



Structural interventions on the drums of the Parthenon’s north colonnade

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ABSTRACT. The Acropolis monuments are globally recognized as a cultural heritage and a value belonging not only to Greece but also to Humanity. From 2000 the most recent phase of restoration in their history began by the “Acropolis Restoration Service” (YSMA), introducing new, pioneering methods, recognized now worldwide. Especially the restoration of the Parthenon’s North Colonnade is an enormous work-plan to be carried out (extended area of intervention, great number of members to be restored and high degree of damages). Moreover, the structural stability of the Parthenon’s north colonnade is among the most important challenges confronted by experts working in this sector. The complexity of this effort (a combination of scientific research and direct field application) makes the implementation of the restoration project difficult, rendering its division into smaller projects (for similar structural members) a necessity. In this direction, characteristic examples of the procedure followed for the structural intervention on the drums are presented in this paper. Each member’s report includes a short history of its restoration, the intervention steps, pictures/sketches and the methodology chosen for its structural study, focusing on the particularities of the member and the in-field realization [1].

KEYWORDS. Classical Monuments; Drums; Fracture; Restoration; Titanium reinforcement, Parthenon, Acropolis of Athens



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INTRODUCTION

The determination of the reinforcement required to join together multi-fragmented structural members is a prerequisite for properly restoring the member’s structural stability and also for preventing further damages. For the structural restoration of the monuments of the Acropolis of Athens a pioneer method has been developed, already from the early seventies. According to this method fragments of authentic marble or/and supplements of new marble are joined together using titanium bars and suitable cement mortar [2].

The final target is to reach the capacity which corresponds to the maximum load expected to be exerted on the particular member after the completion of the project (taking into account all possible future interventions). This approach is preferred



because usually the reinforcing titanium bars required for reaching the initial carrying capacity can not be fitted due to the shape of the sections of the members, the relatively small size of the remaining authentic parts of the member or the great loss of authentic material [3].

The material used for the erection of the monuments of the Athenian Acropolis was Pentelic marble, well known as the building material of the classical period's masterpieces. The needs of the restoration project in progress (for the construction of "patches" and a few new members) are covered nowadays using Dionysos marble (quarried from mountain Dionysos in Attica), which has similar properties to the authentic one.

In general, the data reported in literature concerning Dionysos marble vary between very broad limits. This scattering can be attributed to the different conditions under which the tests are performed but mainly to the anisotropy of Dionysos marble. There are three different anisotropy directions (parallel to the layers, along the width of the web and along its thickness). After a long series of direct tension and uniaxial compression tests, it was concluded that the mechanical properties along the two of the anisotropy directions are very similar to each other [4-6]. Thus, this marble can be considered as a transversely isotropic material described with the aid of five elastic constants: two elastic moduli, in the plane of transverse isotropy and normal to it, two Poisson's ratios characterizing the lateral strain response in the plane of transverse isotropy to a tensile stress acting parallel and normal to it, and the shear modulus in the planes normal to the plane of isotropy. From these tests it was also concluded that the material appears to be slightly bimodular, i.e. its elastic moduli in tension and in compression are not equal. The combination of these mechanical characteristics with the special internal structure and composition of the material (mainly calcite with very small amounts of muscovite, sericite, quartz, chlorite and areas with imperfections) is responsible for the complicated form of the cracks observed. The shape and extent of the damages are also affected by the particular role of the drums as structural members [7].

In general, the damage of the monument is due to either natural phenomena or human interventions. Among the natural phenomena one could mention aging (and, as already pointed out, the special nature and the imperfections of the material), decay due to physico-chemical/biological actions, freezing, seismic action etc. Catastrophic human interventions include fire, bombing, explosion, vandalism, the problems caused by previous restoration (in the eve of the 20th century) by engineer N. Balanos (thoughtless use of iron elements, which after oxidization expand becoming the origin of a destructive process for the marble surrounding iron elements) and finally the effects of pollution [8, 9].

The first serious damage in Parthenon was caused by the great earthquake of 426 B.C.. The most serious destruction came at 267 A.D., by a German tribe, the Erouli, who burned the place down. During the siege of the Acropolis by the Morosini's Venetians (1687 A.D.) an explosion blew up three of the four walls of the cella, six columns on the south, eight ones on the north (the area of interest in the present paper) and the remains of Pronaos collapsed except one column [9].

