

THE “PALOMBARO” (“SASSI” OF MATERA, ITALY): THE INTERACTION BETWEEN WATER AND CONSTRUCTION MATERIALS

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ABSTRACT

The “Long Palombaro”, part of the network of underground structures and courtyards that was covered by the modern Piazza Vittorio Veneto above it, was once a fully functioning cistern up until the 19th Century. Previously there was an enormous cavity with water proof walls, limestone plastering and a series of dug-out and interconnected caves and tunnels, served by numerous, old, bell-shaped cisterns located underneath the piazza. This research is meant to identify the development phases and the building culture of the 16th Century cisterns and the strong relationship between this “water architecture” and the city. It is intended to make this great, carved architecture “usable” once again, even if other than its original use, preserving all its shape and material characteristics. The cistern represents an emblematic example of “negative” architecture, in which spaces are created by taking away material, contrary to “positive” architecture, where material is added. “Negative” architecture is created in successive phases of rock elimination and modelling, obliterating the material evidence of its building history. Here, remain the traces of carving on the vaulted ceiling intrados and on the rock walls, which, when not erased by finishing interventions, represent an important key in providing precious information about the carving techniques and the chronology of the relative building phases.

In addition, this research is also aimed to make a cement mortar with an increased chemical resistance, capable of being used in cases of existing structure degradation, exposed to different environments, even aggressive. Moreover, the physical-chemical properties will be determined in order to optimize adhesion of the new mortar, as well as the physical, chemical and mechanical properties of mortar already in use. Experiments will mainly be based on analyses and comparison of mortar samples taken from specific spots in the Long Palombaro cistern and inert natural additive based mortars (e.g. sand, pozzolan and limestone). The first research phase will identify the most suitable constituents to be used to make mortars with good adhesion and permeability (of water and vapour), which should develop hydrous phases in different seasonal conditions and, most of all, potentially suitable to replace the pre-existing mortars.

INTRODUCTION [1]

A system of hypogea, located at the edge of the Sassi [2] and part of which was used as cistern, was dug up in the 1990s during requalification works in Piazza Vittorio Veneto. This discovery represents a significant step forward in the knowledge of the city of Matera historical events, particularly in the settlement dynamics related to the geological and hydrogeological conditions and to the water resource availability.

All along and in many geo-historical contexts the search for water led the choice and the development of human settlements. In Matera the water exploitation has “carried” the human frequentations since the Neolithic era. At that time water availability was guaranteed by a natural tank situated in a bend of the stream Gravina, known in the historical toponymy as Jurio or Gorgo. The function of water as “fundamental” element of the urban shape of Matera was interrupted in 1926 when the Sele water was used, finally solving the chronic lack of water especially during the summer season.

From the water exploitation of the Jurio (Neolithic and maybe Palaeolithic eras) to the Sele waterworks, there has been a long and intense history of adaptation to the difficult hydrographical and hydrogeological context. In this history a leading role was played by the Palombaro monumental “negative” architecture, which evoke sceneries “in the style of Piranesi”: an aesthetic and sublime outcome of the laborious search for water and life in the bowels of Matera’s territory.

The University of Basilicata and the IBAM-CNR are carrying out a campaign of cognitive integrated surveys to develop some preservative interventions based on sustainable strategies, within a project carried out in Basilicata by the “Soprintendenza per i Beni Architettonici e del Paesaggio” (Regional Board of the Ministry of Cultural Heritage and Environmental Conservation), whose main aim is to preserve and increase the value of the hypogea.

