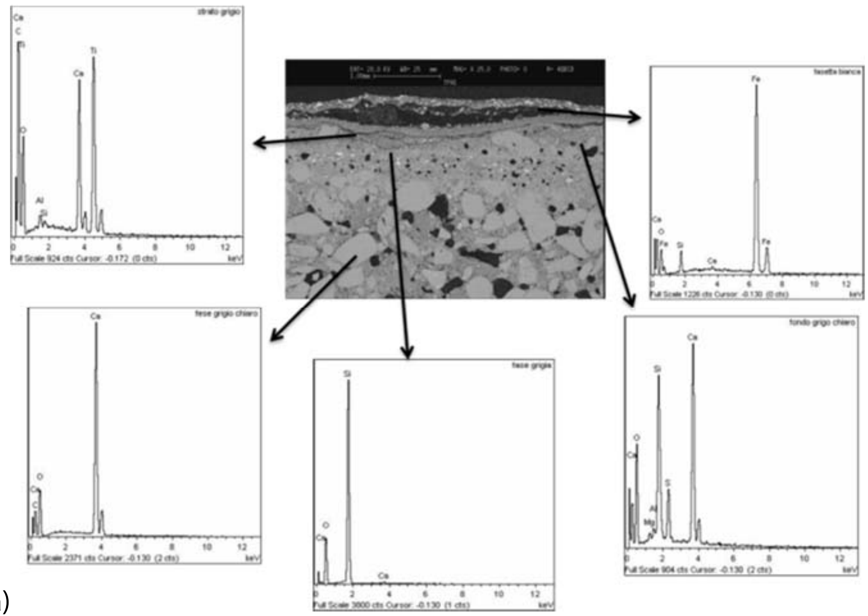
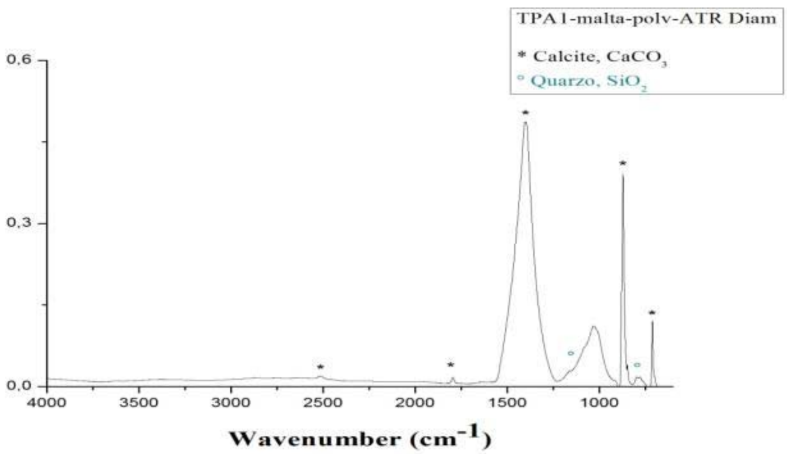
calcite and quartz. As regards the matrix, the micrograph in figure 4.18 puts in evidence a matrix characterized by the presence of calcium, silicon and aluminum that means a cementitious composition, while in the figure 4.19 it is evident a sort of inhomogeneity in terms of color that can be related to the use of two different types of binder. This is confirmed by the results of the EDS measurement performed in the core of the sample that reveals high contents of silicon, calcium and aluminum (typical elements of cement).

The cross-section of TPA1 shows that the concrete sample consists of several layers with different granulometry and the presence of a surface finishing layer. The EDS measurements on this last layer reveal the presence of titanium oxide as possible coloring element.



a)



b)

Figure 4.18. a) SEM image and EDS spectra and b) FTIR spectrum of TPA1.

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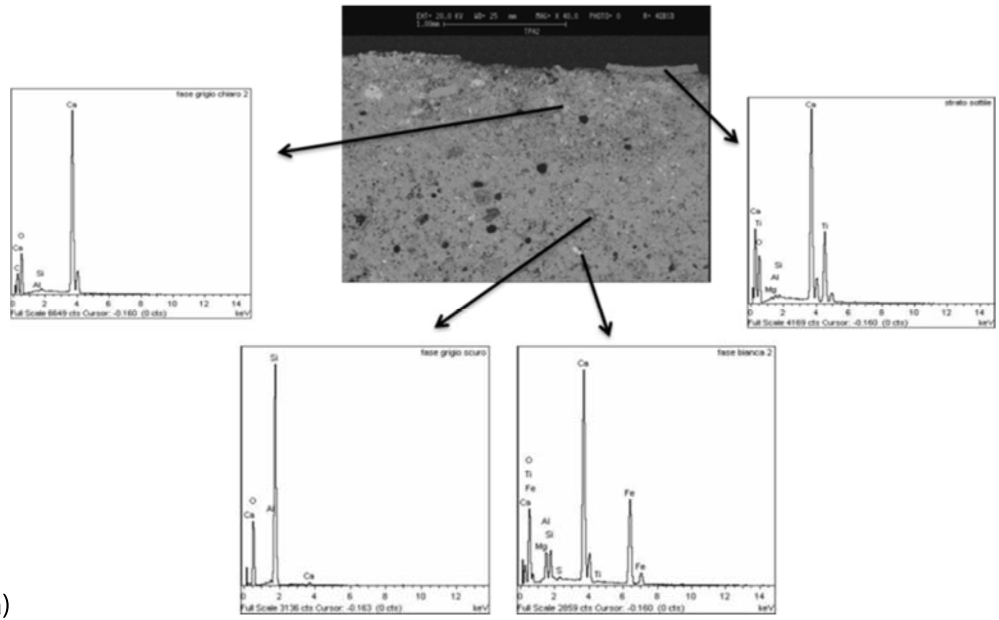
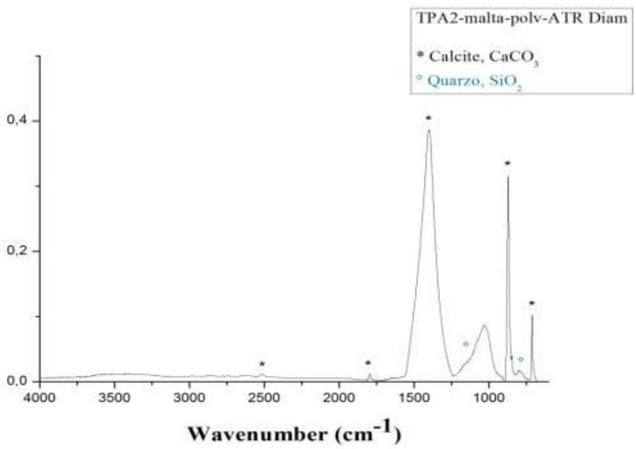


a)



b)

Figure 4.19. a) SEM image and EDS analyses and b) FTIR spectrum of TPA2.

The FE-SEM image reported hereafter in figure 4.20 reveals the presence of microcrystalline ettringite [$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26(H2O)$]. By considering the specific context, the formation of ettringite is probably of secondary origin due to the occurrence of alteration processes. This phase could be formed for example due to chemical degradation processes induced by acid solutions attach on carbonate fractions or more probably by dissolution and precipitation .phenomena of soluble salts.

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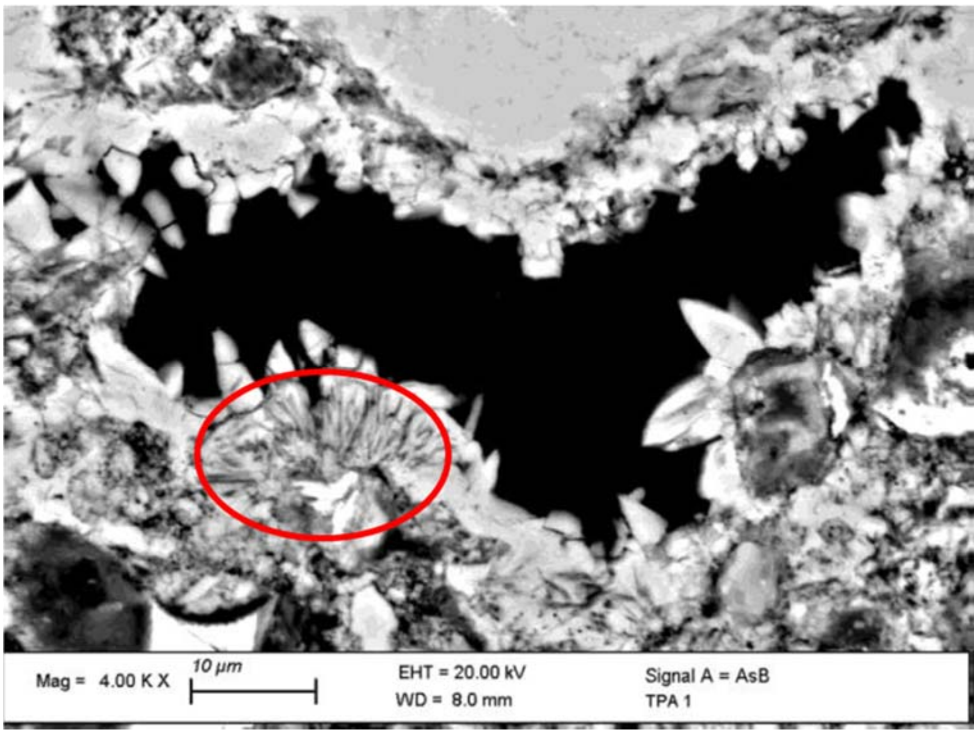

Figure 4.20. TPA1: FE-SEM image inside the pore.it is present secondary crystals with acicular habitus typical of ettringite.