Parthenon Temple is a structural system with special characteristics. The form and the stability of the structure are attained by the perfect contact between the members (absence of connecting material) which leads to the development of friction and the use of horizontal (clamps) and vertical (dowels) metallic connectors that resist tensile and shear forces. Thus a complex construction is formed, the dynamic response of which is governed by the sliding and the rocking of the individual stones, either independently or in groups [10].

The process followed to restore the structural integrity of each drum (in order to make it behaving again as an intact member) is based on the principle of avoiding overturning of the fragment (that is to be joined) from the member (in case friction forces are not sufficient) [11, 12]. The method is improved by taking also into account the critical stress state on its surface. It has the advantage of flexibility and therefore it can be applied in many different cases. The reinforcement required is calculated based on the fragment's volume which sustains the load, its position relative to the drum and its height. Therefore the stress field developed can be estimated taking into account the overturning lever arm and the load applied [3].

Dynamic actions, in this case earthquake and explosion, can lead to drums' raising and loss of their proper position, while the rocking effect produces impact phenomena among adjacent members. This impact damages particularly the edges of the contact area between them, which is linear and consists schematically an arc [13, 14]. As a result fragments are produced, which usually form wedges and the presence of converging strata make it easier for fracture to start [7]. To cope with these problems a special procedure was developed, in collaboration with late Pr. I. Vardoulakis, of the Department of Mechanics (National Technical University of Athens) to determine the stress state and therefore the reinforcement required [1, 15].

The restored drums are usually classified with respect to the corresponding column (4th to 11th) with codes representing their original position. Each drum is denoted by two numbers: The first one indicates the column on which they belong (the columns counting starts from East to West; therefore the eight columns of the North's Colonnade Restoration program have codes 4 to 11) and the second number indicates their exact position on the specific column (the drums counting starts from the lowest one, i.e. the one standing on the stylobate). For example the drum with the code "5.8" belongs to the 5th column and stands on the 8th row.

APPLICATION IN THE FIELD

It's very difficult to categorize the Parthenon's North Colonnade's drums failures because they were caused mainly due to their fall after the Morosini's explosion and as a result in many cases the traces of former fractures were covered. The variety of fragments and remains (many of them were carved during N. Balanos' restoration project) offers the challenge to confront unusual structural problems [15]. It is mentioned characteristically that even in a single member, it is possible to deal with one or more of the following cases:

- Join of fragments or supplements which form wedges on the upper or the lower area of the ancient remain.
- Repair a fracture which penetrates all over the height or the width of the drum and at the same time join supplements, which extend all over the height or the width of the drum.
- Join small fragments to the remaining volume of the drum as well as to repair huge cracks by replacing the existing "Π" and double "T" iron connectors (a sort of clamps) which were placed during the previous restoration by N. Balanos. The proper new ones are made of titanium.
- Create supplements, which include ancient remains.
- Implant ancient fragments in new volumes of marble.
- Join of almost horizontal ancient fragments standing the one above the other.
- Join supplements to the ancient remain core forming the upper or the lower area of the drum.
- Join fragments all-around to a new marble's core.
- Join ancient volumes to a supplement which surrounds all over their height, while at the same time due to the lack of parts of their upper and lower side of the drum, new supplements were also used in these areas.

Due to the irregular shape of the fragments a number of problems often arise during the intervention, which makes it extremely difficult to join the new supplements with ancient sections of the member and to determine a certain direction of the reinforcement bars. In these cases the theoretical approach has to be in situ redesigned.

Attention is paid to avoid crossing of the reinforcement bars coming from different directions, to maintain the proper distance between them, as well as between reinforcement bars and the drum's external surface or the various irregularities /discontinuities in its mass. It is also very important to maintain the proper anchorage length of the reinforcement bars in order for extrusion (or pull-out) to be avoided.



Figure 1: Joining together the ancient fragments A, B, Γ, with the new insert Π to keep them in the right position within the member's volume using cement mortar (left). The joining of this group and the main block of a new marble with "montage" reinforcement bars is presented in the right photo. In the foreground view the opposite fractured surface and the points, where reinforcing bars will be inserted during the next step of intervention, are presented. (Author's note: All pictures in this paper are from the archive of YSMA).

After the intervention, a continuous monitoring and control of the member's response must follow since the work that has been done must provide flexibility to permit future interventions if necessary.

The tactic, complexity and difficulty of the steps' sequence for the intervention of the drums are presented here with a few characteristic examples.

the unified complex of A+B to the supplement Γ (Fig.5 on the right). During these steps the join of these parts was accomplished by inserting titanium bars parallel to the member's upper side from the fractured - contact areas. This reinforcement is the proper one to avoid overturning of the supplements as well as of the ancient remains, before the overturning of the drum as a whole.

