THE CONSOLIDATION AND RESTORATION PROJECT
OF ACHEIROP EIOTOS BASILICA IN THESSALONIKI

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ABSTRACT

This paper examines the composite problem of the Acheiropoietos basilica’s static system, presents the innovative interventions which have been applied for the consolidation of the early Christian structure, analyzes and discusses the main principals and the methodology that have been followed during the decennial consolidation and restoration project of the monument.

INTRODUCTION

Panayia Acheiropoietos [1] is a typical example of the early Christian three-aisled timber-roofed basilica with narthex and galleries (Figure 1-2). The building is 51.90 m long, 30.80m wide and 14m high at the side external walls, and 22m on the top of the roof of the central aisle. Originally it was larger since today the gallery over the narthex, the elevated section of the central aisle, which acted as a light-well, the possibly open outer narthex on the west, and the two-floor gallery that was annexed on the north side of the basilica, are not preserved.

![Figure 1: Acheiropoietos. SE view](image)

It concerns an architectural type with small masonry masses and large openings that seems to have de facto weakness on the N-S axis, since the longitudinal colonnades and the side external walls do not co-operate for the reception of the seismic loads. As it has turned out from the study of the monument’s masonries, the monument had structural problems from the very beginning, since several times the intense seismic activity of the region shifted horizontally the columns, the longitudinal arcades and the upper parts of the external walls and caused their partial dilapidation. Structural –between phases- joints found in the building witness the areas of the edifice that are sensitive to seismic activity: These are centered on the external corners of the superstructure, the arcades of the galleries, the upper part of the main aisle’s west wall and the semicircular apse of
the sanctuary. Overall the destructions were faced diachronically with damage rehabilitation interventions that are characterized by the materials and the know how of the historical periods during which they were applied [2]. They were based on the principal of the maintenance of the remaining part and the restoration of the collapsed parts of the edifice, in such a way that the new construction fell short of the sensitivities of the previous phase that sub-served the destruction.

Figure 2: Acheiropoietos. Ground plan

The last rehabilitation of the monument in the beginning of the 20th century did not manage to raise the weakness of the basilica in the N-S axis, as during the 1978 earthquake the flexible untrimmed wooden floors and the timber roofs of the galleries held but did not prevent the columns from conducting autonomously. That was registered as divergence of the longitudinal walls and colonnades from the vertical axis, caused mainly by their marginal shifting. The basilica, after the 1978 earthquake, that aggravated the pre-existing static sensitivity of the structure, presented multiple masonry disorganizations, caused by intense compressive or tensile strain.

Figure 3: Masonry cracks
Both wide or through masonry-cracks and trichoid fissures (Figures 3-4) were observed almost on all the arches and windowsills of the northern mainly wall, on the semi-dome of the sanctuary apse, as well as on the superstructure of the perimetric walls, due to the thrust of the timber trusses of the central aisle’s roof.

There were also found sectional masonry disorganizations and detachments of the external masonries on their junction corners, with a particular problem on the NE and SW corner. The monuments main problem however remained the declination of the southern colonnade and the northern external masonry from the vertical axis.

THE CONSOLIDATION PROJECT

*Experimental analysis and application of the damage-rehabilitation and consolidation interventions*

The documentation of the monument, that followed the 1978 earthquake, evidenced the diachronic static weakness of the edifice under seismic strength, testified the composite problem of the static capacity of the monument and pointed to a Consolidation Study which was drawn up by the Laboratory of Reinforced Concrete of the Aristotle University of Thessaloniki [3], in collaboration with the 9th Ephoreia of Byzantine Antiquities and the Directorate for the Restoration of Byzantine and Post-byzantine Monuments of the Ministry of Culture.

