Per. Mineral. (2002), *71*, SPECIAL ISSUE: *Archaeometry and Cultural Heritage*, **33-42** http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

Diagnosis, restoration and consolidation's quality control of columns and capitals in "Nostra Signora delle Grazie" sanctuary - Imperia (Italy)

DARIO ALMESBERGER[1]*, ANTONIO RIZZO[1], RAFFAELLA GEOMETRANTE[2] and MARCO RIZZO[1]

[1] SER.CO.TEC. S.r.l. – Piazza S. Giovanni 3 – Trieste – Italy
[2] Università degli Studi di Trieste - Dipartimento di Ingegneria dei Materiali e Chimica Applicata
Via Valerio, 2 – Trieste – Italy

ABSTRACT. — Before the beginning of the restoration work of «Nostra Signora delle Grazie» sanctuary, a complex conservation plan was started; this monument has preliminary been surveyed by an extensive diagnostic investigation which has pointed out structure's state of conservation.

When necessary, consolidation works have been carried out controlling, step by step, the quality of their performance.

The aim of this review, which proposes the project and the realisation of an innovative restoration work, is to offer to a wider public, new information about this type of intervention, about which data now available is still poor.

RIASSUNTO. — In previsione dei lavori di risanamento e restauro del santuario di «Nostra Signora delle Grazie», è stato avviato un articolato piano di conservazione; il monumento è stato sottoposto ad un'approfondita indagine diagnostica che ha portato alla determinazione dello stato di deterioramento della struttura. Ove necessario, sono stati eseguiti interventi di ripristino e consolidamento con l'accortezza di verificarne, passo a passo, la qualità dell'eseuzione.

Con questo elaborato, che propone la progettazione e la realizzazione di un complesso e innovativo cantiere di restauro, si vorrebbe offrire ad un pubblico sempre più vasto nuove indicazioni circa questo tipo di intervento, relativamente al quale, le informazioni ad oggi disponibili sono ancora scarse.

* Corresponding author, E-mail: cetocres@interware.it

KEY WORDS: *Non-destructive tests, ultrasounds, diagnosis, consolidation, resin injections*

INTRODUCTION

«Nostra Signora delle Grazie» sanctuary (Fig. 1) is located in an outstanding position of Imperia (Italy) surroundings, built up at the end of 11th century. This intact monumental area is so important that F. Roosevelt, president of USA, visited it in 1910 during his pilgrimage in Italy.

A limestone colonnade (Fig. 2) constitutes one of the most relevant part of this construction. On some of its columns and capitals, superficial and crossing cracks are present, probably due to thrust and peak loads or because of non-uniform distributions of stresses driven by overhanging elements.

For the correct conducting of the restoration works, preliminary studies of the material and historical data, which denotes and connotes both the cultural aspect and the state of preservation of the structural elements in question, are indispensable.

Initial studies include:

– determination of the work's formal structure (aesthetic analysis);

– analysis and evaluation of the changes the work has undergone (historical analysis);

– assessment of the state of preservation of materials and causes of possible deterioration (diagnostic analysis);

– application of techniques able to prevent or limit decay (maintenance phase);

– work to stop deterioration (restoration phase).[5]

Data collected from the aesthetic and historical analysis have pointed out the colonnade as critical part of the structure. After assessing an accurate anamnesis on it, the work has been concentrated on the following phases of the preliminary studies.

2. DIAGNOSTIC ANALYSIS

The assessment of structural elements' state of conservation and relative elastic characteristics is indispensable for any project of restoration of a hand-made artistic structure which has a bearing function and is subjected to static and/or dynamic loads.

Parameters such as ultrasonic propagation speed, wave attenuation, «in situ» mechanic strength and visual survey are fundamental to assess an extensive diagnosis of such a construction.

Traditional methods used for the determination of these parameters are generally destructive, as they need the application of static loads on samples extracted directly from the structure.

However, non-destructive methods can be successfully used to determine the state of conservation of the architectural elements, with regard of monument integrity.

