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Dionysos marble beams under bending: A contribution towards understanding the fracture of the Parthenon architraves

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ABSTRACT

The response of either intact or fractured and restored marble architraves under bending is the object of the present paper. The study is motivated by the needs of the scientists, working for the extensive restoration program of the Parthenon Temple on the Acropolis of Athens, for an in-depth knowledge of the stress and strain fields developed in restored structural elements when they are placed back in their initial position. A recently introduced procedure is employed for the calculation of the reinforcement required for the restoration. A numerical model with contact elements is developed for the simulation of a prismatic architrave (epistyle) resting on marble supports (capitals, abacuses) and subjected to various types of bending. The points most prone to fail are located for both the intact and the restored architraves and it is concluded that the reproduction of actual bending conditions in the laboratory may lead to erroneous conclusions if the results are not interpreted carefully taking into account the exact way of applying the external loads. The most important findings of the numerical analysis are compared to those of previous experimental studies and are juxtaposed to the conclusions drawn from the study of the present state of the monument.

1. Introduction

In a recent paper Paschalides et al. (2004) assessed experimentally the methodology adopted nowadays by the scientists working on the Parthenon Temple for the calculation of the reinforcement required for joining together the fragmented architraves (epistyles) of the monument. For that study a multi-point bending arrangement (Fig. 1) was designed in order to approach as close as possible the uniformly distributed load applied on the architraves by their own weight and the weight of the superimposed structural elements of the Temple. The used specimens in that study were accurate copies of typical fragmented architraves of the Parthenon Temple in a scale of either 1:3 or 1:2.

The analysis of the results of these experiments revealed some deviations from the theoretically predicted values, especially concerning the maximum expected failure load. After thorough study these deviations were attributed to:

- the improper simulation of the uniform load (actual conditions and theoretical analysis) by concentrated loads (laboratory tests) and
- the assumption that the architrave, after replaced on the abacuses of the capitals of the columns, is equivalent to a statically determined structural element in the form of either a simply supported beam or a double cantilever one (two ways projecting beam).

It was thus indicated that one should consider very carefully both the loading system as well as the details of the supports on which the element rests, in order to determine the actual span and therefore the maximum developed bending moment in the actual state and in the laboratory tests.

Following the above conclusions an effort is undertaken here for a systematic study of the stress and strain fields developed in either intact or fractured and restored prismatic marble architraves under various types of bending loading. The study is carried out numerically with the aid of the Finite Element Method since an analytic (closed form) solution of the problem is prohibitively complicated due to:

- The geometry of the architraves: the ratio of the length over the height does not exceed four and therefore the classical technical bending theory becomes inapplicable.
- The material of the abacuses on which the architraves rest: the abacuses are made from the same marble as the architraves and therefore their deformation cannot be ignored.
- The type of support of the architrave: the relative dimensions of the abacuses and the architraves (the length of the abacus is equal to about one third of the length of the architrave) do not permit clear classification of the configuration neither as simply supported beams nor as double cantilever ones (Fig. 2).

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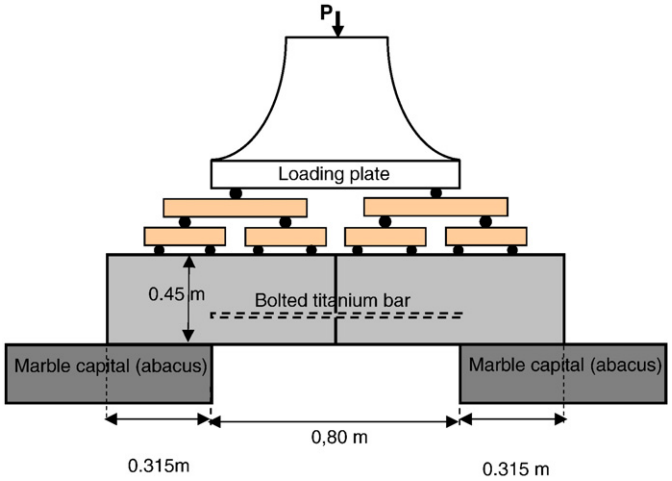

Fig. 1. Schematic representation of the set-up for the eight-point bending experiments.

- The difficulties introduced in case the architrave is fragmented and restored (usually with the aid of one or more threaded titanium bars) due to the interactions developed between marble and titanium and between the marble fragments.
- The perturbation of the stress and strain fields due to the punches used in the laboratory experiments for the application of the concentrated loads which simulate the actual loads acting on the structural member.