WATER RESOURCES AND HYDRAULIC FACILITIES IN MATERA

Matera’s history, as many other cities, is due to the convergence of particular factors which have made possible the survival of a first human community. The territory of Matera had, and still has, a complex morphology, rich in valleys, ravines and tufaceous terraces, once covered with woods and rushing streams, it has therefore been an ideal place for the first spontaneous settlements. The organization of this city and in particular of the Sassi was led by the autochthonous population knowledge, by the laws of mechanics and fluids, by the sun and wind energy, by the soil and water economies. To meet living and inhabiting needs in that particular environment, men action transformed it through a stratification of interventions based on the space harmonious management. Through the centuries the Gravina [3] has been the subject of an intense terracing and excavation work which has caused first the transformation and enlargement of the existing natural cavities and then the conversion of the old Neolithic cisterns into dwellings. The great quantity of Neolithic bell-shaped cisterns demonstrates that a part of the Gravina originally was an agropastoral place. Only afterwards the increased need for houses brought to the reduction of the space for agriculture and to the conversion of a lot of cisterns, which were used to collect the sole domestic water, into dwellings. When, through the centuries, there was a further population increase and consequently the need for more houses “[..] *si realizzano cisterne dalle nuove architetture. Il connubio tra sistemi d’acqua e cavità, il processo di trasformazione di queste in abitazioni, l’evoluzione dei principi costruttivi e l’uso delle nuove tecniche per i dispositivi idraulici, attua nel tempo una continua commistione tra i tipi architettonici delle cisterne e quelli delle case. [..]*”. [4] As time passed by, the water search for an even more numerous population was not limited to the Gravina, but extended to the whole Murgia, in fact Verricelli states in his Chronicles, which date back to 1595, that in Matera’s countryside there were “[..] *funtane d’acqua ed puzzi surgenti abundevoli [..]*” [5].

The availability of spring water wells encouraged the spread of houses in rural areas and the agricultural exploitation. Matera probably reached its turning point thanks to the exploitation *ab immemorabili tempore* of the water tables coming from the Lapillo hill, at the Tramontano castle’s feet. [6] The water-bearing stratum coming from the castle hill was canalized to serve the “*plano della Fontana*” area, located at nowadays Ponticello widening, where a fountain was built. [7]

A first certain *terminus ante quem* for a hydraulic facilities history is 1548, when the University of Matera decided to restore the fountain which needed “*basie et stuppelli et mesure de pietra forte*”. [8] The lack of water at that time brought the town council to forecast new measures in order to increase the water supply. So, around 1564, Matera’s Mayor bought

a private cistern, used since then to water horses, “*pro ibi facendo quoddam Palombaro vecchio*”. [9]

Approximately a decade later other maintenance and repair works for the water facilities were carried out, among which a new Palombaro [10] was built, enlarging the cistern bought in 1564 by the University of Matera. This was made to optimize the Lapillo hill water exploitation. Thanks to the initiative of monsignor Sigismondo Saraceno, the archbishop of Matera, the small fountain with a cross, located on the Palombaro, was replaced by a more imposing one with a bigger cross also visible from the bell tower of the Santa Maria la Nuova Church. Since then the area surrounding the fountain was named “piazza della Croce”.

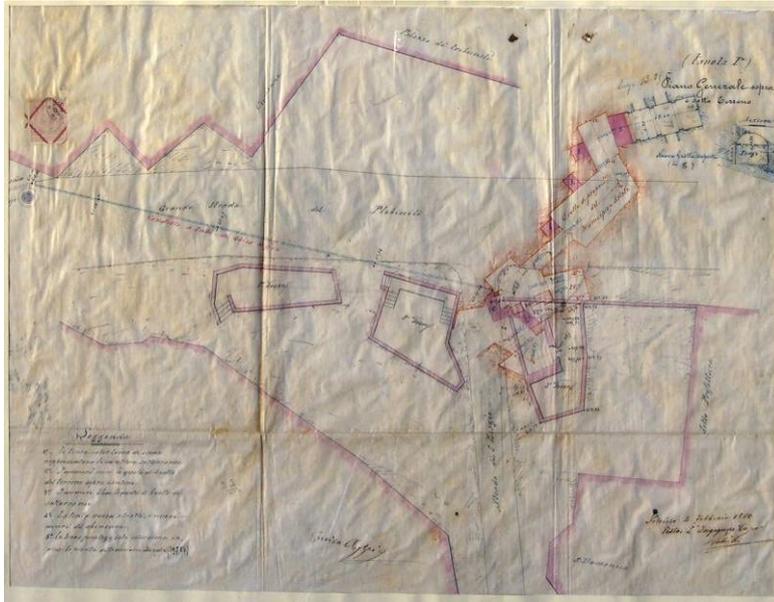
1595, when Verricelli wrote his Chronicles, is another historical stronghold. In fact the chronicler talks about both the public fountain and two big tanks, that he called “*conserve*”, located “*una avante l’arcivescovado e l’altra in altro luoco comodo*”. [11] The fountain underwent other maintenance works in 1591 and in 1748. The whole water supply channel restoration (from the spring to the fountain), blocked by the debris which limited and prevented the water flow, dates back to this epoch. But less than ten years later the fountain dried up once again because of the channel vaults collapse. The water system deteriorated in the following centuries.