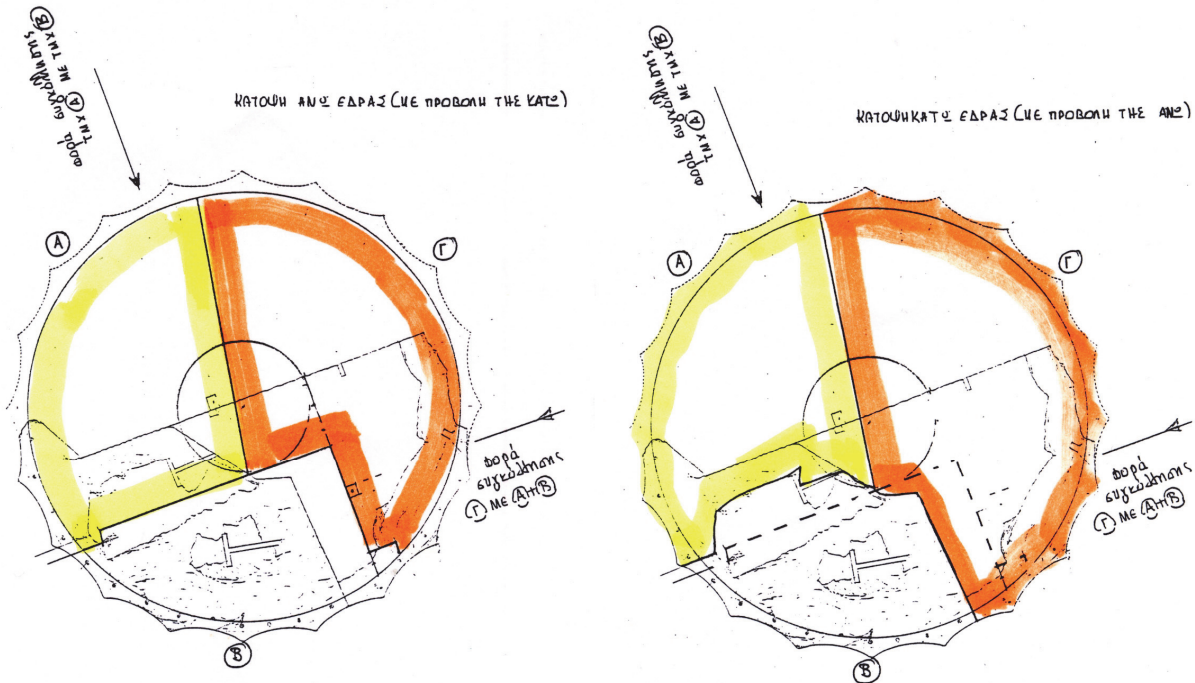


Figure 4: Sketch of the upper (left sketch) and lower (right sketch) side's plan of the drum where the place of the two supplements (A highlighted by yellow and Γ by orange color) and the direction of the required reinforcement are depicted. On the right sketch the dotted lines correspond to the upper side of the ancient part.

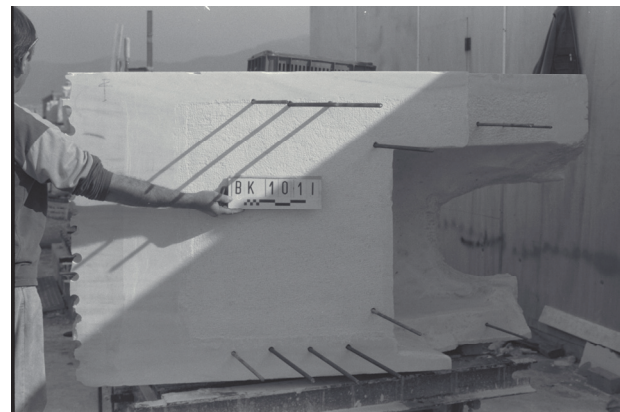


Figure 5: Joining the supplement A to the ancient volume (on the left). The supplement Γ with the proper reinforcement on it, is ready to be joined to the rest of the drum (on the right).