Porosity and pore size distribution

The curves of pore size distribution and the values of open total porosity are quite different for all the investigated samples. The range of pore size dimensions is from 0.007 microns up to 100 microns and the range of pore size distribution completely fits with that. The open total porosity varies from 16% to 24% with an average of 20% approximately with the exception of the samples TPA4 that has the lowest percentage, around 8%.

By considering the results in the table 4.5, the differences between the two groups of samples other than among the samples themselves already evidenced by other investigations are confirmed. Indeed, the samples from the Tower are characterized by higher percentage of macro-pores than the Angel's samples.

Observing the distribution curves (Fig. 4.21), except for the samples TPT1 and TPA4, the dimensional classes of the pores diameter define a Gaussian curve. In the samples from the Tower the mode is in correspondence of 1 micron, while in the Angel's samples it moves towards 0.1 micron.

The sample TPT6 has a mode in the range 3-4 microns indicating a high presence of larger pores.

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The Gaussian curves of the Angel samples are characterized by an asymmetric trend with a tail toward the smaller pores, comprised between 0.07 and 0.1 microns. The pores with diameter in the range 10-100 micron are however quite represented. Some behavior can be explained maybe by considering the position of the collected samples and the level of degradation of the samples themselves. As regard the samples TPT1 and TPT2, for example, the differences in the pores diameter distribution can be due to the former is a finishing layer. It is possible, in fact, that the smoothing process provoked the closing of larger pores for the smaller. While the variation occurred between the samples TPT3 and TPT4 can be related with the alteration state that affects the sample TPT4 that provokes a decreasing of the percentage of larger pores for an increasing of the smaller ones.

Table 4.4. Torricella Peligna's samples: porosimetric results.

Sample	Open porosity (%)	Type of distribution	Mode (φμm)
TPT1	19.53	Bimodality	(0.01 -0.02) and (1 – 2)
TPT2	16.24	Unimodality	0.03 - 1
TPT3	21.48	Unimodality	0.3 - 0.6
TPT4	17.50	Unimodality	0.3 - 0.6
TPT6	23.72	Unimodality	3 - 4
TPA1	16.74	Unimodality	0.08 -1
TPA2	19.65	Unimodality	0.08 - 0.1
TPA3	17.08	Unimodality	0.07 -1
TPA4	8.05	Bimodality	0.01 and 0.1

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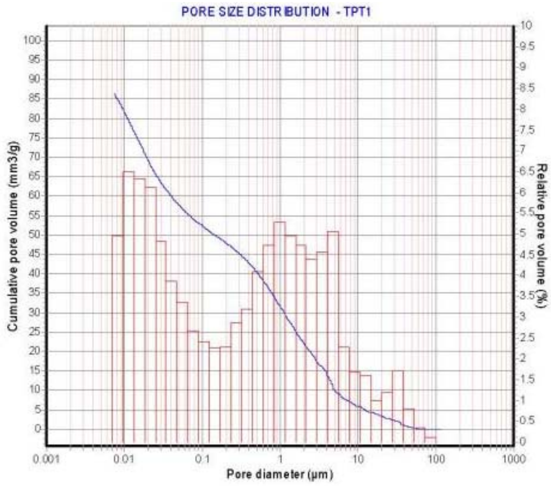