In a 1825 report, the Province of Basilicata’s chief engineer described the worrying deterioration condition of the “*dirupo acquedotto angustissimo*” [12] and stated that any kind of further restoration would be vain. [13] Therefore two new waterworks were built and new tanks were dug. A first waterworks system was finalized in 1831 and inaugurated in 1832. It sprang from the Montigny [14] hill and arrived in “piazza della Croce”, adorned with a new monumental fountain, which displayed on the architrave an inscription celebrating its inauguration. [15] In 1844 monsignor Antonio di Macco ordered to build another waterworks system in order to convey the La Nera hill water and supply a drinkable water tank located in the Sasso Caveoso district. [16] Only at the end of the 19th century the town council of Matera decided to radically solve the problem of water deficiency doubling the capacity of Piazza Plebiscito’s Palombaro, where a new public fountain was built.

THE “LONG PALOMBARO”

On 15 September 1879 the town council of Matera decided that the third well located near the Prefecture (Figure 1) would become a drinkable water tank and the works were assigned to engineer Rosi, whose project report is dated 18 September 1879. This new tank had to collect and preserve the public fountain’s drinkable water (located in Piazza Plebiscito), exceeding from winter time, to be used in summer during dry periods. Therefore a cast-iron water pipe was built to connect the third well to the fountain, in order to assure 4.51 litres of daily water per person during summer (against the daily ration of 0.88 litres per person in August 1879).

Eng. Rossi’s research proved that the two cisterns already in use could fill a 85-thousand-barrel volume (60,000 the biggest Palombaro and 25,000 the smallest respectively) and that, once the two cisterns were filled up, the water wasted during winter nights could fill up another tank bigger than the existing ones. For this reason the project planned that the third tank would have a volume of 67,000 barrels and store 152,000 barrels of water, that is equivalent to 5,320.00 cubic metres.



Figures 1-2: Project design of the Long Palombaro (1880) and historical photo of the Ferdinanda fountain

The new tank ground level was lowered to 397.83 metres, the “neviera” level. [17] 16 lined up drawing-holes had to be built and were divided by a 2.50 metre stretch of old walls long, preserved because below there was “*il pilastro della Grotta che conviene conservare a tutela maggiore della stabilità del recipiente a quel modo scavato ed ampliato in Galleria*”. [18]