Drum 6.3

The ancient member almost maintains its shape, although two parts are missing: one, which forms a gap of wedge's shape in the upper side of the drum and an adjacent one, which extends all over the drum's height. In addition a crack runs across its lower side, which produces, as it was found out, an inclined fracture level (Fig.6a). The supplement used to fill the first mass loss is joined to the main volume by titanium bars which resist shear forces (one horizontal bar - Fig.6b and the remaining ones in different directions after the fitting of the two volumes using suitable cement mortar, from the upper side of the supplement - Fig.7a) to avoid sliding. The supplement used to fill the second gap is joined to the main

volume with horizontal internal titanium bars (Fig.7b). This reinforcement is the proper one to avoid overturning of the supplement. Finally titanium bars are also inserted from the bottom of the drum, vertical to the existent plane of fracture to repair the crack (Fig.8). This reinforcement was determined by zeroing the internal moments from the equilibrium of the fragment which probably will be created by the fracture's completion.

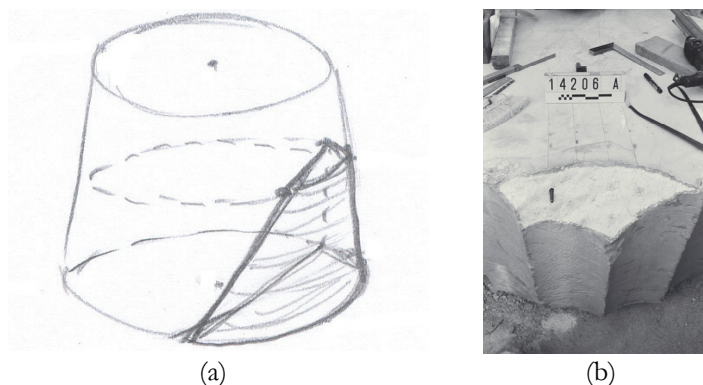


Figure 6: (a) Sketch of the inclined fracture plane produced by the crack which runs across the lower side of the drum (Drawing: M. Mentzini, YSMA Archive). (b) As a first step, the supplement used to fill the first mass loss is joined to the main volume by one horizontal titanium bar.



Figure 7: (a) Titanium bars are inserted from the upper side of the supplement used to fill the first mass loss after its fitting with the main volume of the drum. The second fracture is discernible on the left. (b) The supplement used to fill the second mass loss is joined to the main volume with horizontal internal titanium bars.



Figure 8: Titanium bars are inserted to repair the crack. In this picture the drum is upside down.

Drum 7.8

The ancient member was broken in two main fragments (probably due to the Morosini's explosion) which were joined together through iron clamps during the previous restoration of N. Balanos. Nowadays, the two pieces are joined together



using horizontal titanium internal bars as reinforcement and suitable cement mortar to avoid their overturning (Fig.9a). In addition the double “T” iron connectors were replaced by new titanium ones which contributes to the strength required (Fig.9b). Furthermore three supplements of new marble are created to complete the drum’s shape. Two supplements fill the gaps in the upper side of the drum and they are joined to the ancient volume only through montage reinforcement because of their balance state due to their shape (Figs.10a,b), while the third supplement was used between the two main fragments, forming a wedge. The reinforcement required for the latter one to resist shear stresses to be developed, was inserted from the drum’s lower side, after its fitting with the rest drum’s volume using cement mortar (Fig.11). In this way (easier to adjust the pieces) the holes are invisible after the drum will be placed on the column.



Figure 9: (a) The two main fragments of the drum are joined together using titanium bars. (b) Replacing the double “T” iron connectors by new titanium ones on the upper side of the drum.



Figure 10: (a) Titanium bars were inserted from the upper side of the first supplement after its fitting with the rest volume of the drum. (b) Titanium bars were inserted from the upper side of the second supplement after its fitting with the rest volume of the drum.

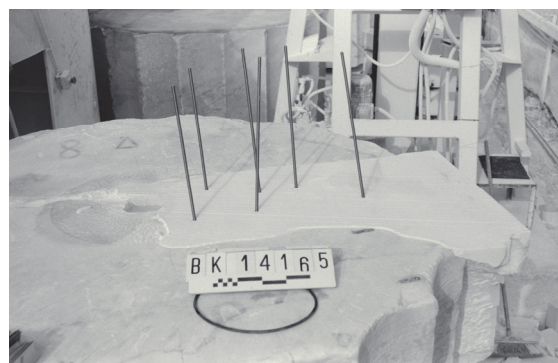


Figure 11: Titanium bars were inserted from the lower side of the third supplement after its fitting with the rest volume of the drum.

Drum 8.8

The ancient member is characterized by two losses of material sited in opposite areas all over its height. To restore the drum's volume two supplements of new marble are created. Their join to the ancient remain core was accomplished by inserting titanium bars which were parallel to the member's upper side from the fractured area (Figs.12a,b). This reinforcement is the proper one to avoid overturning of the supplements, before the overturning of the drum as a whole.