2.1 Investigation methods and techniques

In order to draw up and define the restoration project for a building of historical and artistic interest, a preparatory phase is necessary. During this phase, data on the architectural structure itself and on its surroundings is collected to obtain a model for the interpretation of the decay action.

In line with the gradual and the non-destructive approach, the initial visual inspection should be followed by investigation using instruments able to provide extensive information on the structural-environmental system in both space and time.

This information should lead to other well-defined investigations to be carried out locally utilizing chemico-physical methods, both destructive and non, on particularly significant and representative areas.

The shape, size and geometric proportions of the structural elements and their interconnections must be studied together with the physico-mechanical properties of the materials and any sign of deterioration.

Visual survey

On most of the capitals, different defects' typologies have been observed: clayey veining's presence, structure's weak spot, crossing cracks (due to both thrust and peak loads), local cracks (causes by the oxidation of iron wedges located in capital-column joints).

Columns are constituted by compact limestone segments, most of which show superficial cracks and bedding. These damages are due to non-uniform distributions of stresses driven by overhanging elements.

On that column where the worst deterioration is present (identified by number 6 - Fig. 2), scaling and detachment plates are evident. Capital and stone footing of the same column are deeply damaged. In particular on the stone footing, scaling and delamination processes have developed because of the crystallisation of salts brought by capillary raise humidity or present in the stone composition. Generally, the formation of salt crystals takes place with volume increasing which generates inner stresses similarly to those caused by the transformation water to ice. This phenomenon depends on the number of evaporation and saturation cycles, on stone porosity and on the condition of water priming and superficial evaporation.

As these damages have always been relevant for this construction, in the past lots of footing

Fig. 1 – 'Nostra Signora delle Grazie' sanctuary

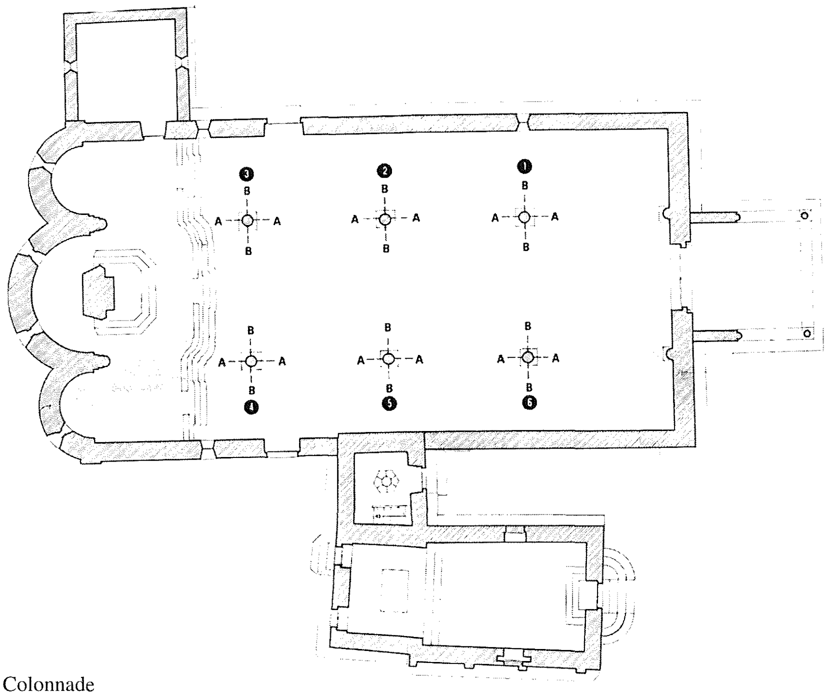

Fig. 2 – Colonnade

stones, voussoirs and capitals have been replaced, without a preliminary diagnosis carried out to determine the causes of the deterioration.

Determination of the relative humidity «in situ»

A series of micro-cores have been obtained in the critical points of the structural elements. The relative humidity (R.H.) has been measured inserting the thermo-hygrometer HANNA HI 8564 in the micro-cores. The humidity content has been indirectly determined from R.H. using a specific correlation graphic.

This investigation has been very helpful to assess the presence of capillary raise humidity, in the lower part of the columns, and of spreading and infiltration from the roof, in the upper part of them.