The main aim of the Consolidation Study was to strengthen the structural characteristics of the monument that conduced to its maintenance throughout the centuries. From the subsequent analysis of the present state of the monument, as far as its behavior under seismic activity is concerned, among other conclusions came up that the non- partial or overall - dilapidation of the basilica during the 1978 earthquake was due to the diaphragmatic function of the timber floors and roofs of the galleries. Because of that, the seismic stress was transferred on the west wall of the narthex and on the east wall of the main aisle, both of which functioned as rigidity walls. Because of the aforementioned inference, the conversion of the timber floors and roofs of the galleries into diaphragms with controlled shear strength and rigidity was considered an important parameter for the rehabilitation of the static adequacy of the monument, since this intervention could enforce the continuity of the external perimetric walls with the internal longitudinal arcades and reduce their flexibility, without changing the static type of the edifice. Before the construction of the timbered diaphragms with controlled shear strength and rigidity, it was considered necessary to rehabilitate the continuity of the masonries with mortar joint-fillings and local masonry-crack rebuilding, as well as to reinforce the unification of the external perimetric walls in the corners of the edifice and the conjunctions of the internal longitudinal arcades with the external traverse walls with metal anchor rivets.
The Consolidation and Restoration Project [4] of the monument started in the 1990s with local interventions, the main aim of which was the damage rehabilitation of the masonry continuity. The project went on with drastic but reversible general interventions (Figure 5) for the restitution of the edifice’s static adequacy, and was completed in 2008 with public service establishments, such as a new heating system with portable electric thermal devices of infrared radiation.

![Figure 5: Acheiropoietos. Cross section. Consolidation study series](image)

Local damage rehabilitation interventions, as joint fillings and masonry crack rebuilding were made with mortar, whose synthesis was based on laboratory analysis of the original mortars of the various phases of the building as well as on long-lasting in situ investigations in order to access how far the worksite conditions would affect their mechanical characteristics. Arches and windowsills were rebuilt locally in such a way as to ensure that the interventions would be distinguishable both architecturally and aesthetically from the original masonry.

The analysis of the authentic structural mortars of all the building phases, which are generally characterized as lime mortars with coarse aggregates (inert materials), lead to the definition of three consolidation mortars, compatible to the preexisting according to their structure and morphology. The - even limited - use of cement on the damage rehabilitation mortars was essential in order to achieve strength equal to those of the authentic mortars of the Early Christian or Byzantine structure which, according to the results of the conducted control is 2.7N/mm². The degree of influence of the worksite conditions on the mechanical characteristics of the mortars during the consolidation work was the object of a research program that lasted for more than three years and comprised of two parts: The laboratory controls of trial mortars and the on the spot controls of the damage-rehabilitation mortars in the mortar joints of the monument’s masonries. From the results after the completion of the research it is concluded that the stamina and the elasticity of the damage rehabilitation mortars, responded generally to the mechanical characteristics of the monument’s authentic mortars [5].

The local damage rehabilitation was followed by the grouting of the masonry core [6]. The type of grout used in Acheiropoietos and the method of its application in the masonry, was determined after laboratory investigations of both the geometry and the natural, chemical and mechanical
characteristics of the structure. The aim of the masonry grouting was not to simply fill the interior gaps of the masonry but also to reduce the porosity of the mortar. For this reason it was decided that the grouts would be composed by inorganic traditional materials, compatible to the building materials of the authentic masonry, that they would not contain sand, while the rest of the inert materials would be fine in order for the grout to be of high fluidity and thinness, since 65% of the pores of the authentic mortars is smaller than 1mm. For the same reason for the preparation of the grouts, which were applied through pipes-nozzles inserted in the masonry every 0.50m, with flow time 18:20”, a grout mixing machine of high vorticity was used with rotation speed 1500-2000 turns/minute and built in manometer.

When all the masonries of the monument were successfully grouted, metal junctures were inserted in the corners of the building, as well as in the vertical conjunction of the internal longitudinal arcades with the external traverse walls (Figure 5), using prestressed anchor rivets made by Titanium (Commercially Pure - Grade Four 150/75 – DIN 37065). It is a metal that presents no damage caused by any oxidant factors and is the top material globally in terms of stamina and corrosion. The prestressed titanium anchor rivets were constructed in order to strain the external walls together and pin the widthwise external walls to the longitudinal arcades of the galleries. The number and the length of the anchors rivets were based equally on technical criteria and on structural characteristics. After a series of alterations on the application method and the final assignment of the anchor rivets, 112 anchor rivets were applied, which were shared on the four corners and the four conjunctions of the external walls and the arcades. The prestressed anchor rivets were finally placed alternately at a distance of 0.30m from the external surfaces of the walls. The anchor rivets of each row are placed with a distance of 2m among them in a way that the alternately placed to have vertical distance 1m among them.