Figure 12: (a) Joining the first supplement. (b) Joining the second supplement. On the left the first –raw- supplement is already joined.

Drum 9.5

Although the drum seems intact, a fracture plane runs across its upper side and through its mass –all over its height- reaching the center of the lower side. Both upper and lower sides were carved during N. Balanos' restoration and three iron clamps -of double "T" shape- were inserted (two clamps on the upper side and one on the lower one). Nowadays the restoration of the drum requires more reinforcement, therefore the iron clamps were substituted by new ones made of titanium and some extra reinforcement was also added. The additional reinforcement (titanium bars) was inserted in certain areas through both sides of the drum and their direction was 30° with respect to the horizontal level in order to succeed the proper combination of bars' strength and forces lever arm (Figs.13a,b,c). The required moment was calculated so as to avoid the separation of the drum in two fragments i.e. to succeed the stability of each one.

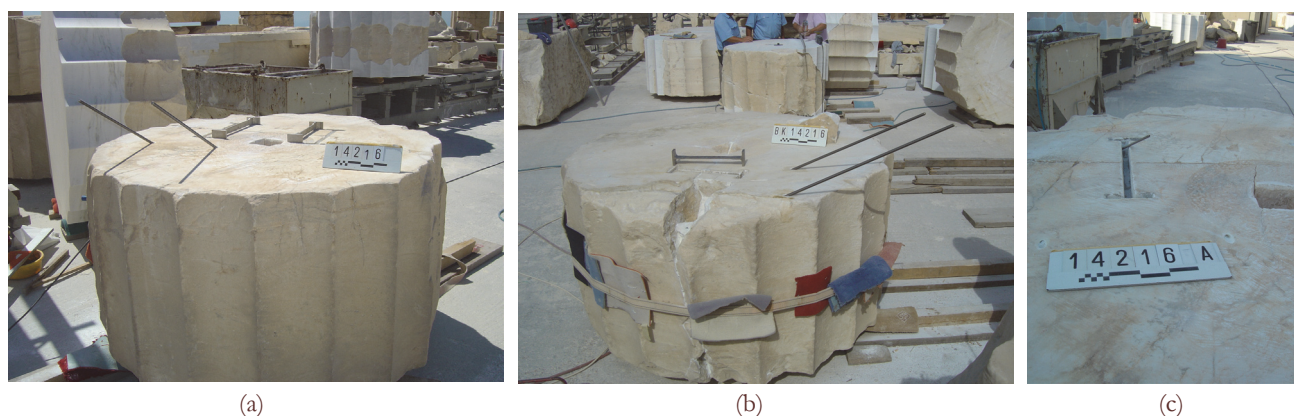


Figure 13: (a) Inserting reinforcement on the upper side. (b) Inserting reinforcement on the lower side. (c) Inserting reinforcement bar to repair a small crack on the upper side through the Balanos' mortise, before replacing the clamp.

Drum 10.9

Although the drum maintains its shape, a fracture plane runs across its upper side and through its mass - all over its height - reaching the lower side of the drum all over its width (Fig.14a). Three iron clamps - of double "T" shape - were placed in mortises carved on the surface of the drum, during N. Balanos' restoration, to repair the crack only on the upper side. Nowadays the restoration of the specific drum requires more reinforcement. The iron clamps were replaced by new titanium ones and the additional reinforcement (titanium bars) was inserted normal to the fracture plane, from areas of the drum's view which exhibit marks of decay and having lost their original ancient surface (Fig.14b, Fig.15), so as to achieve the

proper combination of bars' strength and forces lever arm in order to avoid the separation of the drum in two fragments i.e. to ensure the stability of each part.



Figure 14: (a) View of the fracture plane. (b) Inserting the reinforcement on the lower side of the drum. In this picture the drum is upside down.