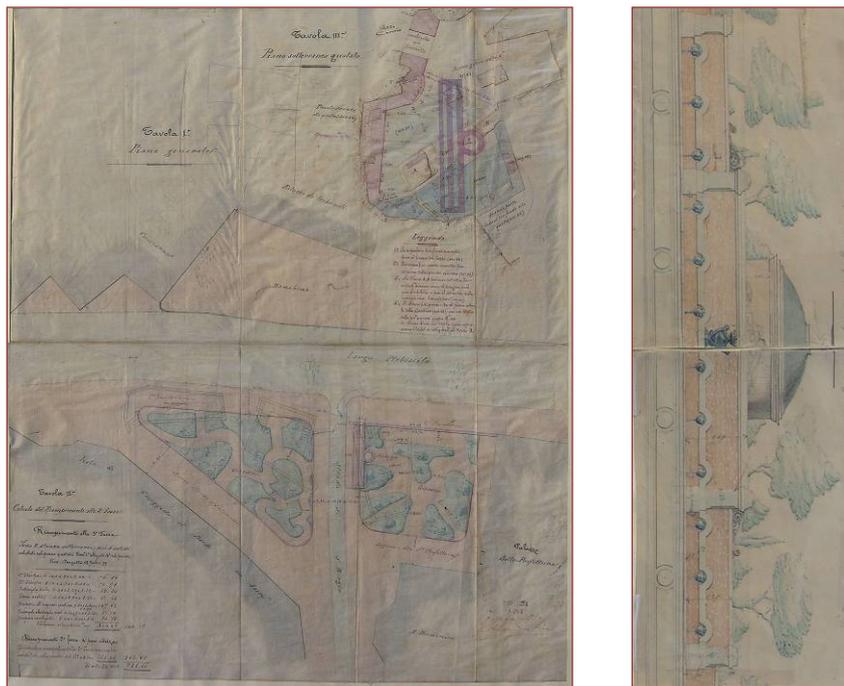


Figure 3: Project design of Piazza Plebiscito layout and of the new Long Palombaro water drawing-fountain (1880)

This third tank construction, however, would not solve the adequate water supplies problem, would certainly lightly increase the drinking water availability, with the advantage of supplying crystal and fresh water, even though “*attignimento malagevole e penoso per elevazione di 12 a 14 metri di profondità*”. [19] Moreover the estimated quantity of available drinkable water, 4.51 litres per person in summer time, would not have been adequate and represented a minimum quantity in respect to the 29 litres per person which, on the contrary,

were necessary to meet the agricultural and industrial needs too, as well as any unforeseen emergency (for example fire). For this reason in Eng. Rosi's report it is hoped that the local government would also solve another and more helpful problem, that is *"bene intesa conduzione di acque da allacciarsi né naturali Fonti che molto probabilmente debbono trovarsi nei bacini del principale colle sud-est tra i Cappuccini ed il Castello Baronale"*. [20]

Nowadays these tanks bear a unique and extraordinary evidence of an hydraulic architecture of great worth. Today the tanks are a remembrance of those times and a unique enchanting place. These researches have been carried out specifically to preserve and enhance this memory and of this "great engineering" piece of work. They are also aimed to study and preserve the materials and building techniques and to plan all the necessary interventions in the places, now available for visits and for the benefit of scholars and tourists.



Figures 4-5-6: Long Palombaro interior

PLASTER COMPOSITION: STRATIGRAPHY AND MINERAL-PETROGRAPHIC FEATURES [21]

Matera's Palombaro covering has a very good state of preservation both for the adherence to the stone support and the cohesion conditions. Only some areas of the vault, near the entrance, present a light detachment from the surface coating. Those areas present a clear plaster pulverization and there are some scales, with consequent lost of material.

This diagnostic research wants to verify the coating sequence on site; to describe the coating plaster from a mineral-petrographic and porosimetric point of view and to obtain information about the mortar compositional ratio; to identify the possible presence of salts responsible for the coating disintegration. To carry out the survey some coating samples, collected in different parts of the cistern, have been analysed in laboratory to get their mineral-petrographic, physical and chemical features.



Figures 7-8-9: Sampling collection in the Long Palombaro

The laboratory analysis proved that the Palombaro cistern coating is made of an hydraulic mortar of "cocciopesto" kind, characterized by two mortar layers put on in succession and a

third very thin brownish finishing layer. The lower layer, thick about 2 cm, is in direct contact with the rock calcarenite substratum; it is whitish and characterized by the presence of an aggregate with a very variable granulometry which goes from a coarse arenaceous to conglomeratic (from middle-thin to thin). Next to the entrance vault this layer is marked by the presence of a lot of *cocciopesto* coarse fragments. Above this layer there is another pinkish coating, thick about one centimetre, which has a tinier (from arenaceous to microconglomeratic granulometry) and more abundant aggregate than in the lower layer. This layer succession ends with a third level, less than one millimetre thick, which is more like a patina than a real mortar layer, with a brownish-yellowish colouring.