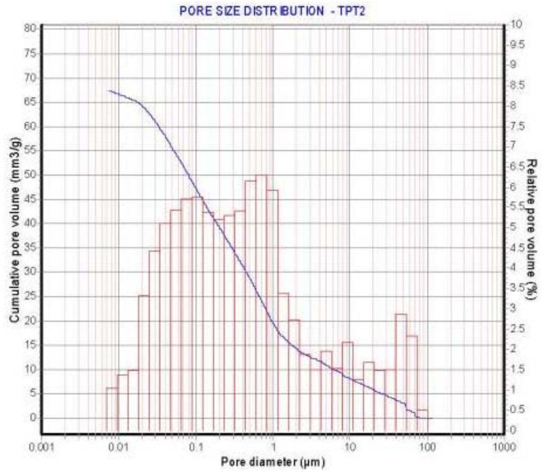

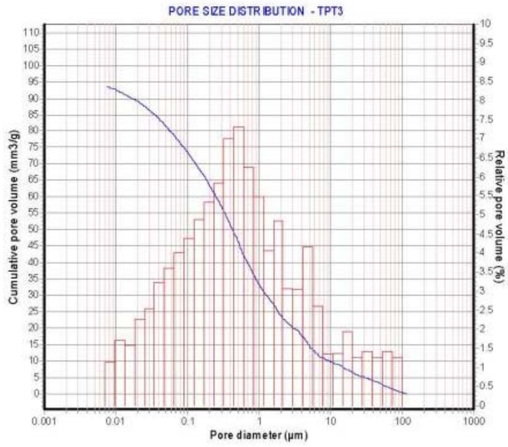

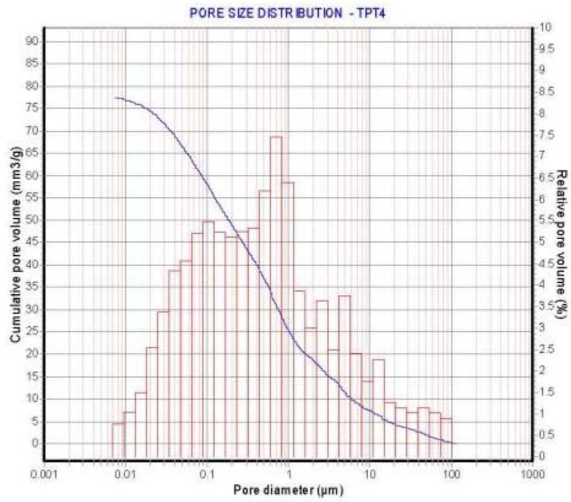

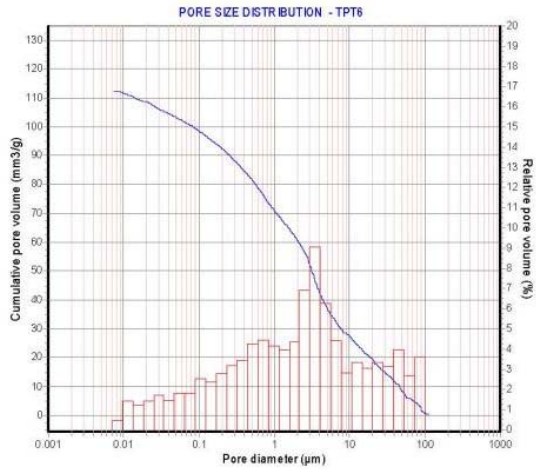

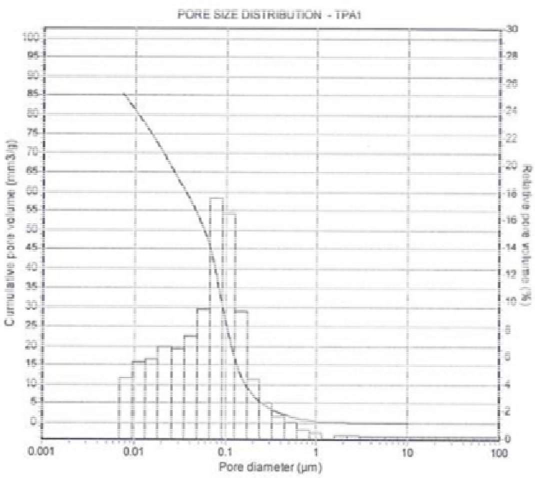

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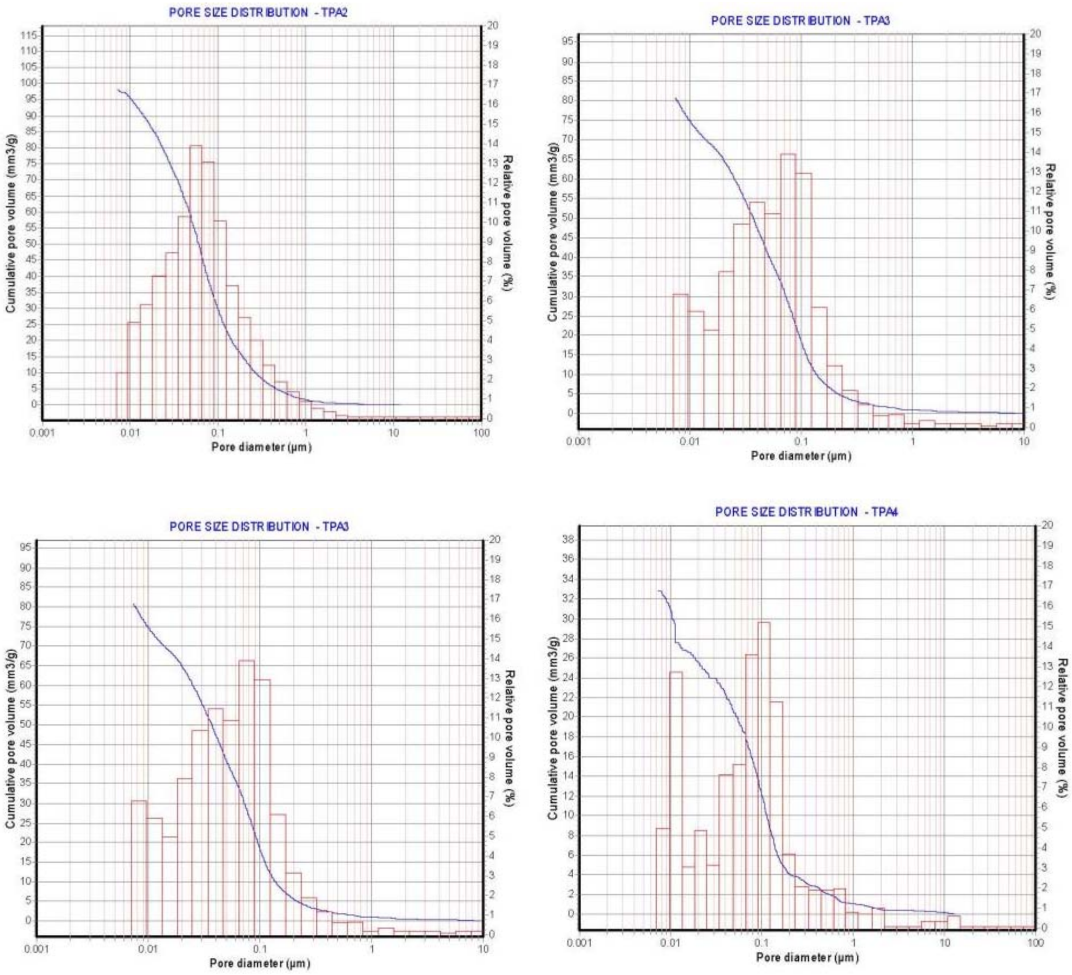

Figure 4.21. Torricella Peligna's samples: Graphs of porosimetric distributions.

Electrochemical measurements

Electrochemical measurements on site were performed by using the Galvanostatic Pulse technique with a GalvaPulse equipment GP-5000 Germann Instruments. The galvanostatic pulse measurements are based on a fast polarization technique that is used to evaluate the corrosion rate of rebars. A short-time anodic current pulse is impressed galvanostatically from an electrode system, with a counter electrode ring and a guard ring placed on top of the concrete together with a reference electrode Ag/AgCl contained in the body of the electrode. Based on the reinforcement diameter and the measured reinforcement length, the instantaneous corrosion rate of the reinforcements can be calculated.

When the Galvanostatic pulse measurements are performed, the Half-Cell Potential, the Corrosion Rate and the Resistance are simultaneously determined.

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All the measurements were performed by applying a galvanostatic pulse current of 100 µA and a pulse duration of 10 seconds. The small anodic current results in change of reinforcement potential, which is recorded by means of data logger. The concrete surface was wetted three times every 15 minutes just before the measurements according to ASTM C876 in order to reduce the electrical resistance between the GalvaPulse electrode placed at the concrete surface and the reinforcements embedded into the concrete monument.

By using the GalvaPulse measurements, it is possible to estimate the corrosion rate (mm/year) of rebars which represents the volumetric loss of metal per unit of area and unit of time. For the steel, 1µA/cm^2 is equivalent to a corrosion rate of 0,0116 mm/year for uniform attack.

It's important to consider that the GalvaPulse measurements only gives an instant picture of the condition of the reinforcements. Into the concrete structure the corrosion activity of the reinforcements is influenced by different parameters, as moisture, temperature and oxygen concentration. A wrong estimation for example of the rebar location, the presence of cracks and delamination problems can affect the estimated corrosion rate values. However, this technique is widely used to study the rebars with an in situ and not invasive method.

A scheme of the electrochemical measurements carried out in situ by using the GalvaPulse is reported in figure 4.22.

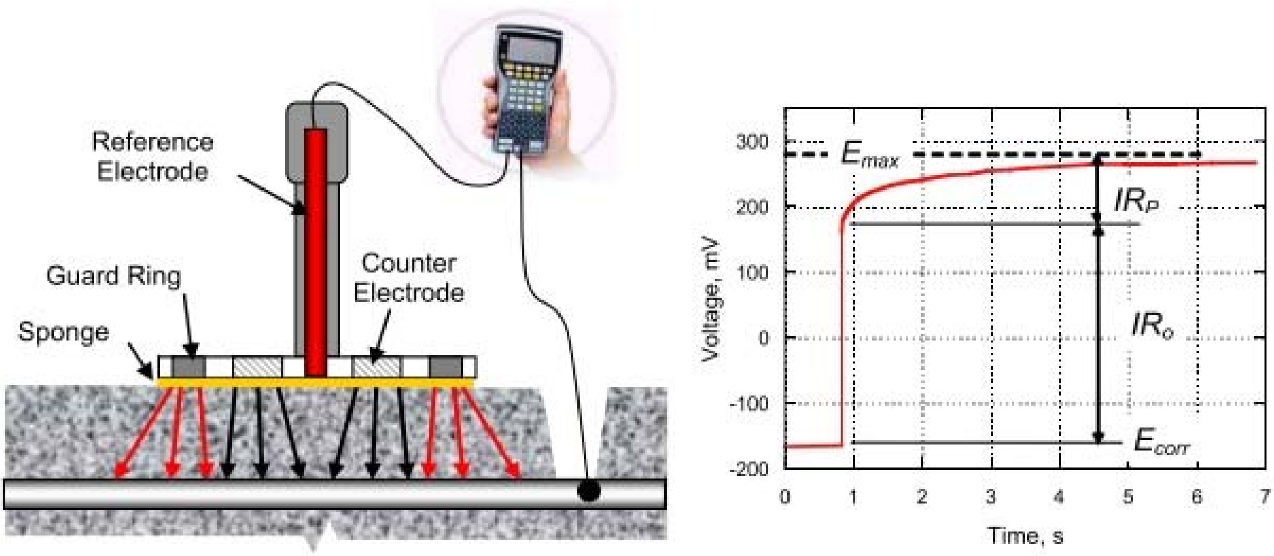

Figure 4.22. Scheme of the in situ electrochemical measurements.

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The electrochemical measurements were carried out to investigate the reinforcements of three pillars of the Tower war memorials. In the case of the Angel, these measurements were not performed for technical reasons.

In the Tower, simultaneous measurements of half-cell potential (Ag/AgCl), corrosion rate and electrical resistance of the three pillars were carried out using the GalvaPulse. In all the three pillars the concrete cover is 2-3 cm thick.

From the corrosion rate map of pillar 1, a high corrosion activity is observed in the throughout measured area (only a value is out of the range). Regarding to pillar 2, the corrosion activity is moderate in all the measurement area with the exception of point 1;2 in which it is high.

At a visual inspection, the pillar 3 shows an advanced degradation state with deteriorated concrete cover and partially exposed and corroded bars. These observations are confirmed by the electrochemical measurements that record a high corrosion activity. A possible correlation between the corrosion activity and the Tower's geographic exposure is observed. In fact, pillars 1 and 3, respectively exposed to North and West, are more degraded compared to pillar 2 exposed to the East.

The identification of the corrosion activity was performed according to the literature [T. Frolund, 2002 (with GalvaPulse Instrument)]. The relationship between the corrosion rate values and the corrosion activity is the following:

<6 µm/year - passive area

6-23 µm/year - negligible corrosion activity

23-58 µm/year - low corrosion activity

58-174 µm/year - moderate corrosion activity

>174 µm/year – high corrosion activity.

Information and results of the in situ electrochemical measurements are reported in figure 4.23 -4.26.

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Figure4.23. Pictures during the detection of reinforcement position and during the measurements with the GalvaPulse instrument.