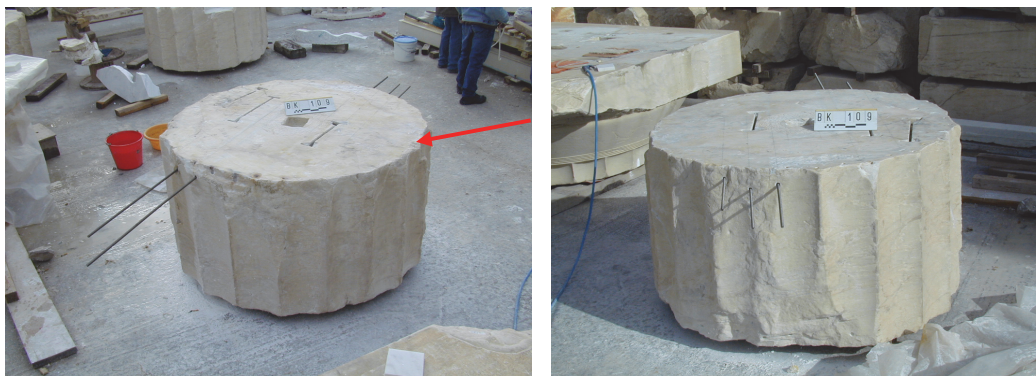


Figure 15: Inserting the reinforcement on the upper side's area. The red arrow in the left figure points out the crack's tips.

Drum 11.6

Two areas of the ancient member have severe material losses. The first area, which forms a wedge of 45.50cm height, is on the upper side of the drum (depicted schematically in Fig.16 and symbolized by the letters DF). The second one extends all over the drum's height and it is symbolized by the letters D_1F_1 in Fig.16. In addition a crack appears on the upper side, it is symbolized by the letters ΔF_1 in Fig.16, which runs between the aforementioned mass losses, creating a fragment of 34.50cm height (ΔFF_1 top view on the upper side in Fig.16). Finally a severe crack extends all over the height of the drum through the second loss's surface creating a fault (symbolized by the letters df_2 in Fig.16).

The sequence of the actions taken is the following:

1. To restore the drum's volume two supplements of new marble are created. The join of the supplement "DF" to the ancient remain core was accomplished by inserting titanium bars (to resist tensile and compression forces and subsequently to avoid overturning of the main volume or/and separation from the main volume) from its external surface, after the two volumes came into contact using cement mortar and montage reinforcement (Fig.17). In the next step the main reinforcement (titanium bars) was inserted from outside. In order to achieve the proper anchorage length of the bars, because of the thin thickness of the new volume, the end of the bars has been specially threaded to fit a screw nut through a titanium plate anchor (Fig.18 on the left).
2. The join of the fragment " ΔFF_1 " to the ancient remain core to avoid separation was accomplished by inserting inclined titanium bars forming 38° to the horizontal level, through holes of the drum's view (created from N. Balanos during the intervention). One of the bars used for the join of the supplement "DF", contributes to the strength required (Fig.17).
3. To repair the crack " df_2 " (avoid the separation of the possible resulting fragment from the rest of the drum's volume, prohibiting its overturning), titanium bars were inserted from the fracture plane of surface " D_1F_1 " on the upper side of the drum, while the extension of two of the bars used for the join of the supplement "DF", contributes to the strength

- required. On the lower side of the drum the reinforcement was inserted from outside, from areas of the drum's view, which appeared marks of decay, losing their original ancient surface (Fig.18 right).
4. Finally, the join of the supplement to the ancient marble to fill the loss “ D_1F_1 ” was accomplished by inserting titanium bars both on the upper and on the lower side of the drum through the fractured area with direction parallel to the member's upper side (Fig.19 left). This reinforcement is the proper one to avoid overturning of the supplement, before the overturning of the drum as a whole. In order to achieve the proper anchorage length of the reinforcement on the supplement's lower area, because of the thin thickness of the new volume there, the end of these bars has also been specially threaded to fit a screw nut through a titanium plate anchor (Fig.19 right).

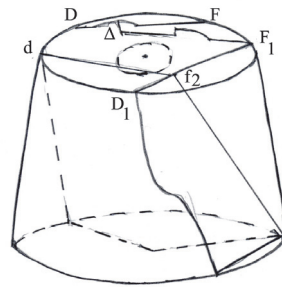


Figure 16: Sketch of the failures of the drum (Drawing: M. Mentzini, YSMA Archive).

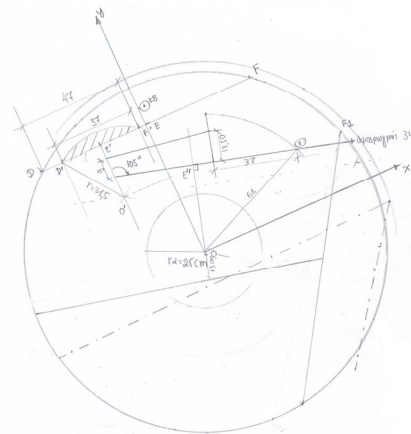


Figure 17: Adjusting a new marble (supplement “DF”) onto the upper side of the drum (left). Near by, the reinforcement required to restore the fragment “ ΔFF_1 ” is presented (ellipse in the left figure). Drawing of the parts to be joined together and their geometry for the calculation of the stress field and consequently the reinforcement required (right) (Drawing: M. Mentzini, YSMA Archive).

