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Analysis of the statical behaviour of the Costantino's arch in Rome

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ANALYSIS OF THE STATICAL BEHAVIOUR OF THE COSTANTINO'S ARCH IN ROME

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SUMMARY

The Arch of Costantino in Rome has recently undergone complete restoration.

During restoration work surveys were also made in order to establish the static situation of the monument.

This report gives the results of this research and attempts to show the validity and utility of the results obtained both through coordinated experiments - by relieving tension at certain points with the technique of flat jacks - anf theoretically by accurate numerical models whose results, when compared with the experiments, enabled us to establish tensions over the entire monument and understand the causes of the present damage.

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1. INTRODUCTION

The restoration of a momunment involves a process of both knowledge and trasformation. Knowledge is acquired from a direct analysis of the materials, which may reveal new relationships and facts; transformation is the result of the interventions made to counteract the degradation wrought by time.

One might tend to assume that the state of an ancient monument has remained essentially the same from the time it was built until its present day restoration. However, the actual events of the classical era prove the contrary: the structure and surface ef each monument often preserve signs, however corroded by time, of those alterations - both ancient and more recent restorations, changes of use and re-surfacing - to which the monument owes its very survival.

From times of antiquity to the present day, Roman monuments constitute a repertoire of technical interventions and restorations made in different periods that have gradually changed the appearance of the buildings and their individual relationship to their urban surroundings.

The present from a monument is thus the product of the different cultures that have influenced the planning and realisation of the original work, and subsequent restoration works. Thus knowledge of an individual monument does not attempt only to assess its state of conservation. but also to interpret the palimpsest resulting from ancient and modern transformations of both its architechtonic and its structural aspect, while giving emphasis also to the way previous restorations have been carried out and to the less obvious maintenance practices, as well as restoring the original structural concept wherever possible.

Until recent restoration work the architectural drawings on which knowledge of the Arch of Costantino was based were those made by A. Desgodez in 1682 before the monument underwent restoration by Clement XII. The new drawings made it possible for considerations that had hitherto been limited to the art historical study of the sculptures to be applied to the construction and stability of the monument.

Even in antiquity, at the time of its origin, this monument dedicated to Costantino's victory over Maxantius in 312 A.D. was already a palimpsest of materials assembled with different techniques. The construction is massive and extremely austere. The lower part, formed by four columns and three arches, is built entirely of large blocks of marble, while the upper part is built of blocks of marble on the exterior and brick walls in the interior: on these rests a vault in tufa conglomerate; Core boring tests carried out recently have shown the continuity and homogeneity of the construction in marble up to the crown of the vaults and in the piers (fig. 1).

The rich and varied iconography has always been a source for the study of the monument. The present of reliefs coming from different monuments makes the Arch a compendium of Roman sculpture.

The reliefs are partly sculptured on the blocks already in position and partly on huge slabs of marble using different techniques and figurative concepts.

Dismembered panels of a continuous frieze originally more then twenty-eight metres long, from the Trajan Forum, are mounted in the central vault and on the smaller sides of the attic. This frieze celebrated the campaigns against the Dacians, which are also commemmorated by the fully sculptured statues on top of the columns; the facades are decorated with eight medallions representing hunting and sacrificial scenes that were originally part of a monument built by Hadrian; on the attic there are eight large rectangular panels, probably from an arch erected near the columns of

Marcus Aurelius, narrating episodes from his life. The reliefs celebrating Costantino's victories and other episodes during his reigh are all sculpted on blocks that were already in position, with the exception of the two lateral reliefs.

Recent architectural drawings, drawn up on a scale of 1:25, have made it possible to develop a new line of research into the construction and structural behaviour of the monument, with the aim not only of conserving the building, but also of understanding it as a work of architecture.