Magnetometric investigation

The magnetometric investigation exploits materials' magnetic properties and, in this work, it has been carried out in order to determine the presence of metallic elements (magnetizable) hidden in the columns. The localisation of these elements has been done by the induction magnetometer IMP METAL DETECTOR – PROTOVALE –Oxford.

Sclerometric investigation (UNI 7997)

This method consists in the determination of stone's superficial hardness derivable from a parameter depending on the bounce rate of the sclerometer beating bulk.

In general, for tests done on the most common structural elements (beams, pillars, etc.), a sclerometer original SCHMIDT type N has been used (2.207 Nm impact energy). The sclerometric index is a conventional parameter calculated with a specific procedure, which gives information on homogeneity and wearing resistance of the area under investigation.

Ultrasonic investigation

Ultrasonic pulse signals are produced by a transmitter in contact with the surface of the material under investigation and propagated through it; the delay with which a receiver, located at a certain distance from the transmitter, collects those signals determines the propagation speed of the ultrasonic pulse in the path between the two sensors (UNI 9524/89).

This velocity depends on the elastic characteristics of the material under investigation and can rapidly vary in presence of non-homogeneity (cracks, damaged areas, defects, etc.). This kind of survey can be used not only as a comparison method but also for the determination of the dynamic elastic modulus.

The ultrasonic pulse recorded by the receiver probe, is transformed in an electrical signal suitably amplified, visualised on the oscilloscope screen and printed.

In this specific work, ultrasonic investigations have been carried out on the colonnade so to assess its state of conservation and to determine residual strength, present in limestone voussoirs and capitals, stone's mono-axial compression strength and dynamic elastic modulus. Furthermore, during the maintenance and restoration phases, this technique has been also used to check both resin injections and replacement stones.

The ultrasound probes used are piezoelectric transducers VERNITRON of 55kHz.

2.2 Results

Most of the structural elements surveyed were strongly deteriorated with important signs of degradation. Different level of damages have been studied and their development have been traced back to peak load and to seismic event. In fact, when the jointing mortar used as a connection between the different part of the colonnade is insufficient or when columns' surface is not suitable finished, concentrated loads are present on column's bearing bonds. These loads, here called «peak loads», create stone's defects from which crack patterns develop. In case of seismic events, this mechanism is amplified and the resulting cracks are visibly more substantial.

Ultrasonic investigation results, with particular interest for the qualitative analysis of the signal received and the attenuation of the wave along its path, have been elaborated so to achieve important conclusions, essential for the following quality control.

Column 1

The high ultrasonic speed generally recorded on the different parts of this column, pointed out the good compactness of the limestone. However, there are few directions, which should be taken under control, along which ultrasonic wave's attenuation has been very high because of stone's veining and an inner crack.

The current inclination of the column, which is 2 cm out of its vertical line, has been contributing to the cracks formation.

On the capital, crossing cracks, surely formed during the past seismic events, were evident. For these reasons, column and capital's consolidation has been necessary. This procedure has been implemented by using epoxy resin injections, suitable for the restoration of the material continuity.

Column 2

In the upper part of this column, micro cracks and a flaking have been created by peak loads due to the absence of jointing mortar between voussoirs; so a consolidation intervention with epoxy resin injection has been indispensable.

Currently, the capital is reinforced by a metallic wrapping.

Column 3

On this column, a diagonal superficial fissure, inner micro cracks and crossing cracks were present. Epoxy resin injections have been used for its consolidation.

Column 4

Most of the voussoirs of this column have been damaged by cracks probably due to peak and thrust loads. The capital was slivered, too.

Column 5

Plates near the detachment and micro cracks were present along this column. The micro cracks on the column's segment located just under the capital were due to peak loads and seismic stressing. The capital was in good conditions.

Column 6

The non-destructive survey carried out on this column has pointed out its severe decay and deterioration (Fig. 3 and 4).