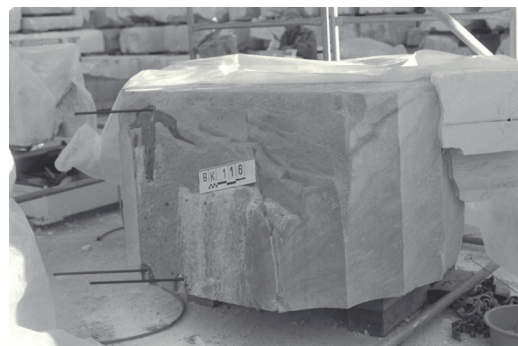


Figure 18: After joining the supplement “DF” to the main volume of the drum, the holes (in order to adjust the titanium plate anchor) on its surface sealed with the pieces of the extruded new marble (on the left). Repairing the crack “ df_2 ” (on the right).



Figure 19: Inserting titanium bars on the upper side's area of the drum to join the supplement “D₁F₁” to the ancient marble (on the left). After joining the supplement “D₁F₁” to the main volume of the drum, the holes on its surface (in order to adjust the titanium plate anchor) sealed with the pieces of the extruded new marble (on the right).

FRACTURE DETECTION

During the intervention of the Parthenon's North Colonnade forty-seven (47) drums were structurally restored while the study and the structural intervention for additional fourteen (14) ones have been supervised (in total sixty-one (61) members).

It is noteworthy that although most of the damages were caused from the members' fall due to Morosini's explosion, and many remains were worked out by N. Balanos, changing the shape of the fracture planes of the members as well as their original exact position on the monument, the detailed observation and the data processing succeeded to identify and verify the conclusions of previous research. For example an existing fracture and the consequent loss of mass at drums cause similar failures to the adjacent ones, a kind of imprints. During rocking a severe stress field is developed in the edge of the remaining part of the drum, leading to the creation of cracks at the adjacent members. As a result the bearing capacity and behaviour under seismic loading of the entire structure are drastically deteriorating. Therefore it is necessary to repair the damages and restore them even using new marble supplements [7].

In case of the drums of the Parthenon's North Colonnade, fractures' coincidence has been detected between the following members:

- The upper side of 4.8 in correspondence to the lower side of 4.9
- The upper side of 5.6 in correspondence to the lower side of 5.7
- The upper side of 6.3 in correspondence to the lower side of 6.4
- The upper side of 6.4 in correspondence to the lower side of 6.5
- The upper side of 6.5 in correspondence to the lower side of 6.6
- The upper side of 6.6 in correspondence to the lower side of 6.7
- The upper side of 6.7 in correspondence to the lower side of 6.8
- The upper side of 9.7 in correspondence to the lower side of 9.8
- The upper side of 10.9 in correspondence to the lower side of 10.10

CONCLUSIONS

The structural interventions on ancient members during the extensive restoration program of the Parthenon Temple on the Acropolis of Athens, offers to the scientists working in this field an in depth knowledge of the stress and strain fields developed in the structural elements to be restored.

In addition the scientist has to face the challenge of redesigning and adapting the results of the already described theoretical process to achieve the structural integrity of ancient members in a way, which is flexible during its realization.

The shape of the remaining ancient volumes determines the exact geometry of the supplements since their contact areas must be perfectly fitted. As a result the direction of the reinforcement needed is limited.



The present paper reveals the special skill, imagination and creativity of the scientists in order to determine the sequence of actions which must be undertaken to join the pieces forming the drum and to apply the proper reinforcement so as the structural integrity of the drum as a whole to be achieved. In this way in many cases the same reinforcement expands to cover the structural needs of another section.

Moreover, the problems arising due to the irregular shape of fracture's planes or the discontinuities in marble mass, could be solved by changing the number, the diameter or/and the place of the reinforcement bars and keeping in the same time the produced stress field constant. If internal reinforcement bars can not be used (so as to be unseen) because of the inability of the adjustment or the maintenance of the proper anchorage length, alternative solutions are invented, such as: the insert from the sides (which will be covered when the drums will be placed back in their initial position on the column) or from areas of the drum's view, which exhibit marks of decay, having lost their original ancient surface. Even the mortises of N. Balanos' restoration are used to insert bars or to place "II" and double "T" shape titanium connectors to contribute to the stress required and also to minimize further loss of the authentic material.