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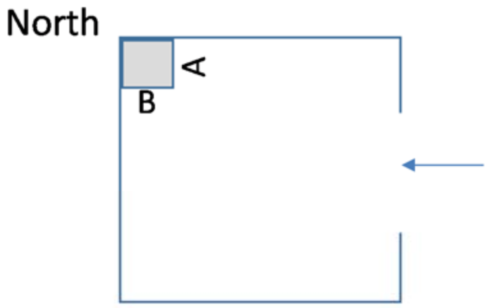
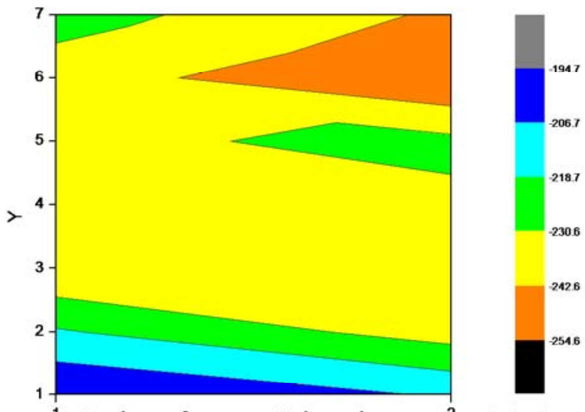
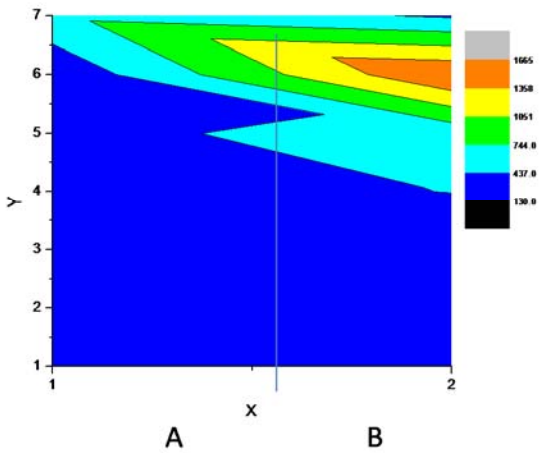




2-D plot of potentials values - Int 1 B-A



2D plot of corrosion rate values –Int-1 B-A

Y/X	1-B	2-A
7	-225 650 1.8	-244 402 1.1
6	-237 204 0.9	-254 1661 0.8
5	-232 372 0.4	-228 546 0.5
4	-235 326 0.4	-233 442 0.4
3	-241 130 0.7	-241 260 0.5
2	-217 158 1.8	-236 225 1.0
1	-194 312 2.6	-208 246 1.4

Values in the table: Potentials mV vs. Ag/Ag/Cl
Corrosion rate µm/year
Resistance KOhm

Whether condition T 13°C, Rain
Grid space used 15 x 15cm
Steel reinforcement area: 3519 mm^2
Method of measurement: Galva Pulse

Figure 4.24. Picture of the internal pillar n. 1 of the Tower, the location inside the Tower, 2D plot of potential and corrosion rate values determined by in situ measurements, table with potential, corrosion rate and resistance values in the different X and Y positions at the wall grid.

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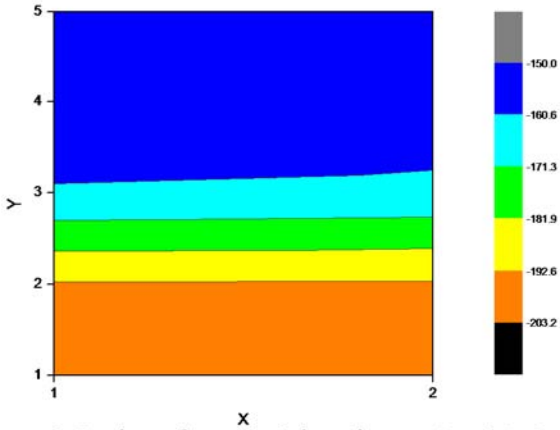
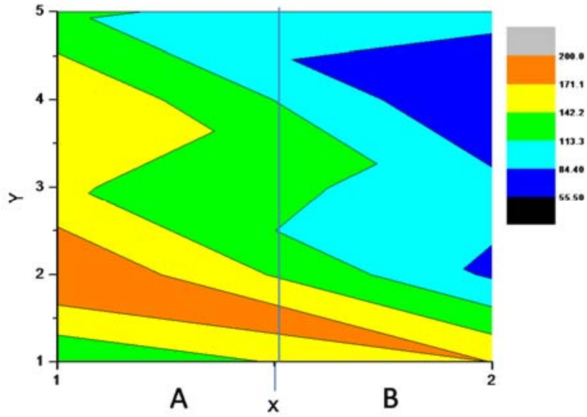


2-D plot of potentials values - Int 2 A-B

Y/X	1-A	2-B
5	-159 118 4.9	-153 94.0 4.8
4	-150 170 7.0	-153 55.7 4.4
3	-161 147 4.4	-163 92.9 3.3
2	-193 200 2.5	-193 80.0 2.6
1	-220 116 1.7	-203 171 5.8



A B

2D plot of corrosion rate values –Int-2 A-B

Values in the table: Potentials mV vs. Ag/Ag/Cl
Corrosion rate µm/year
Resistance KOhm

Whether condition T 13°C, Rain
Grid space used 15 x 15cm
Steel reinforcement area: 3519 mm^2
Method of measurement: Galva Pulse

Figure 4.25. Picture of the internal pillar n. 2 of the Tower, the location inside the Tower, 2D plot of potential and corrosion rate values determined by in situ measurements, table with potential, corrosion rate and resistance values in the different X and Y positions at the wall grid.

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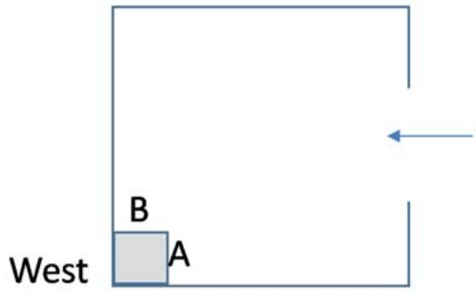
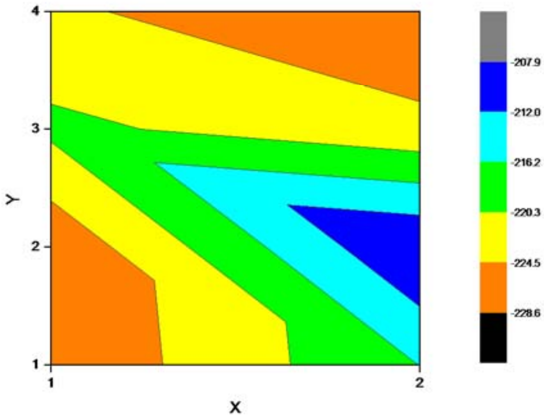
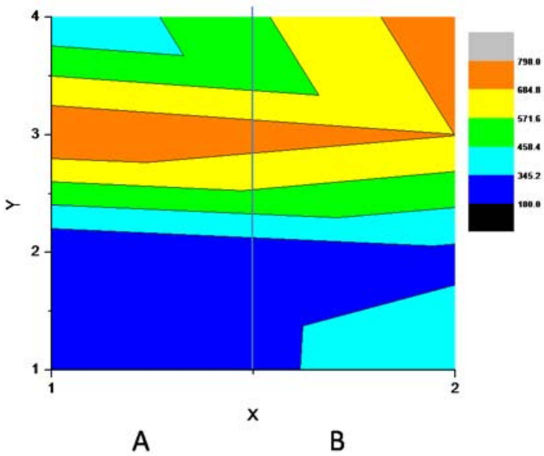




2-D plot of potentials values - Int 3 A-B

Y/X	1-A	2-B
4	-223 348 0.8	-228 761 0.5
3	-219 797 0.5	-223 686 0.4
2	-227 232 0.7	-208 319 0.5
1	-228 235 1.5	-216 414 0.7



2D plot of corrosion rate values –Int-3 A-B

Values in the table: Potentials mV vs. Ag/Ag/Cl
Corrosion rate µm/year
Resistance KOhm

Whether condition T 13°C, Rain
Grid space used 15 x 15cm
Steel reinforcement area: 3519 mm^2
Method of measurement: Galva Pulse

Figure 4.26. Picture of the internal pillar n. 3 of the Tower, the location inside the Tower, 2D plot of potential and corrosion rate values determined by in situ measurements, table with potential, corrosion rate and resistance values in the different X and Y positions at the wall grid.

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Schmidt Hammer Test

The rebound hammer test also known as Schmidt Hammer Test developed by Swiss engineer Ernst Schmidt in 1948 is one of the oldest, simplest and most popular non-destructive tests of concrete. The device uses a spring and measures the hardness of concrete surface using the rebound principle. The rebound hammer test is codified in ASTM C805, and CSN EN 12504-2.