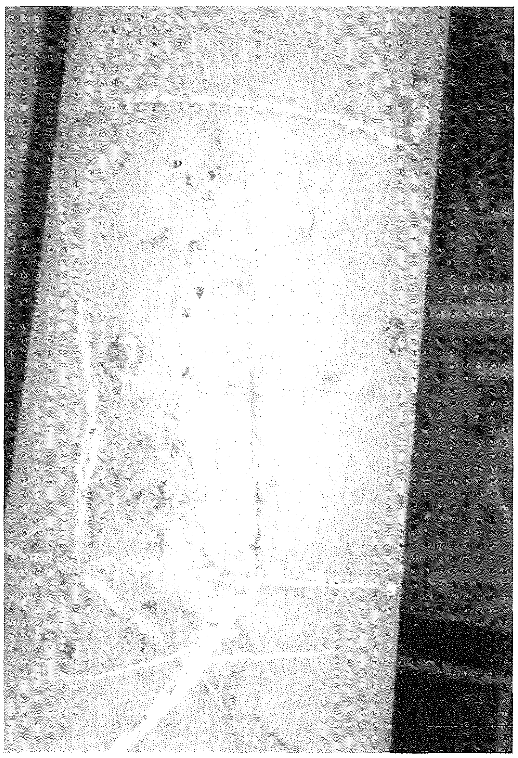

Fig. 3 – Particular of column 6

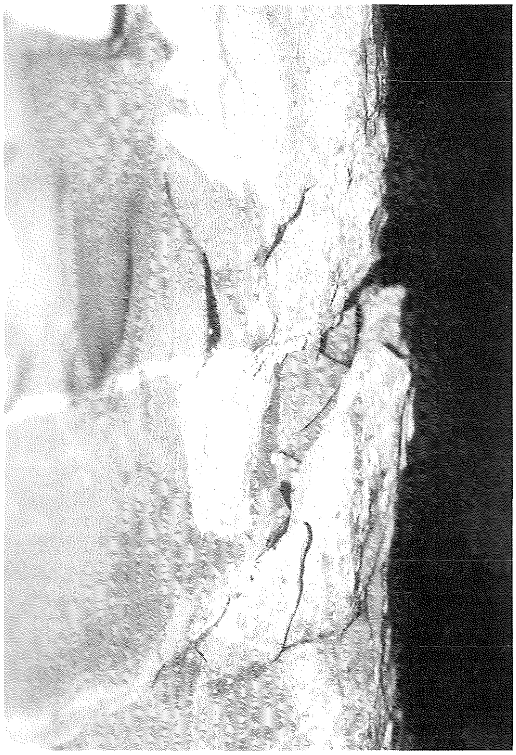

Fig. 4 – Particular of column 6

Important flanking and delamination were evident on the footing stone, surely due to the capillary rise which transports sulphates from the soil. Sulphate, in addition to moisture, may develop ettringite and thaumasite, two very well-known compounds in Portland cement chemistry. However, they can also form in the materials of historical buildings constructed before Portland cement was discovered. Both the formation of ettringite and that of thaumasite appear macroscopically through swelling of the original material that can scale or be reduced even to pulp when thaumasite is produced[7]. Volume's increase develops extremely dangerous stresses inside the material causing, in some cases, its destruction.

Possible solutions were the complete substitution of the footing stone or a delicate work of «prosthesis» with an epoxy mortar and filler of the same stone.

The two lower segments of the column have been substituted because of the severe damages (plate detachment and stone flaking) caused by past earthquakes and scarce jointing mortar.

The capital was in very bad conditions with crossing cracks such to require a special intervention (Fig. 5).

3. Maintenance and restoration phases

The diagnosis of colonnade's state of conservation has assessed that most of its structural elements were so damages to need a consolidation intervention.

In some structural elements the restoration project has focused on the re-establishment of the static functionality endangered by cracks and detachments, while in others the material cohesion has been improved to impede time deterioration.

Cracks have been restored with pure epoxy resin injections.

During all this phase, each choice have been done in accordance with NORMAL Recommendation N° 20/85 which is binding for the artistic and monumental restoration sector.

3.1 Cracks joint sealing by traditional injections

The traditional injection at moderate pressure (1-3 atm) is applied for damages larger than 500mm. The number of injectors per linear meter is at least 3. They can be thickened in case of finer cracks. Before injection, the fissures are sealed in the outer part with epoxy plaster or similar material.