In the first part of the paper the results of a recent work (Kourkoulis et al., 2006) are recapitulated concerning the influence of the way that the actual loading conditions are simulated during a typical laboratory bending test. In the second part the stress and strain fields developed in a prismatic marble architrave consisting of two equal fragments joined together with either one or two titanium bars are explored in case the specimen is loaded according to:

- the loading mode indicated in the first part of the analysis as producing the most severe stress field (for safety reasons) and
- the loading mode actually applied (eight-point bending) in the laboratory (for comparison reasons).

The analysis revealed that for intact architraves the points most dangerous to fail are the ones very close to the edges of the supporting abacuses while for restored architraves failure is expected in the immediate vicinity of the reinforcing titanium bars. The results of the numerical analysis for the stress and strain fields in restored architraves are juxtaposed to those of the experimental study by Paschalides et al. (2004) as well as to the conclusions of a recent study of the present state of the architraves of the Parthenon Temple (Mentzini, 2006) and the agreement is satisfactory.

2. The material: Dionysos marble

The material used for the erection of the monuments of the Acropolis of Athens was Pentelic marble, one of the most famous of ancient statuary marbles, used among others by Phidias and Praxiteles. It is an extremely durable white marble quarried from Mount Pentelicus in Attica, a few kilometers northwest from Athens. Unfortunately the ancient quarries are nowadays exhausted and the needs of the restoration project of the monument for substitution or completion stone are covered with Dionysos marble quarried from Mount Dionysos in Attica, since it has the nearest properties to the authentic marble of the monument (Zambas, 1994).

Dionysos marble is composed by 98% of calcite. It contains very small amounts of muscovite, sericite, quartz and chlorite. Its density is about 2730 kg/m^3. The porosity is very low varying between 0.3% in the virgin state to 0.7% after the action of various natural weathering and corrosive agents (superficial porosity). Its grain size varies around

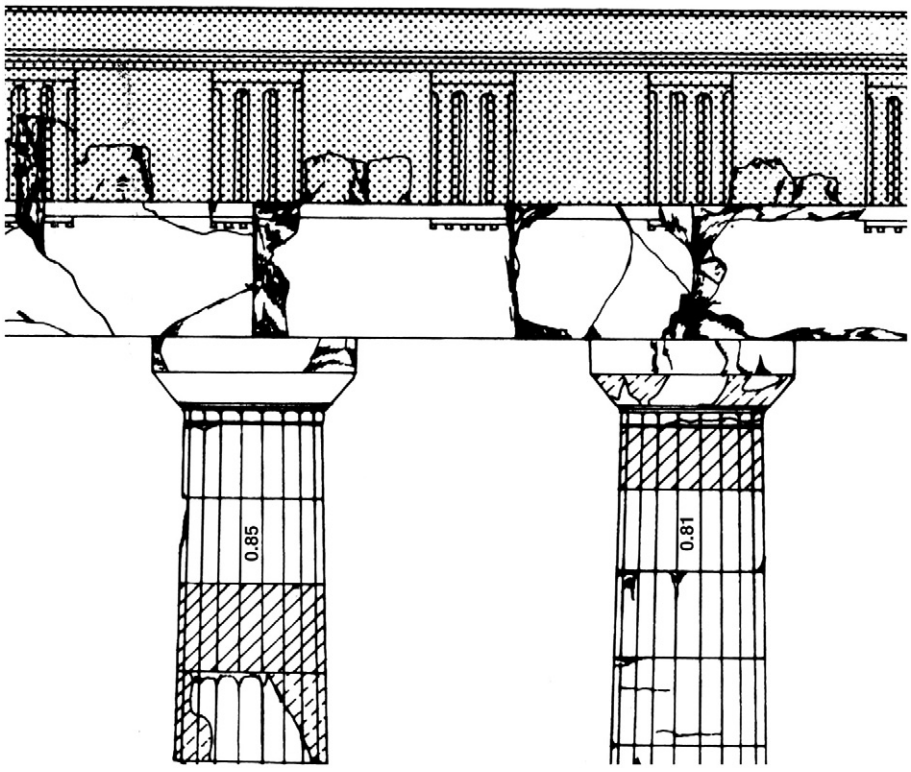

Fig. 2. Schematic representation of a part of the north colonnade of the Parthenon Temple indicating the relative dimensions of the architraves and the supporting abacuses.