A steel hammer impact, with a predetermined amount of energy, a steel plunger in contact with a surface of concrete, and the distance that the hammer rebounds is measured.

The device consists of a plunger rod and an internal spring loaded steel hammer and a latching mechanism. When the extended plunger rod is pushed against a hard surface, the spring connecting the hammer is stretched and when pushed to an internal limit, the latch is released causing the energy stored in the stretched spring to propel the hammer against the plunger tip. The hammer strikes the shoulder of the plunger rod and rebounds a certain distance. There is a slide indicator on the outside of the unit that records the distance traveled during the rebound. This indication is known as the **rebound number**. By pressing the button on the side of the unit, the plunger is then locked in the retracted position and the rebound number (R-number) can be read from the graduated scale. A higher R-number indicates a greater hardness of the concrete surface. The tests can be performed in horizontal, vertically upward, vertically downward or any intermediate angled positions in relation to the surface.

Two models of rebound device: N-type with impact energy of 2.207 Nm, best for thickness of cement >10cm - L-type with impact energy of 0.735 Nm for thickness of cement >5cm <10cm were used for testing the resistance of the concrete present in some parts of the Monumental test site of Torricella Peligna (Fig. 4.27).

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Fig. 4.27. Application of the Schmidt hammer device on the external wall of the monumental test site

The rebound number (R) measured in different zones of the monumental test site has been correlated with the correspondent value of hardness as indicated in the conversion curves for each instrument (L,N) and on the basis of the horizontal or vertical impact.

Taking into consideration the average classes of resistance (From Table 3.1 of the Eurocode 2, EN 1992-1-1), the concrete present in the structure of the Torricella Peligna has a good resistance (<25/30) in the Zone A (external south west side) made of sound reinforced material. In the case of the internal pillar in the north-east angle (Zone B) the concrete shown a discrete resistance only in the upper part (>20/25). In fact the lower area (up to 50 cm from the ground level), is flaking and with very poor resistance (<20/25). The data from the internal longitudinal pillar (Zone C) shown low resistance (<20/25) for both the instruments.

Classes of resistance of concretes

Strength class	20/25	25/30	30/37	35/45	40/50	50/60
Cylinder (Mpa)	20	25	30	35	40	50
Cube (Mpa)	25	30	37	45	50	60
Modulus of elasticity (Gpa)	30	31	32	34	35	37
Tensile strength (Mpa)	2.2	2.6	2.9	3.2	3.5	4.1

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Correlation data between R values and Compressive strength (MPa)

Zone A
Type L

R value	Kg/cm^2	MPa
30,75	280	**27,46**

Zone B
Type L

Height	*170*	*115*	*65*
R value	25	21,13	12
Kg/cm^2	265	185	<100
MPa	**25,98**	**18,14**	**<9,8**

Zone B
Type N

Height	*175*	*120*	*70*
R value	27,5	30,75	19,25
Kg/cm^2	220	260	< 100
MPa	**21,5**	**25,5**	**<9,8**

Zone C
Type L

R value	24.75
Kg/cm^2	180
MPa	**17.65**

Zone C
Type N

R value	30.25
Kg/cm^2	200
MPa	**19.61**

Zone A - External wall - west side - exposed concrete - Rebound type N

Point	R value
1	27
2	28
3	28
4	34
5	30
6	28
7	35
8	34
9	30
10	33
11	33
12	29
mean	**30.75**
st dev	**2.86**

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Zone B - Internal rear pillar corner N/E - Rebound type N and L

Cm from ground	*170*	*115*	*65*
L1	19.5	15	12
L2	38	26	<10
L3	24.5	23.5	11
L4	18	20	13
mean	**25**	**21.13**	**12**
st dev	**9.10**	**4.77**	**1.00**
Cm from ground	*175*	*120*	*70*
N1	17	24	12
N2	39	43	28
N3	29	28	24
N4	25	28	13
mean	**27.5**	**30.75**	**19.25**
st dev	**9.15**	**8.38**	**7.97**

Zone C - Internal pillar under 1st floor - central cleaned area - side beneath

Rebound type N and L

L1	28
L2	19
L3	24
L4	28
mean	**24.75**
st dev	**4.27**
N1	30
N2	30
N3	30
N4	31
mean	**30.25**
st dev	**0.50**

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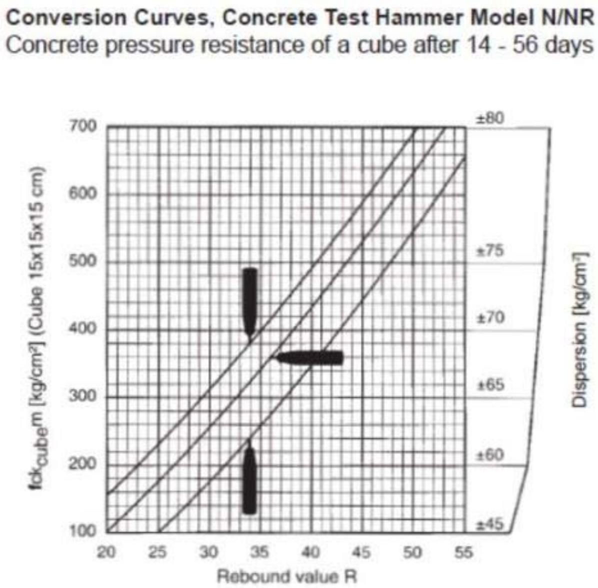
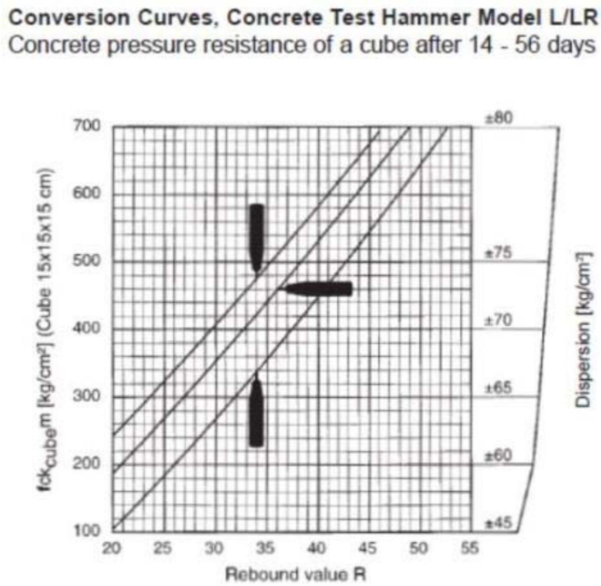
Conversion curves for rebound type N and L (for cubic sample)





<u>Measurement of moisture content and salts content</u>

The SUSI measurement system is an evanescent-field dielectrometry measurement system. It is a recent diagnostic method based on dielectric spectroscopy at 1 to 1.5 GHz microwave frequency. The measuring instrument is a portable resonant microwave device for mapping in a non-destructive way the moisture content (MC) and salinity on walls up to a depth of 2–3 cm in real time. It detects the MC and the salts presence in the material under test by estimating the dielectric properties of a wall that is viewed as a "binary" dielectric mixture consisting of bulk material and water, for the contrast between the dielectric constant ε of a dry wall (e.g. ε < 4 for mortar, plaster, brick) and water (ε approximately 80). The material under investigation should not include metals. Readings are relative, but might be tentatively transformed into quantitative values after calibration for the specific material made by comparison with gravimetry. The method measures MC in the range 0-20% and provide semi-quantitative information about the presence of soluble salts in terms of a salinity index (SI) from 0 to 10.

On figure 4.28 is shown the system SUSI during the measurement on the monuments dedicated to the civilian victims of the second World War in Torricella Peligna.

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Figure 4.28. Application of the SUSI system on the external wall of the monumental test site (a) and (b), and in the internal parts (c).

The measurements of MC and SI by the SUSI instrument presents an increasing trend in moisture content from the bottom level to upward. This is phenomenon is clear from the results on the internal wall rear pillar on the corner North/East.

The measurements in the other places don't show relevant values in terms of moisture content. On the Zone A on the external wall (West side) negative value of MC were detected, in this case the measure was affected by the reinforced bars very close to the surface. Similar operative conditions were find on the point 17 of the external pillar clean corner.

The results in terms of salinity index highlighted a high concentration/presence of salts on the internal rear pillar corner on the North-East side in correspondence to the water demarcation line.

The measurements by dielectrometric systems, SUSI, detected the presence of raisning dampness on the pillars on the North and South side. The system also detected the presence of salts in

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particular on the North pillar on the internal side. The highest levels of salinity index (SI) were detected in correspondence of the water demarcation line, that confirms the presence of raising dampnes phenomena.