The two inner mortar layers have been made with a lime binder and with an aggregate which was mainly made of *cocciopesto*, whose granulometry goes from very thin silicious to conglomeratic. The thin silicious part, which is more abundant in the superficial layer, originated the pinkish colour. The *cocciopesto* fragments come from two different ceramic materials: one has a reddish colour, the other a brownish-yellowish-greenish one. The aggregate includes also a very small addition of quartz sand.

Both mortars contain a very small quantity of calcareous aggregate, probably derived from the calcareous rock tuff crushing in which the cistern was built. The two mortars present a very slight difference in the composition: the binder/aggregate ratio is 2.5:1 in the bottom layer and 2:1 in the upper. The analysis of the superficial mortar samples collected by the treading level named “spiaggetta” [22] has revealed features which are different from the superficial mortar collected in the other parts of the cistern. There is more quartz and brownish-yellowish fragments of *cocciopesto*. Those features could lead to a different phase of construction, as for example an enlargement of the cistern.

All the superficial coating samples present a continuous level of reprecipitation calcite, whose thickness goes from 20 to 200 microns in relationship to the different samplings. That neo-formation calcite level presents the same characteristics as a carbonate patina, present in hypogea.

The analyses have also revealed the presence of salts in localized areas, such as gypsum and ettringite. The salt, in the form of efflorescence, can be seen in the coating level when lit with the lamps which are inside the Palombaro. The presence of ettringite can be ascribed to recent interventions, because, as generally known, this compound comes from cement components; in fact the ettringite can be found only in the area of the cistern near the tower foundation, built by Count Tramontano, that is where Piazza Vittorio Veneto floor covering works took place. Also the presence of gypsum is localized; in particular it has been found in the vault covering near the entrance. The presence of gypsum and its disaggregating action can be at the origin of the mortar crushing with the consequent loss of material, which can be observed in this part of the cistern. It is important to point out that this degradation situation is very limited and that the rest of the Palombaro has a very good state of preservation both for the adherence between the layers and the stone support and for the cohesion conditions.

RESTORATION – MORTARS PLANNING FOR THE INTEGRATION INTERVENTIONS [23]

After having analysed the mineral-petrographic, physical, and chemical features of the historical “Long Palombaro” cistern mortars, new mortars suitable for the restoration interventions have been identified. The attention was focused on the identification of the most suitable constituents to be used to make mortars with good adhesion and permeability (of

water and vapour), which should develop hydrous phases in different seasonal conditions and, most of all, potentially suitable to replace the pre-existing mortars. The experimental analyses have been carried out both on prepacked mortars and on laboratory mortars prepared with different binders and aggregates. In particular the mortars chosen were those with physical, chemical and mechanical performances more similar to the old mortars made of finishing hydrated lime, pozzolan-lime or hydraulic lime, which were originally applied to the surfaces exposed to particularly humid conditions, such as water cisterns.

Before making the new mortars, some surveys have been carried out on the materials to be used: binders and aggregates. Special hydraulic binders with pozzolan reactivity have been used, which, after the mixing with water and the addition of aggregates, originate a mortar with fluid consistency, easily workable and so comparable to hydraulic lime mortars. Their use is particularly suitable to improve the adherence and chemical-physical resistance to soluble salt, trying to avoid the soluble salt transfer to the plaster. Those hydraulic binders present mechanical performances, tensile modulus and a porosity very similar to the old mortar, based on finishing hydrated lime, pozzolan-lime or hydraulic lime.