For this restoration work, the PIT COLOR 902 epoxy resin with a suitable low viscosity has to be used. After finishing the work, the injectors have been removed and the surplus sealing material has been eliminated by a flat trowel.

Fig. 5 – Capital of column 6

TABLE 1
Main characteristics of the epoxy resin

PIT COLOR 902 EPOXY RESIN	
Compression strength [N/mm^2]	85 - 95
Tensile strength [N/mm^2]	60 - 65
Elastic modulus [N/mm^2]	3100 - 3300
Linear thermal expansion coefficient [cm/cm °C]	74x10-6 with T between 20 and 50 °C

3.2 Reconstruction of missing parts by prosthesis

The prosthesis have been realised either by gluing detached original or precast parts or by using epoxy mortar with stone filler (to maintain a colour similar to the original one).

In the case of the capital sixth column (Fig. 5), element particularly damaged, the application of stainless steel pins with improved adhesion ('REVAL 31' Δ 10mm bars) has been necessary (Fig. 6). In the middle of detached parts, a 12 mm hole has been obtained; the bar has been inserted inside it.

Each pin, shaped both to assure good adherence and to allow a possible removal without excessive damage, is fixed by the epoxy resin PIT COLOR 902, in this case used as a structural adhesive. Moreover, this resin exerts a protective function on the metal, avoiding the contact with water which could move through stone porosity.

Recent researches carried out on materials behaviour in the long run, have assess that the epoxy resin's resistance to UV radiation and to heating is not excellent. In this case, as the resin has been used as injection product, the final performance will be good; at the moment, epoxy resin is the best adhesive that can be used in the restoration of extremely damaged structural elements.

Fig. 6 – Consolidation of capital of column 6

3. QUALITY CONTROL

Only after completing all the steps of the colonnade's restoration project (historical research, preliminary surveys, diagnosis etc.), it is possible to design the actual restoration plan on a large working scale. At this point, the problem of monitoring the restoration work has to be introduced and should be viewed, in the light of a broader range of problems, as a «Quality Control».

In fact, while one can decide immediately whether the work has been done correctly from an aesthetic point of view, adequate verification and technical investigations are needed to tests its efficacy.

More in details, ultrasonic surveys have been carried out to assure the complete filling of cracks; from the comparison of the oscillograph obtained before and after the restoration intervention, important information can be obtained about both improvements provided and cavities possibly still present.

In Fig. 7 and 8, two of the numerous oscillographs recorded on column 6 in deteriorated and restored conditions are reported. In Tab. 2, part of the ultrasonic data measured on the same column is presented. In both cases an evident improvement is evident.

4. CONCLUSIONS

One of the essential aims of this complex project has been to assess the need of a consolidation work and its efficacy in relation to particular parts of the colonnade involved.

The lack of reliable information on the interaction, the limits of previous restoration works made this systematic approach essential.

Non-destructive diagnostic surveys have enabled to detect and plot the areas in a state of advance decay which constitute the so-called risk area and also have helped to better understand conditions internally.

TABLE 2

Ultrasonic survey results before and after consolidation

COLUMN 6 - CAPITAL				
position	**probes distance [mm]**	**u.s. velocity before [m/s]**	**sclerometer**	**u.s. velocity after [m/s]**
1	548	1030	50	4680
2	548	2760	50	4600
3	600	over	50	3860
4	600	over	50	3300