Zone A - External wall - West side - exposed concrete

Point	MC	SI	From ground
1	-9.1	1.5	110 cm
2	-9.1	1.4	
3	-9.1	2.8	
4	-14.7	2.3	
mean	**-10.5**	**2.0**	
st dev	**2.8**	**0.7**	
5	-13.5264	1.85	60 cm
6	-12.2956	1.95	
7	-14.721	2.11	
8	-9.11	1.32	
mean	**-12.4**	**1.8**	
st dev	**2.4**	**0.3**	
9	-16.5672	2.49	60 cm
10	-13.5264	2.56	
mean	**-15.0**	**2.5**	
st dev	**2.2**	**0.0**	

Zone B External pillar clean corner

Point	MC	SI	Point	MC	SI	Point	MC	SI
15G1A	2.9	1.31	16G1A	1.8	1.05	17G1A	-6.5	1.82
15G2A	1.8	0.91	16G2A	6.1	8.8	17G2A	0.7	1.29
15G3A	5.0	1.2	16G3A	2.9	9.8	17G3A	-3.6	2.17
mean	**3.3**	**1.1**	**mean**	**3.6**	**62.4**	**mean**	**-3.1**	**1.8**
st dev	**1.6**	**0.2**	**st dev**	**2.2**	**53.3**	**st dev**	**3.6**	**0.4**

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Zone C - Internal rear pillar corner North/East

Point	MC	SI	From ground
18GA	2.6	2.0	180 cm
19GA	7.0	2.5	
20GA	2.1	6.6	
21GA	8.2	4.7	
22GA	9.4	4.0	
23GA	5.1	5.8	
mean	**5.7**	**4.3**	
st dev	**3.0**	**1.8**	
24GA	10.0	3.46	110 cm
25GA	8.2	3.03	
26GA	7.6	2.14	
27GA	8.8	2.14	
28GA	7.0	3.85	
29GA	6.3	4.19	
mean	**8.0**	**3.1**	
st dev	**1.3**	**0.9**	
30GA	5.1	4.72	50 cm

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Zone D internal transversal pillar Sud side

not cleaned			cleaned		
Point	**MC**	**SI**	**Point**	**MC**	**SI**
31	4.5	1.97	34	3.2	1.69
32	5.1	2.26	35	3.2	1.59
33	5.1	1.88	36	3.2	1.78
mean	**4.9**	**2.0**	**mean**	**3.2**	**1.7**
st dev	**0.4**	**0.2**	**st dev**	**0.0**	**0.1**

Bonded water and carbonation of cement paste in the concrete (DTA/TG)

All the samples from World War monuments show typical thermal curves of hydraulic materials (fig. 4.29 – 4.30), that means a continuous weight loss in the investigated temperature range. In table below the values of the weight losses (wt.%) calculated from the curves in specific and characteristic ranges are reported together with the associated mineral phases. The obtained results are in accordance with those from other investigations, in particular XRD analyses. Therefore, the explanation for the presence of the mineral phases recognized in thermal spectra are the same exposed in previous paragraphs. In addition, the thermal curves of the two finishing layers are also reported. They were analyzed in order to determine their real nature and composition and so to plan the future removing interventions. The external layer green in color, TPTG, shows an exothermic peak at 390°C attributable to an organic substance and an endothermal peak referable to the de-carbonation of calcite. The calculated content of calcite is around 16%. The white layer TPTW presents endothermal peaks attributable to the de-hydration gypsum, another at 371°C, maybe

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hydroxide or carbonate phase, and the last corresponding with the de-carbonation of calcite, that is calculated around 27%. Resuming the TPTG can be a paint layer while the TPTW a mortar made of lime and fine aggregates.

By comparing the TGA curves and the values in the temperature range 110-750°C, it is possible to state that the samples from the Tower (TPT) are characterized by a low level of hydraulic behavior. In these samples indeed the weight loss is less than 10% on the average, while in the samples from the Angel it is around 20%. This consideration is also supported by the fact that our materials have similar binder/aggregate ratio. Only the sample TPA3 eludes the rule and the sample TPA4 confirms its originality.

Table 4.5. Torricella Peligna's samples: results of thermal investigations

Sample	110-750°C	750°C (calcite)	Ettringite	Gypsum	Binder/aggregate ratio
TPT 1	10 %	76 %	x		1:2.5
TPT 2	5.6 %	76 %	x		1:3
TPT 3	4.7 %	78 %		x	1:3
TPT 4	10.1 %	57 %		x	1:2.5
TPT 6	4.1 %	80 %		x	1:3
TPA 1	18.6 %	20 %	x	x	1:1.5-2
TPA 2	19.4 %	21 %	x	x	1:2
TPA 3	21.5 %	25 %	x		2:1
TPA 4	6.6 %	58 %	x		1:2

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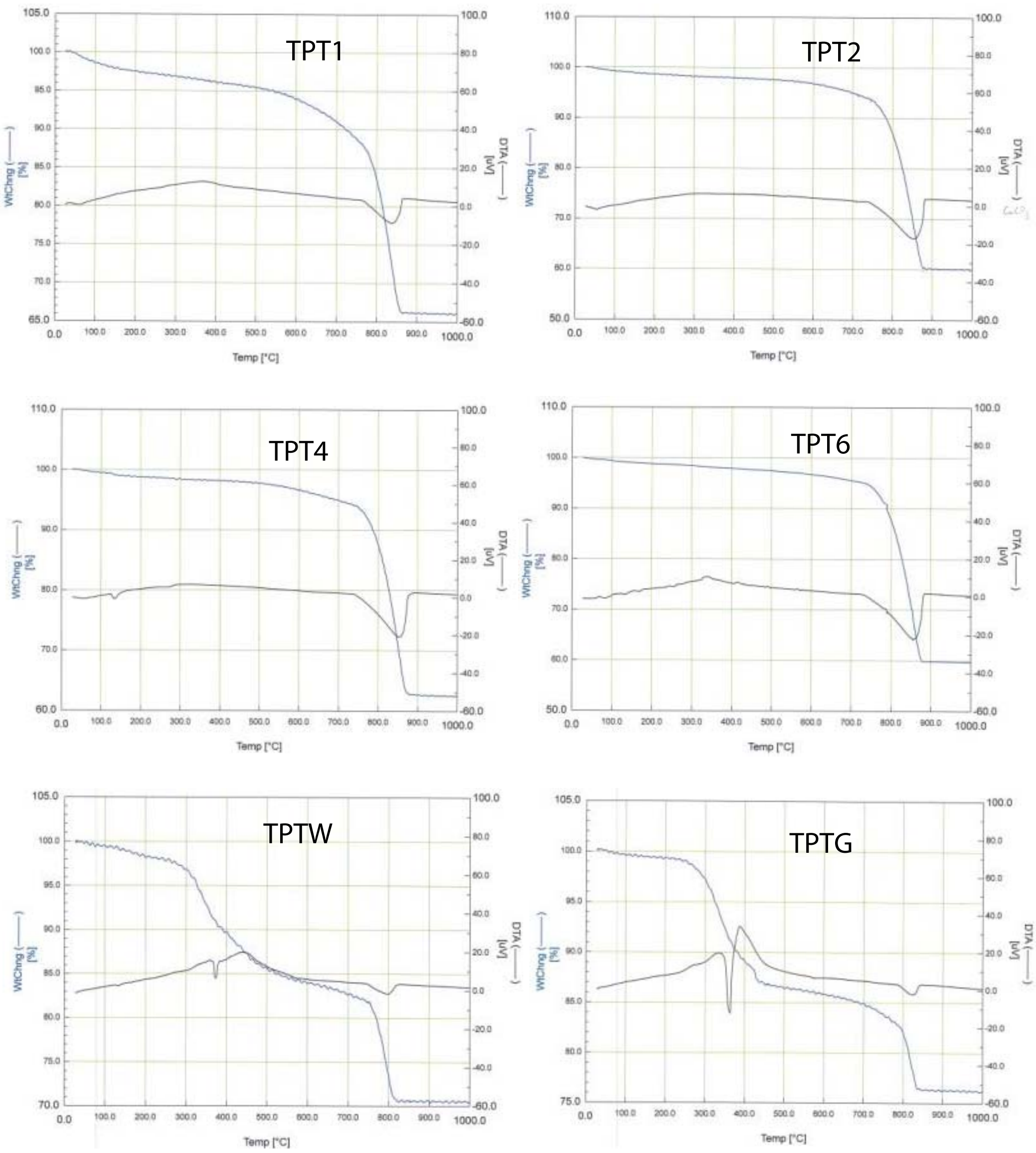