The experimental activity was basically linked to the use of 7 different types of binders (LEG1, LEG2, LEG3, LEG4, LEG5, LEG6 e LEG7). The binders LEG1, LEG2, LEG3 have been analysed with XRF, XRD and DTA-TGA; the binders LEG4, LEG5 e LEG6 have been analysed with XRD. The table below (Table 1) shows the chemical composition of the binders LEG1, LEG2, LEG3 in term of the main oxides.

Table 1 – Chemical composition of the binders used, % of their weight

	CaO	Al ₂ O ₃	SiO ₂	SO ₃	Fe ₂ O ₃	MgO	*p.a.f.
LEG1	47,81	5,70	22,58	1,11	1,00	3,64	15,71
LEG2	49,50	5,57	19,53	-	0,80	3,24	17,99
LEG3	32,06	7,49	41,79	2,70	2,50	1,82	8,50

*p.a.f. = perdita al fuoco (high temperature characteristic loss) at 950°C

To make the hydraulic limes, natural aggregates (natural sand, pozzolan, cocchiopesto and tuff) and polymeric charges have been used; the pozzolan, coming from the Vulture area, was preliminarily tested with the XRD and DTA-TGA analysis so that the main mineral phases could be qualitatively estimated, along with the amorphous reactive component.

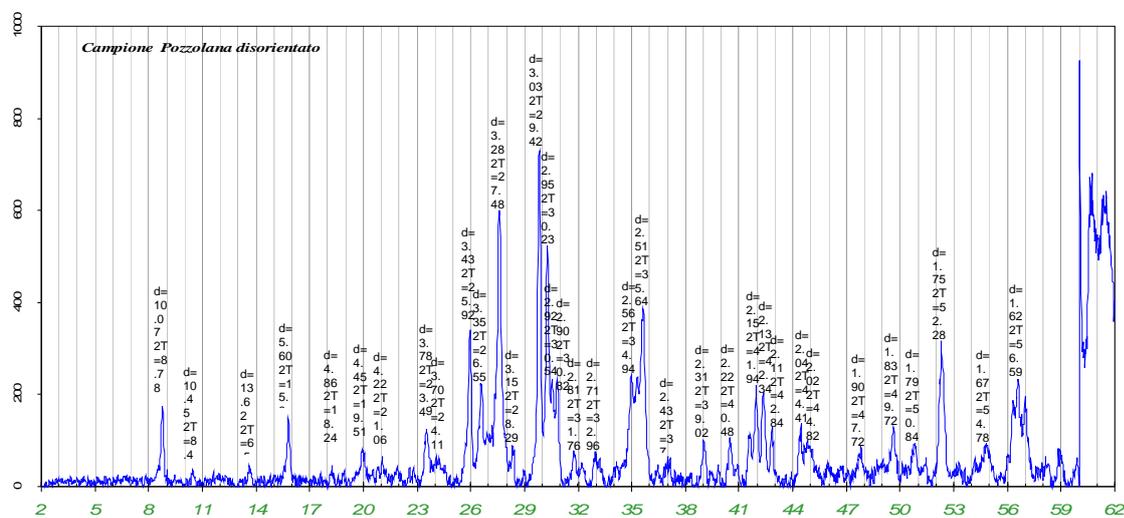


Figure 10: XRD analysis of the natural pozzolan

The diffractometric profile has given qualitative information about the mineralogic composition of the samples; it turns out to be mainly made by quartz, feldspar (most of all plagioclase), clinopyroxene (augite), calcite and portlandite.

The *cocciopesto* has undergone only DTA-TGA analysis (Table 3) so far.

The DTA-TGA analysis has given very important information about the presence of oxides in the *cocciopesto*; the thermogram test points out that there is a modest presence of calcium carbonate (endothermic peak at about 750°C) and a minor content of water, weakly bond to the aluminosilicate minerals present in clay.

The “tufina” (tuff dust), coming from a quarry situated in the Murgia of Matera, was preliminarily tested with the XRD and STA-TGA analyses to evaluate the calcium carbonate level. Both analyses point out that there is a strong presence of CaCo₃, whose grade is about 97%, according to the TGA analysis.