For the 55mm diameter - drillings in which the anchor rivets are inserted and enwalled electric drilling machines with diamond heads were used (Figure 6). In order to prevent the creation of micro cracks by the vibrations, the drilling was made with no percussion but with rotation and with continuous water provision through the drilling head, in order to avoid small scale cracks. The main difficulty faced during the course of the drilling works was the absolute alignment of the drilling machine with the masonry so as to avoid the danger of its diversion from the route it had to follow inside the masonry core.

After each one of the masonry core-drillings was completed, the 25mm diameter - titanium bar was inserted after it had been carefully formed (Figure 7). The formation included the incision of its surface and the application of a washer, 1.5m before the junctures’ inner end, which attached two small pipes on the titanium bar. From the lower pipe, grout of extremely high fluidity was pushed to the inmost 1.5m of the total length of the drilling. From the upper pipe that started right before the washer, air was coming out; this way the grout was filling the core drilling successfully without air enclosures in the anchor area, which otherwise may have resulted in the construction
of defective anchoring of lower strength. After the passing of enough time the anchor rivet was prestressed. Then the rest of the drilling was filled with concrete grout for the protection of the titanium. The force applied with the prestressing was transferred on the masonry through titanium plates 20x20x2cm of the same quality as those of the anchor rivet which were in touch with the masonry through a leveling layer of high strength non-shrinking mortar. The anchoring plate was placed 8-10cm deeper than the surface of the masonry. Then the area was rebuilt.

Figure 7: Prestressed, titanium anchor rivet. Section (as constructed)

After the construction of the prestressed anchor rivets at the monument’s corners, the top of the east wall of the main nave was braced using six stainless steel tie beams Ø 25 -three on the exterior and three on the interior-, the ends of which were anchored in stainless steel plates. Each one of them, of an overall length of approximately 16m, consists of three bars ending to screws with external threads, connected with two stainless steel turnbuckles with RH/LH internal threads.

The general interventions focused on the conversion of the timber floors and roofs of the galleries into diaphragms with controlled shear strength and rigidity (Figures 8-12). According to the initial Consolidation Study it was anticipated that the diaphragms of the timber floors and roofs of the galleries would be constructed by alternate rows of planks, hydraulic nine-plywood panels and planks, 2.50 + 2.10 + 2.50cm thick, connected with each other with hydraulic glue and woodscrews and with the bearing joists of the floor or the semi trusses of the roof with steel shearing joints.

Figure 8: Diaphragm with controlled shear strength and rigidity. Timber floor of the northern gallery. Plan (as constructed)
Figure 9: Diaphragm with controlled shear strength and rigidity as the floor of the northern gallery. Section (as constructed)

The application mode of the diaphragms of controlled shear strength and rigidity was tested in the worksite according to the specifications of the Consolidation Study. However, during the construction of the trials, difficulties in the application and misses in the allocated wooden layers of the timberwork were noted, especially during their conjunction with the steel shearing joints. After cooperating with the Laboratory of Reinforced Concrete and counting in the trials applied in the worksite, the Consolidation Study was altered. According this alteration the diaphragmatic function of the timberwork is gained by two successive –instead of one- layers of compressed, impregnated, hydraulic nine-plywood panels, each 2.10cm thick.