Figure 4.29. Tower War Memorial's samples: some thermal spectra

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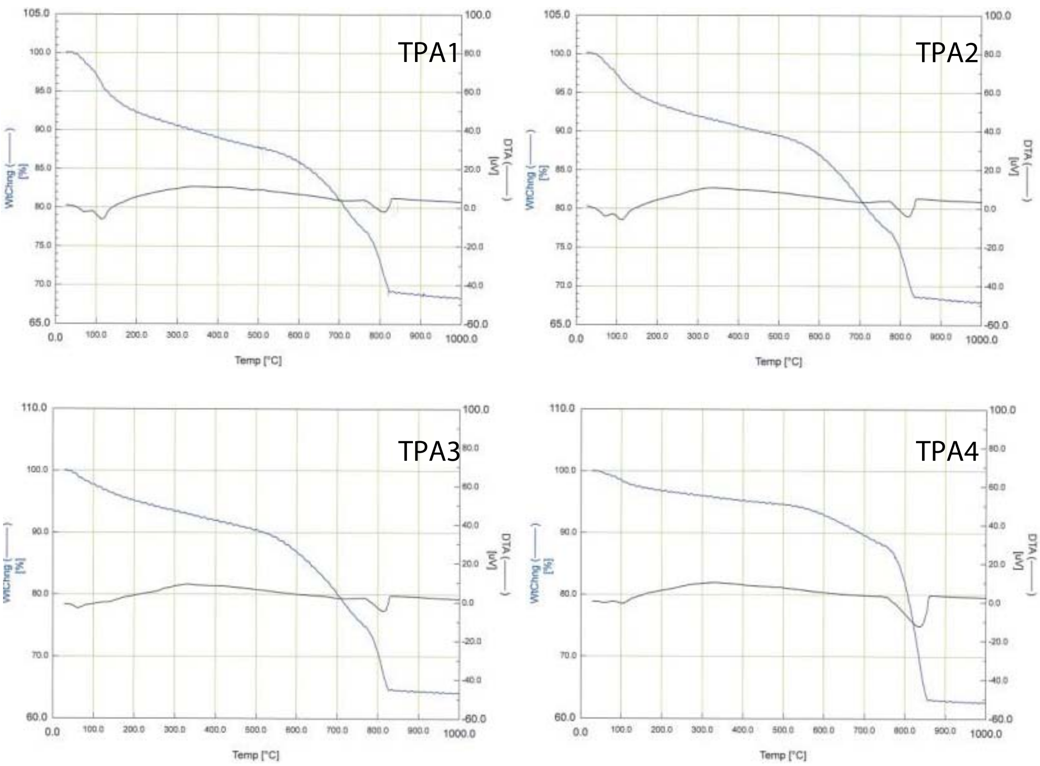

Figure 4.30. Angel War Memorial's samples: Thermal spectra

1.3.1 Compositional and textural properties of concrete

The characterization of the samples from the two sites in Torricella Peligna showed the use of different typologies of cementitious mixture:

- Tower in Torricella – it was used a typical cementitious mixture, in which residues of clinker grains are visible. No evidences of important degradation phenomena are. By comparing two samples collected for this specific reason, scarce secondary crystallization inside pores was noted. At the present, it is not possible to establish the exact origin of this crystallization, but it is important to underline that in the sample believed altered, this crystallization is accompanied with a different pore size distribution is showed. In fact, there is a reduction of the percentage of the larger pores in favor of smaller ones. In addition, there is also the presence of a mineral phase (ettringite) with doubtful origin.

- Angel in Torricella – in several samples there is the contemporary presence of two types of mortars: cementitious and mixed mortar. In this last the cement is mixed with lime. It is possible that is a trick used to increase the workability of the cement in particular for making the statue and its

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decorative elements. Also in some sample there are secondary materials inside pores, but at the present it is not possible to verify the real importance of this result.

It is possible to point out the use of local materials in terms of aggregates. The carbonate fragments in Torricella samples come for example from the alluvium materials of confluence basin of Aventino and Sangro rivers.

Regarding the working technologies, it is evident an handicraft approach at least in Torricella monuments, by considering the heterogeneity of dimensions of residual clinker and variability of morphology and roundness of the aggregates.

As regards the preservation state, some hypotheses can be done about the presence of secondary materials inside the pores that can derive from the alteration of pre-existing mineral phases. A consequence of this secondary crystallization it may have been the partial or complete closing of the pores and therefore a reduction of the percentage of the larger pores and an increase of smaller pores. A high presence of small pores could give some problems in terms of freeze-thaw resistance.

Some problems could also derive from the eventual presence of soluble salts, for which no evidences are, in particular from their solubilization and re-precipitation.

1.3.2 State of conservation of the monument

THE TOWER

Although, from a general overview, the monument may seem to be in a reasonable state of conservation (Fig.4.31), scientific investigation confirms what may already be noted by careful visual observation – that there are significant detachments of portions of plaster, from past maintenance work which aimed to renovate certain areas of wall-edges and smooth walls. A series of significant sites of vertical damage (lesions) were found, which were especially concentrated at the corners of the first level in correspondence to the concrete detachment from the pillars. At the bottom of the Tower, the significant presence of dampness was detected, which has contributed significantly to the degradation of concrete and reinforcements. The formation of structural macro-cracks was observed. Another critical situation was found, by thermographic survey, at the top of the monument, which is probably due to complete exposure to weathering agents. Both these critical areas (the first and last levels) have serious problems that can be detected both externally and internally. The decay processes have generated damages and cracks which are critical for the conservation of the monument.

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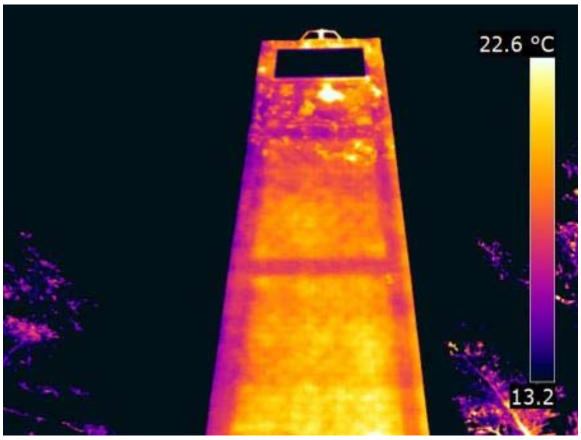