Then pozzolan and *cocciopesto* have been crunched and ground; to obtain a fair grain size of the two aggregates, a sifting action was also made.

The binders LEG1, LEG2, LEG3 have been hydrated by means of pulps (water/cement ratio, 0.50) and underwent XRD and DTA-TGA analyses, but also mercury porosimetric analysis. The pulps, shaped as cylindrical disks (15 mm high and 30 mm in diameter), have been aged in temperature baths (FALC WBMD24 model) at 20°C for 7, 14 and 28 days. At the end of each period of aging a part of the disks underwent a mercury porosimetric analysis or were crushed for the XRD and DTA-TGA analyses, after having been grinded with acetone (to stop the hydration reaction), treated with diethyl ether (to remove water) and conserved in a dryer with silica gel and soda lime (sheltered from H₂O and CO₂).

The XRD and DTA-TGA analyses made possible the evaluation of the reagent system conversion in contact with the desirable hydration products. In particular, the results obtained with the thermal analysis DTA-TGA permit a quantitative determination of the hydration products though the measurement of both the endothermic effect in DTA and the correspondent ponderal reduction recorded through TG. The analysis of the diffraction patterns and the DTA-TGA diagrams of all the binder mortars designed and hydrated at 7, 14 and 28 days have revealed the presence of calcium carbonate and calcium silicate hydrate products (C-S-H and portlandite).

The overall analysis of the porosimetric graphs shows that, due to the cumulative volume and the critical pore diameter threshold, there is a generally decreasing progress when the aging process goes on. In particular a bimodal progress is present in all the systems analysed after 7 aging days; at the intermediate aging (14 days) the derivation volume progress is bimodal only for the LE3 pulp and unimodal for the LEG1 and LEG2 pulps. All the binding pulps show an unimodal progress at the longest aging (28 days).

At the end of the investigation so far conducted, mortar samples have been made: they contain 450g of bonding agents [LEG3, LEG7 and a 50% mix of LEG3 and LEG7 (LEG37)], 1169g of pozzolan, or *cocciopesto* or mixture of pozzolan and *cocciopesto* in equal parts; the water quantity has been determined by the normalized consistence of the furnish (Table 3).

The mortars based on LEG3 and pozzolan or lime have been respectively named M3P, M3C; those based on LEG7 and pozzolan or lime, M7P and M7C; the remaining, based on LEG37, containing equal parts of pozzolan and *coccio*, has been named M37PC.

Table 2: Repairing mortars composed of LEG3 and/or LEG7 mixed with pozzolan and/or *cocciopesto*

	Bonding agent (gr)	Inert (gr)	Water pulp (gr)	Water/binder
M3P	450	1169	350	0,78
M3C	450	1169	450	1,00
M37PC	450	1169	475	1,05
M7P	450	1169	500	1,11
M7C	450	1169	600	1,33

The so composed mixtures, put in special moulds, have been aged in laboratory for 72 hours in a saturation closet (R.H.=100% and T= 20 + 1°C); after then they have been aged in a thermostatic environment (R.H.=70% and T= 20 + 2°C). Finally, to simulate an aging acceleration, a part of the mixtures in the form of cylindrical disks, have been aged both in thermostatic bath (FALC WBMD24 model) at 20°C and in a laboratory stove at 40°C. All this has been made to know how the mixtures act in the first phase of aging.

CONCLUSIONS

This research is still in progress, in fact, after aging at different periods, the mortars will undergo a series of chemical, physical and mechanical tests which will evaluate the potential behaviour during the installation. This first evaluation will be made in laboratory, but then there will be an application on site of the mortars made, in order to have an important confirmation of the laboratory results.