Figure 10: Diaphragm with controlled shear strength and rigidity. Timber roof of the southern gallery. Plan (as constructed)

These diaphragms, after a series of constructional amendments consist of:
(a) The joists of the floor placed every 0.45m approximately or the semi-trusses of the timber roof placed every 2.70m approximately in axial distance. The condition of those was checked and the pathology was dealt according to each case: either one or both their enwalled edges were enforced with stainless-steel blades, or they were totally replaced.
(b) A perimetric metal frame, made of properly electric-winded pieces of galvanized steel rectangular hollow section beams. Aiming the enforcement of the diaphragmatic function of the timber structure, the rectangular hollow section frame was attached on the perimetric masonries with stainless steel anchor rivets Ø 16.
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Figure 11: Constructing the diaphragm with controlled shear strength and rigidity on the timber roof of the southern gallery

(c) Two successive layers of humidity resistant, compressed, impregnated nine-plywood (betoform) panels, 2.1cm thick each. On the timber floors of the galleries those nine-plywood panels, measuring 1.5 x 3m, were placed with the longitudinal seams continuous and vertical to the timber-beams, as with the traverse seams alternately. On the timber roofs of the galleries they were placed with the longitudinal seams continuous and parallel to the timber semi-trusses and the traverse seams alternately. On the second layer the seams between two panels of compressed nine-plywood were placed in the middle of the underlying panel. The two layers of compressed nine-plywood were connected with woodscrews, in lateral and horizontal rows, 10cm distant of each other, whereas among them hydraulic glue was spread for the reinforcement of the allocated layers.

(d) The timberwork was connected with the bearing joists with numerous steel shearing joints (Figures 11-12).

Results of the consolidation project

From the beginning of the consolidation project, it was attended that the interventions would be controlled by a parallel program that would examine their effectiveness as well as the possible distress of the structure by their application.

Based on the analysis of data that were gathered during the application of the masonry grouting, it was calculated that the average absorption of grout on the north masonry of the monument, comes
approximately to the 20% of the overall mass of its mortar. According to the Consolidation Study the percentage of the vacuous pores of the masonry was estimated up to the 30% of the mass of its mortar, whereas the rest of the mass is analyzed in to 50% stone and 20% brick. Consequently the prime aim of the masonry grouting was approached.

In samples of cord drilling, extracted from the masonry, the ideal grip of the grouting on the stone and the brick was obvious, whereas sonograms on part of the monument’s masonry, before and after the grouting of the structure, showed that locally the increase of strength of the masonry came up to 70%.

During the drilling for the application of the titanium anchor rivets, but also after their insertion and final pre-stressing, as well as after the deligation of the east wall’s superstructure, no new masonry-cracks were faced.

Regarding the construction of the diaphragms with controlled shear strength and rigidity that aimed at the static co-operation of the perimetric walls with the arcades of the monument, topographic measurements that were taken after the completion of the consolidation did not show new micro-shifts of the structure, proving that the masonries’ and colonnades’ declination from the vertical had become inactive.

However, during a construction countercheck of the diaphragm of shear strength and rigidity constructed on timber floor of the southern gallery a year after the completion of the works, a looseness of the successive layers of compressed nine-plywood was observed. This was a problem caused probably by the contractions and expansions of the timber joists that were replaced by new timber beams, not adequately dry during their placement. Only a year after the construction of the timberwork it was necessary to tie again all the woodscrews and the steel shearing joints, in order for the new timber structure to come to its expedient condition.

**THE RESTORATION PROJECT**

As was expected, the consolidation project arose various problems of restoration and final presentation of both the external and the internal views of the monument. As far as the restoration is concerned [7], the general principal was that of minimal intervention, just enough to preserve the monument’s historical qualities and as far as possible to enhance its aesthetic merit. In order to integrate all the interventions harmoniously into the simple forms of the early Christian structure and the spiritual atmosphere of its interior, the materials used during the restoration were compatible to the authentic ones, but also distinguishable enough so as not to obscure the architectural and historical phases.

Restoration took place only locally, where there were clear indications of anterior phases, whereas generally no previous forms were restored. During the restoration of the Basilica’s interior, it was considered necessary, for scientific reasons, some of the masonries to remain un-plastered so as to be possible to trace the course of the successive deformations of the building, whereas simultaneously, to understand the monument’s original proportions as well as its structural history, as for the first time, unknown up to now structural – between phases - joints of the Early Christian basilica and architectural forms deriving from the building’s byzantine reparatory interventions were revealed. However, on the un-plastered masonries the toneless color uniformity gained by the residues of the removed plaster was preserved. On the masonries that were newly plastered, the traces of the most important phases remained evident by retaining the depth of the phase dividing joint on the new plaster (Figure 13).