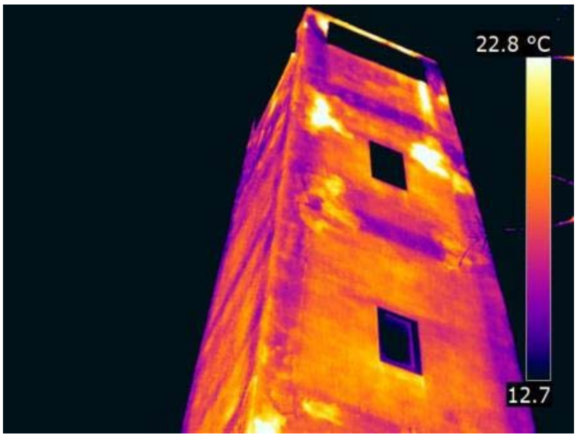

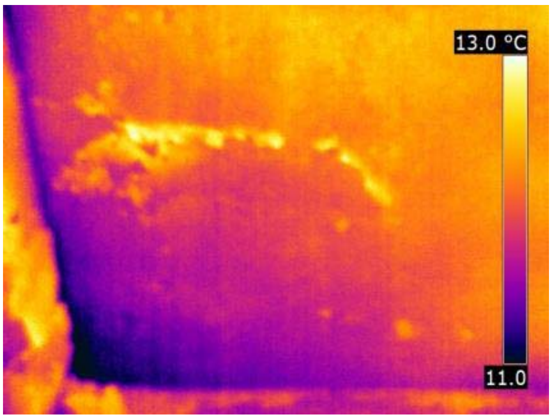

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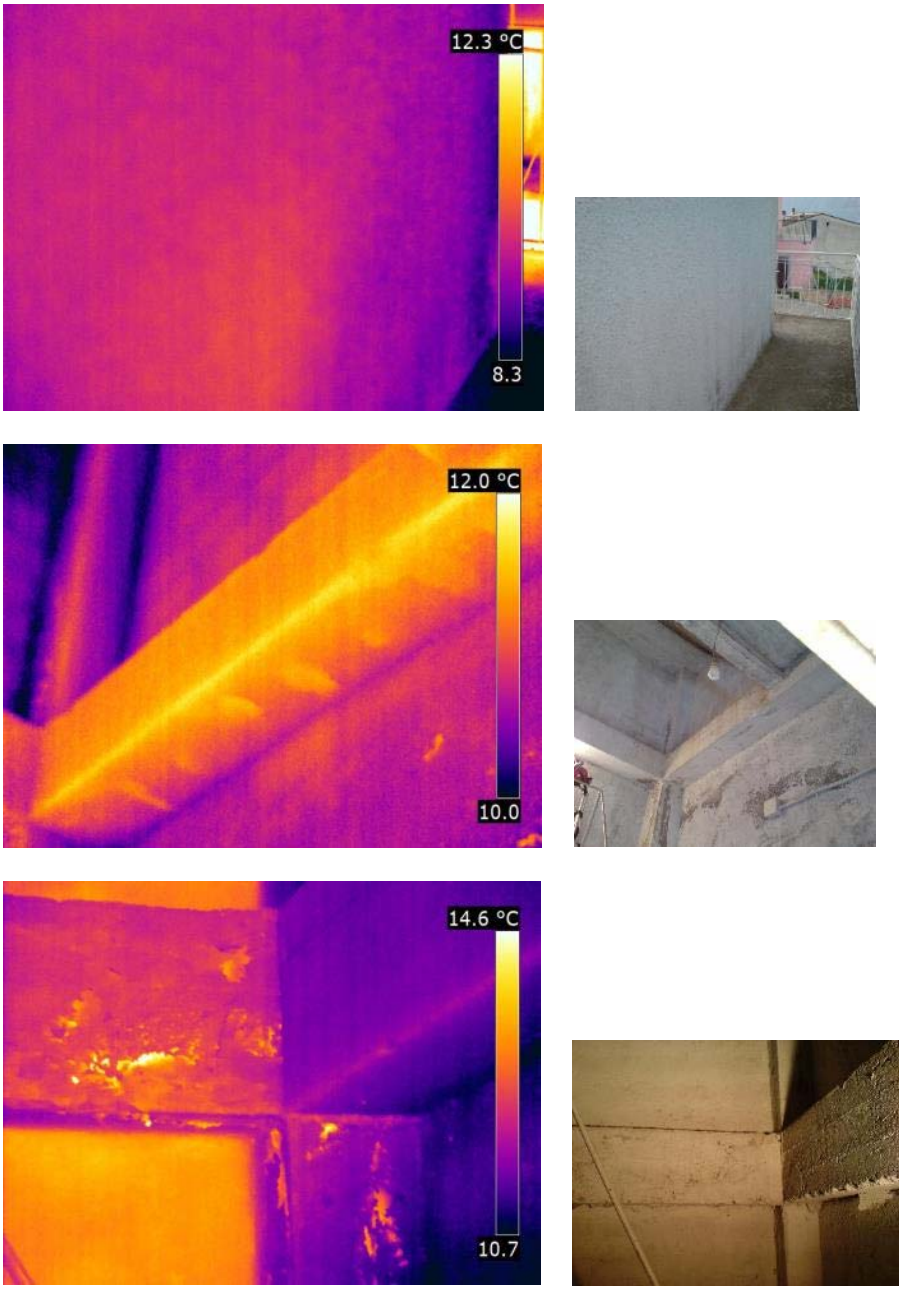

Figure 4.31. Thermographic analyses

THE ANGEL

The Angel War Memorial, made of reinforced concrete, as noted also by archive documentation, was damaged due to different adverse events, such as natural phenomena, bombing during the Second World War, maintenance not in line with modern methods of conservation carried out by local workers. A number of maintenance operations were carried out to repair detached pieces, through the application of films of different types, probably used to mask reconstructed parts and to protect

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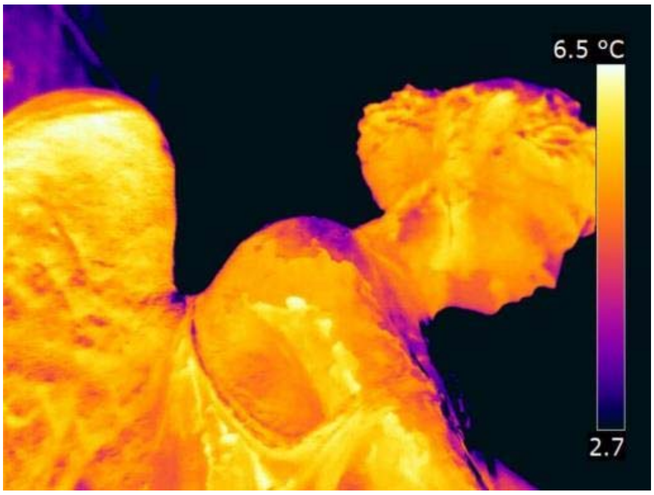
the surfaces originally made of a poor material (concrete). It was painted green, perhaps to imitate the patina of bronze statues or, perhaps, to remember military actions by recalling the colour of the army. Later, white paint was applied, probably after the restoration in the 1950s, and during the last intervention about 20 years ago, it was also covered with a thick layer of grey industrial paint.

The state of conservation is affected by several critical points which can be attributed to phenomena of peeling of the many paint layers and to detachments of material at variable depths. The ageing of unsuitable surface coatings with a different expansion compared to the underlying material has favoured macro-cracking and detachment, with consequent water infiltration into the concrete. Unfortunately, it has also prevented evaporation, with internal formation of high humidity levels that have favoured the accelerated degradation of concrete and reinforcements.

Thermographic surveys have revealed that the layers of paint have created a barrier to reaching the deepest layers, in some cases altering the reading of the results, but demonstrating the insulating action of the paint. Both the wings and the head of the eagle, at the base of the statue, show deep concrete detachments, probably due to the oxidation of the reinforcements and to the use of poor materials. The book had very deep lesions in the upper and lateral part with loss of material leaving the reinforcements uncovered. The damages are concentrated mainly in the areas which are most exposed to weathering, that have micro- and macro-lesions. The degradation of the cement material is evident in all parts of the memorial (Fig. 4.32).



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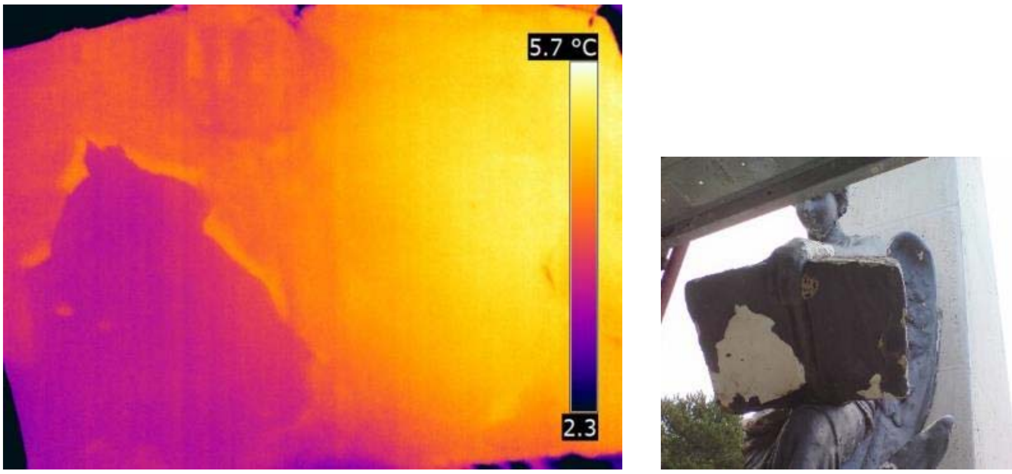

Figure 4.32. Some results of thermographic investigations

1.3.3 Mapping of the damages

In the pictures in figure 4.33, it is possible to observe the major critical points of conservation of the monuments.

The external surface of the Tower shows the presence of some alterations, whereas in the internal area it can be clearly observed the presence of detachments, salt efflorescence, humidity and cracks.

In the Angel, the surface painting is very degraded throughout all the statue, thus allowing the infiltration of water inside concrete. Signs of alterations are evident, such as biological patina, cracks, detachments and steel corrosion. The surface painting has probably a not positive effect of the state of conservation.

Turquoise: detachments

White: cracks

Green: rebuilt areas

Red: painting detachments

Blue: reinforcement corrosion

Yellow: humidity areas

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Figure 4.33. Maps of damages: a) external of Tower; b) internal of Tower; c) Angel

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1.4 Summary

The Tower and Angel War Memorial monuments have different characteristics, in terms of construction period, structural properties and exposure to weathering. The deterioration is mainly due to the presence of humidity, thermal gradients and to the use of materials with a poor quality, the only ones available.

The investigations revealed that the walls of the Tower are made of concrete bricks, locally produced during its realization. This construction technique was not common, but was observed several times in the Abruzzo region.

The characterization of the samples from the two War Memorials in Torricella Peligna showed the use of different typologies of cementitious mixture.

Regarding the Tower, there is a homogeneity from the compositional point of view: the binder is quite similar in all the collected samples as well as the binder-aggregate (B/A) ratio (1.3 approx.) and the aggregates composition. On the contrary, the Angel's results put in evidence high differences in terms of composition and texture. In fact, only one sample consists of a mortar made of cementitious mortar, the others are composed by mixed binder (cement and air lime). In addition, the grainsizes of clinker residues are more variable due to different levels of grinding and working processes. In the analysed samples, degradation forms were detected, such as soluble salts crystallizations inside the pores and shrinkage cracks.

Appropriate conservation interventions are necessary in order to preserve these monuments and to avoid that they will be completely lost. Between the two War Memorials, the Tower has been selected for the validation of the InnovaConcrete products and the results of the characterization will be used to prepare the mock up.

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