As it was pointed out before, the previous restoration by the engineer N. Balanos changed in many cases the original exact position of the drums. During the structural intervention of the dismantled pieces the access to their fractured areas and the verification of coincidence between different members' fractures, reveal their original position and identify whether the certain drum belongs or not to a certain position on the column. Thus by these observations the original exact position of the drums was also confirmed in perfect agreement with the findings of the Architectural study [16].

REFERENCES

- [1] Mentzini, M., Report of the project of the Parthenon's North Colonnade restoration, Ancient members' structural intervention: Columns and architraves. The Drums, vol. A, Archives of the General Direction of Antiquities and Cultural Heritage (2015).
- [2] Zambas, C., Ioannidou, M., Papanikolaou, A., The use of titanium reinforcements for the restoration of marble architectural members of Acropolis Monuments, Proc. IIC Congress on Case Studies in the Conservation of Stone and Wall Paintings, Bologna: The International Institute for Conservation of Historic and Artistic Works, (1986) 138-143.
- [3] Mentzini, M., Joining together architraves and drums of Parthenon using titanium: A new approach, Proc. 5th Int. Symp. for the Restoration of Acropolis Monuments, Athens: Committee for the Preservation of the Acropolis Monuments (2002) 233- 242.
- [4] Exadaktylos, G.E., Vardoulakis, I., Kourkoulis S.K., Influence of nonlinearity and double elasticity on flexure of rock beams - II. Characterization of Dionysos marble, *International Journal of Solids & Structures*, 38 (2001) 4119-4145.
- [5] Kourkoulis, S.K., Exadaktylos, G.E., Vardoulakis I., U-notched Dionysos-Pentelicon marble in three point bending: The effect of nonlinearity, anisotropy and microstructure, *International Journal of Fracture*, 98 (1999) 369-392.
- [6] Kourkoulis, S.K., Prassianakis, I., Agioutantis, Z., Exadaktylos, G.E., Reliability assessment of the NDT results for the internal damage of marble specimens, *International Journal of Material and Product Technology*, 26 (2006) 35-56.
- [7] Mentzini, M., Drums' fracture-The example of the 6th column of Parthenon's Pronaos, Proc. 8th Int. Sym. on the Conservation of Monuments in the Mediterranean Basin, M. Kouli & F. Zezza (eds.), Patras, Greece (2010) 56-57.
- [8] Balanos, N., The Restoration of the Acropolis monuments, Editor S.N.Taroussopoulos, Athens, (1940)
- [9] Korres, M., Bouras, H., Study for the restoration of the Parthenon, Athens: Ministry of Culture of Greece, Committee for the Preservation of the Acropolis' Monuments (1983).
- [10] Mentzini, M., Structural interventions on the Acropolis monuments, Newsletter of the Acropolis restoration service of the Ministry of Culture of Greece, 6 (2006) 15-18.
- [11] Zambas, C., Structural problems of the restoration of the Parthenon, Vol.2a, Athens: Committee for the Preservation of the Acropolis Monuments (1989).
- [12] Zambas, C., Structural problems of the restoration of the Parthenon, Vol.3b, Athens: Committee for the Preservation of the Acropolis Monuments (1994).
- [13] Psycharis, I.N., Lemos, J.V., Papastamatiou, D.Y., Zambas, C., Papantonopoulos, C., Numerical study of the seismic behaviour of a part of the Parthenon Pronaos, *Earthquake Engng. Struct. Dyn.*, 32 (2003) 2063-2084.
- [14] Psycharis, I.N., Seismic Response of Classical Monuments with Fractured structural elements, in "Fracture and Failure of Natural Building Stones", Stavros K. Kourkoulis (ed.), Springer, Berlin (2006) 239-255.
- [15] Mentzini, M., Columns and architraves: the process of structural intervention, in: Interventions on the Acropolis monuments 2000-2012, The completed programmes, Proc. 6th Int. Symp. for the Restoration of Acropolis Monuments, Athens: Committee for the Preservation of the Acropolis Monuments (2013) 1-24.



- [16] Lambrinou L., Resetting of columns and architraves of the North Colonnade, in: Interventions on the Acropolis monuments 2000-2012, The completed programmes, Proc. 6th Int. Symp. for the Restoration of Acropolis Monuments, Athens: Committee for the Preservation of the Acropolis Monuments (2013) 1-27.