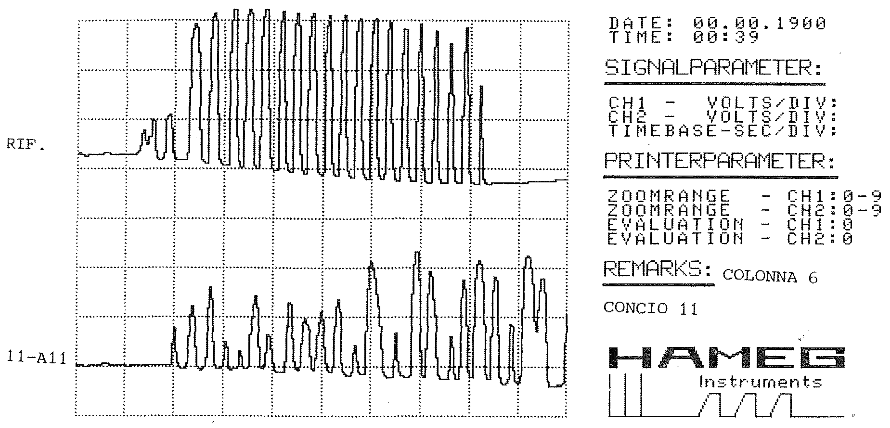

Fig. 7 – Example of oscillograph before consolidation

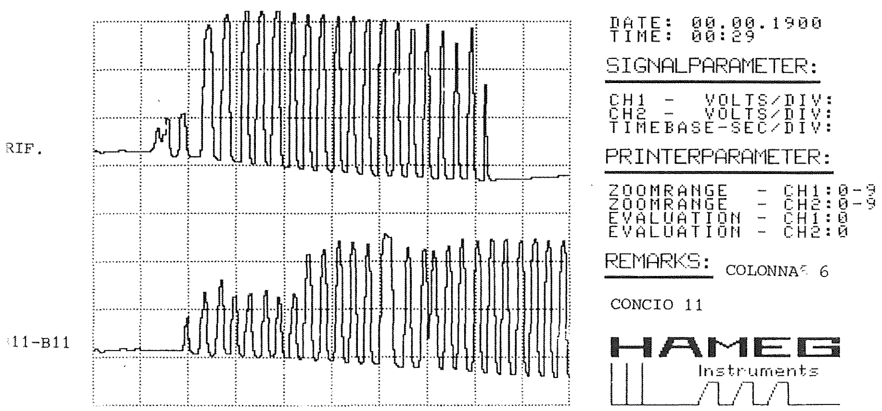

Fig. 8 – Example of oscillograph after consolidation

The results have demonstrated quite clearly that correct assessment prior to the consolidation phase, and an accurate checking after that, can be obtained through relatively simple diagnostic procedures as long as they are systematically repeated and compared.

The conservation plan here proposed has pointed out the effectiveness of multidisciplinary and multi professional investigations; in particular, the original application of non-destructive techniques, not only in the diagnostic but also in the restoration work area, has been determinant. In fact, only the contemporaneous utilisation of different kind of methodologies has allowed a real time monitoring of the restoration intervention assuring the good quality and the complete success of the entire operation.

This paper has been written as a suggestion of organizational patterns and methodologies for the study and the conservation of these important evidences of human art. Its task is to inform experts operating in the fields, of our latest, innovating experiences and of the technologies and methodologies used in our conservation work. This mean subjecting investigation's results and techniques to verification being willing to change radically direction as soon as this should prove necessary.

REFERENCES

ALMESBERGER D., GEOMETRANTE R., RIZZO A. and URAN P. (2000) — *Characterisation of the state of compression of pietra d'Istria elements by non destructive ultrasonic technique.* In : «15th World Conference on Non-Destructive Testing». Proceedings on CD-ROM.

ALMESBERGER D., GEOMETRANTE R., RIZZO A. and URAN P. (2000) — *Ultrasonic testing method for the characterisation of Pietra d'Istria structural elements.* In : «9th International Congress on deterioration and conservation of stone», Proceedings. Vol. 2, pp. 317-325.

BOURBIE T., COUSSY O., ZINSZNER B. (1987) — *Acoustic of porous media.* Editions Technip.

KRAUTKRAMER J. and KRAUTKRAMER H. (1983) — *Ultrasonic testing of materials.* In: «Il progetto diagnostico – The diagnostic project». Pouchain edizioni. 1990.

ALMESBERGER D. and TONCIC M. (1999) — *Diagnosi delle colonne e dei capitelli del santuario di N. S. delle Grazie (IM) con strumentazione ultrasonica.* Technical report.

COLLEPARDI M. (1990) — *Degradation and restoration of masonry walls of historical buildings.* Materials and Structures, **23**, 81-102.