For the promotion of the inner space of the early Christian Basilica, an attempt was made to
amplify the up till now limited natural lighting in its interior by replacing the glass panes of the monument’s windows with new ones of special structure and coloring (Figure 13). The new glass panes do not allow the flowed in of light in the basilica’s interior in the form of light beams, but they refract the limited natural light in a way that reduces the harsh shading and equally rises the monument’s various internal aspects.

![Figure 13: Interior view of the basilica after the restoration project](image)

At the same time facilities were installed for the service of the congregation and the monument’s visitors. For the heating of Acheiropoietos, a new heating system was chosen that included the installation of portable electric thermal devices of infrared ray, since they allow the heating of the congregation area without causing the continuous change of the micro-climate of the monument’s interior space. These systems influence the temperature only at the areas they cover in such a way so as to avoid any temperature or humidity modification at the sensitive painted or mosaic surfaces that intentionally remain outside the area covered by the thermal radiation. At the same time the infrared ray systems cause minimum dispersion and re-circulation of pollutants caused by other sources such as candles or people.

**CONCLUSION**

The consolidation of the Early Christian basilica of Acheiropoeitos is one of the greatest consolidation projects that took place at a national level during the last decades with interventions of great difficulty that were for the first time applied on a large scale monument. The modern, nevertheless, technology was moderately used and always in combination with traditional methods.

The interventions, adequately justified by the pathology that the monument presented after the 1978 earthquake, were extensively in an experimental-laboratorial as well as in a worksite level and were applied with methods and techniques as mild as possible towards the building.

All the restorative interventions were based on clear data and not to hypothetical theories. Generally do not restore older forms but maintain and clarify accentuate historical phases, with an effort of loosing as little authentic material as possible and leaving open the possibility that future restorers will have a different approach.
The interventions were not faced as definite consolidation of the building, which should probably be the object of future reference and study. On the contrary the consolidation-restoration project that took place in the end of the 20th century is – as all the anterior rehabilitation historical phases of the structure – another phase of repair that aims to extend the monuments life and helps the edifice to continue its course through time, carrying the messages of the generation that worked with it.

Throughout the consolidation works there was continuous co-operation with the researchers, something that proved to be an important factor that facilitated the project. The various structural data that arose during the interventions and which were not known in advance, led many times in redefining the interventions; mainly during the application of the titanium anchor rivets and the construction of the diaphragms with controlled shear strength and rigidity.

In conclusion, during the consolidation and restoration of Acheiropoietos, based on the continuous analysis of the building and the observation of analogous historical constructions and with main tool a flexible, in terms of its application, Consolidation Study, an effort was taken up by all the inter-scientific contributors of the project for a historical and dialectical consideration of the building’s problems in order to bridge the distance between the conclusions of a static analysis and the reality called monument.

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The local rehabilitation interventions begun under the direction of the fmr Ephor of Antiquities E.Kourkoutidou-Nikolaidou, the main Consolidation interventions were applied during the period 1997-2007 under the direction of the fmr Ephor of Antiquites Ch. Bakirtzis, and the public service establishments were installed during 2008 under the direction of E. Marki.

During the interventions there was a close co-operation of the 9th Ephoreia of Byzantine Antiquities with the Laboratory of Reinforced Concrete of the Aristotle University of Thessaloniki, and especially with prof. G. Penelis for the modification and application of the consolidation mechanical interventions and profs M. Karaveziroglou-Weber and I. Papagianni for the composition and the control of the application of the mortars and the grouts correspondingly.

The degree of influence of the worksite conditions on the mechanical characteristics of the mortars during the consolidation work was the object of research undertaken by the supervising engineers of the 9th Ephoreia of Byzantine Antiquities in the worksite of Acheiropoito and the Laboratory of Reinforced Concrete of the Aristotle University with supervisor the prof. M. Karaveziroglou-Weber.

The new heating system was installed according to a Study that was worked out by the Laboratory of Heat Transfer and Environmental Engineering of the Department of Mechanical Engineering of the Aristotle University of Thessaloniki with scientific supervisor the prof. A. M. Papadopoulos.
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