NOTES

1. The paragraphs: *Introduction* and *Conclusion* were edited by A. Guida and I. Mecca; *Water resources and hydraulic facilities in Matera* and *The Long Palombaro* were edited by A. Guida; *Plaster composition: stratigraphy and mineral-petrographic features* and *Restoration-mortars planning for the integration interventions* were edited by I. Mecca.
2. The Sassi (Barisano and Caveoso) are the two old districts of Matera, dug-out along the oriental edge of the stream Gravina, which goes across the territory of Matera. The Sassi are shaped around the rock morphology which is made of tender limestone, calcarenite or tuff.
3. The “Gravine” are deep and spectacular ravines, which have been carved in the millennia from the erosive action of the water streams in the calcareous soil.
4. “*cistens were built using new architectures. The union between water and cavity, the transformation process of these into dwellings, the constructive principles evolution and the new technique use for the water system, have carried out a continuous mixture of cistern and house architecture.*” Laureano P., *Giardini di Pietra. I sassi di Matera e la Civiltà Mediterranea*, Torino 1997, p. 84.
5. “*a lot of fountains and spring water wells*”.
6. Padula M., Motta C., *Piazza Vittorio Veneto*, Matera 1992, p. 57
7. See Padula S., *Il Plano della Fontana*, in “*Bollettino della Biblioteca Provinciale di Matera*”, n. 13, 1987, pp. 71-75.
8. This quotation has been taken from Padula-Motta, op. cit., p. 57 and is also present in a Fondo Gattini document (Archivio di Stato di Matera, Fondo Gattini, busta n. 6 (I), f. 6.)
9. Gattini G., *Note storiche sulla Città di Matera*, Napoli 1882. Ristampa Anastatica, p. 292.

10. The “Palombari” were very big and deep. They collected both rain and spring water. Their walls were covered with plasters, which became waterproof thanks to the *cocciopesto* technique. The water stored in the Palombari was usually used as a stock for dry periods.
11. “*one in front of the archbishopric and the other in another comfortable place*”.
12. “*very tight and steep waterworks*”.
13. Padula S., op. cit., p. 73.
14. This toponym is connected to Charles de Montigny character, a French general sent in Basilicata by the king of Naples G. Murat, who had chosen Matera as headquarters.
15. “*Ferdinando II rege fon set aquae ductus aere civium conlato / instauratus ampliatusque fuit A.D. MDCCCXXII curante / aequite Ferd. De Gemmis propraefecto ac dm.*”
16. Fonseca C.D., Demetrio R., Guadagno G., *Matera*, Bari-Roma. Laterza Ed., 1999, p. 80, 140 note 18.
17. A “neviera” was used to store snow. For details see figure 3.
18. “*the cave pillar which would better be preserved to safeguard the tank solidity, whose gallery had been dug and widened*”.
19. “*difficult and painful drawing as it would be raised from a depth of 12/14 meters*”.
20. “*well done water system to channel natural spring water, that most probably must be found in the main south-east hill located basin, between the Cappuccini and the Baronial Castle area*”. The report, dated 18 September 1879, was edited by the construction and hydraulics engineer Alessandro Rosi, after he was charged with the “*progetto di un serbatoio di acqua potabile da stabilirsi alla terza fossa presso il palazzo della sotto Prefettura in Matera con relativa conduttura in ghisa per le acque del Pubblico Fonte*” [project of a drinking water tank, to be located in the third well near the Prefecture of Matera, connected to the public fountain by a cast-iron water pipe]. The original report is kept by surveyor Enzo Viti.
21. All the laboratory analyses reported in this paragraph have been carried out by the Lecce IBAM-CNR (Institute of Archaeological Heritage, Monuments and Sites - National Research Council) – the responsible is PhD Angela Calia.
22. “small beach”, that is the name given to the final part of the Palombaro, whose stamping level is higher than the other parts of the cistern.
23. All the tests and researches reported in this paragraph have been carried out in the DIFA Material Chemical Laboratory (DIFA - Engineering and Environmental Physics Department), Engineering Faculty of the University of Basilicata, thanks to the contribution of Professor Milena Marroccoli and PhD Eng. Antonio Telesca.

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