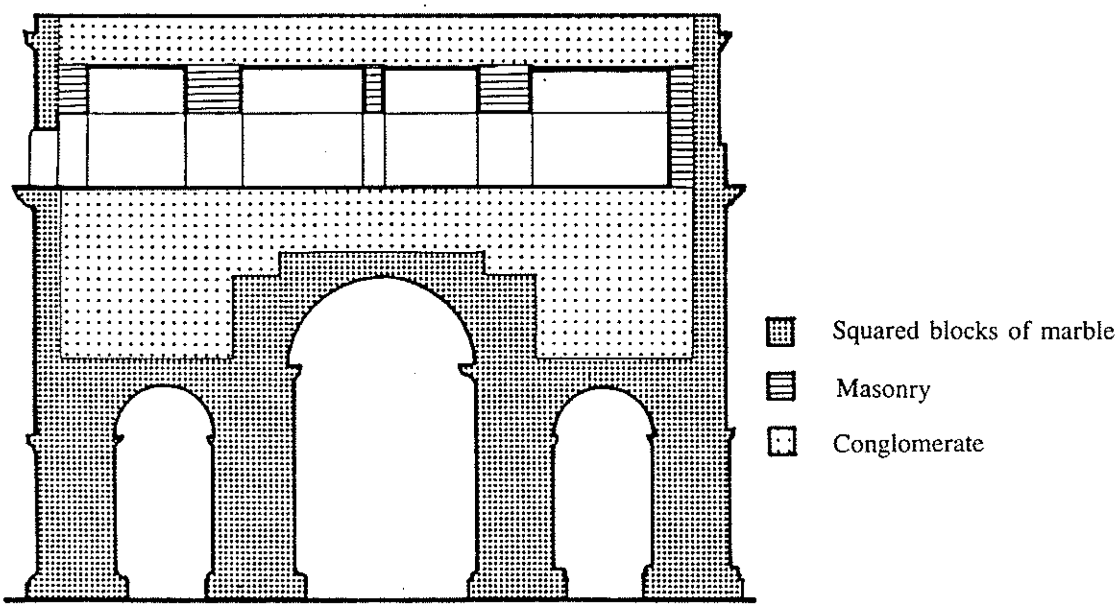

Fig. 1: Section of the arch with the different materials

2. DESCRIPTION OF THE DAMAGE

The monument is particularly robust and well constructed from a static point of view. The pillars are made entirely from squared blocks of marble, as are all the lateral surfaces. In the central part above the arches, containing an internal niche, shown in Figure 1, the walls and vaults are built in masonry.

The parts in conglomerate, as shown in Figure 1, are few and limited to areas that have no static function.

However, at some time in the past, the columns and the statues decorating the facade of the monument had to be consolidated.

Moreover, there are further cracks whose regularity reveals the presence of excessive strain in the material.

Four different types of cracks may be identified (see fig. 2):

a) cracks in the abutments of the large central arch, near the corners, following a course that runs parallel to the curve of the arch;
b) cracks in the masonry columns in the internal cella;
c) cracks in the corbels above the columns;
d) extensive cracks in the columns.

The cracks described in a) and b) reveal the presence of excessive compression stresses, while those described in c) appear to indicate the presence of tensile stresses due to phenomena flection.

The cracks found in the columns may probably be attributed to the poor quality - from a mechanical point of view - of the marble.

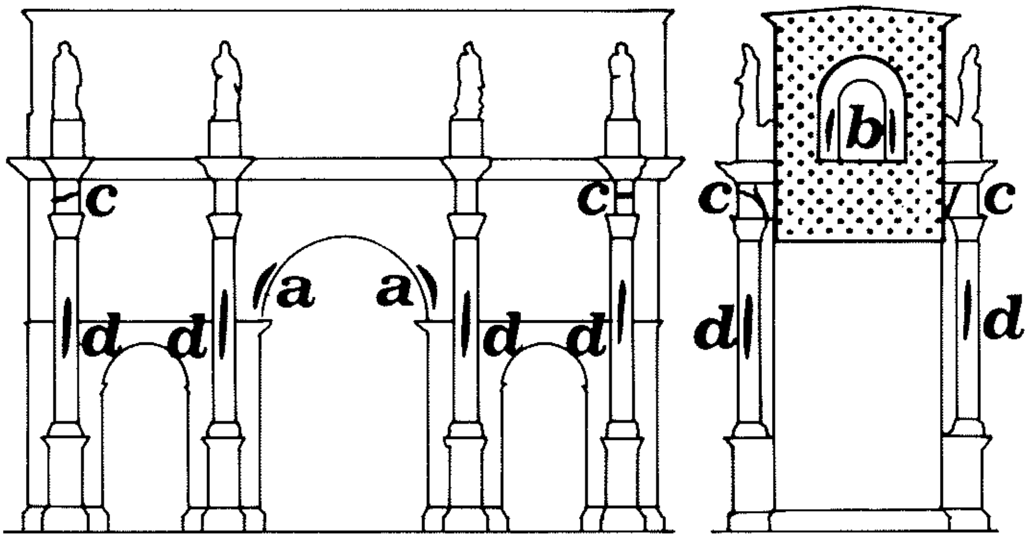

Fig. 2: Cracks on the monument

3. NON DESTRUCTIVE IN SITU TESTS FOR THE MECHANICAL CHARACTERIZATION OF MASONRY STRUCTURES.

The determination of the parameters necessary to evaluate the static conditions of the Arch was carried out by means of the well-know flat-jack testing technique developed some years ago by ISMES. This non-destructive testing technique, which is based on the use of thin flat-jacks inserted into the masonry has been set up in order to given reliable information concerning the following parameters.

— Measure of the state of stress.
— Determination of deformability and strength characteristics.

The reliability of the flat-jack technique has been deeply investigated by means of a wide range of calibration tests carried out on large masonry samples.

On the stone masonry structure of the Arch the measure of the state of stress was carried out by means of flat-jacks having the shape of a circular segment (length 32 cm, height 12 cm and thickness 4 mm), inserted into cuts made by means of a circular plate with diamond tools.

The values of the state of stress, measured in several significant points of the structures, are indicated in the scheme of Fig. 3.

The four tests carried out at the base of the monument show a stress concentration in point 12 (SOUTH-WEST corner) with a value of 2.0 Mpa which is much higher than the average value (0.7 MPa) measured at the other three points (11, 3, 14).

Stress concentration was also determined on the South face of the main arch especially in the point 8 where a value of 3.2 MPa was measured.

The tests carried out over the columns show, at the South face, slightly higher stress values (0.5 - 0.6 MPa) than those measured at the North face (0.5 MPa).

The state of stress was also measured on the brick masonry walls of the chamber in the upper part of the monument (fig. 3) A uniform stress distribution was observed.

The deformability characteristics of the brick masonry were also determined by using two parallel flat-jacks. The masonry shows a linear elastic behaviour up to a stress value of about 1.5 MPa.

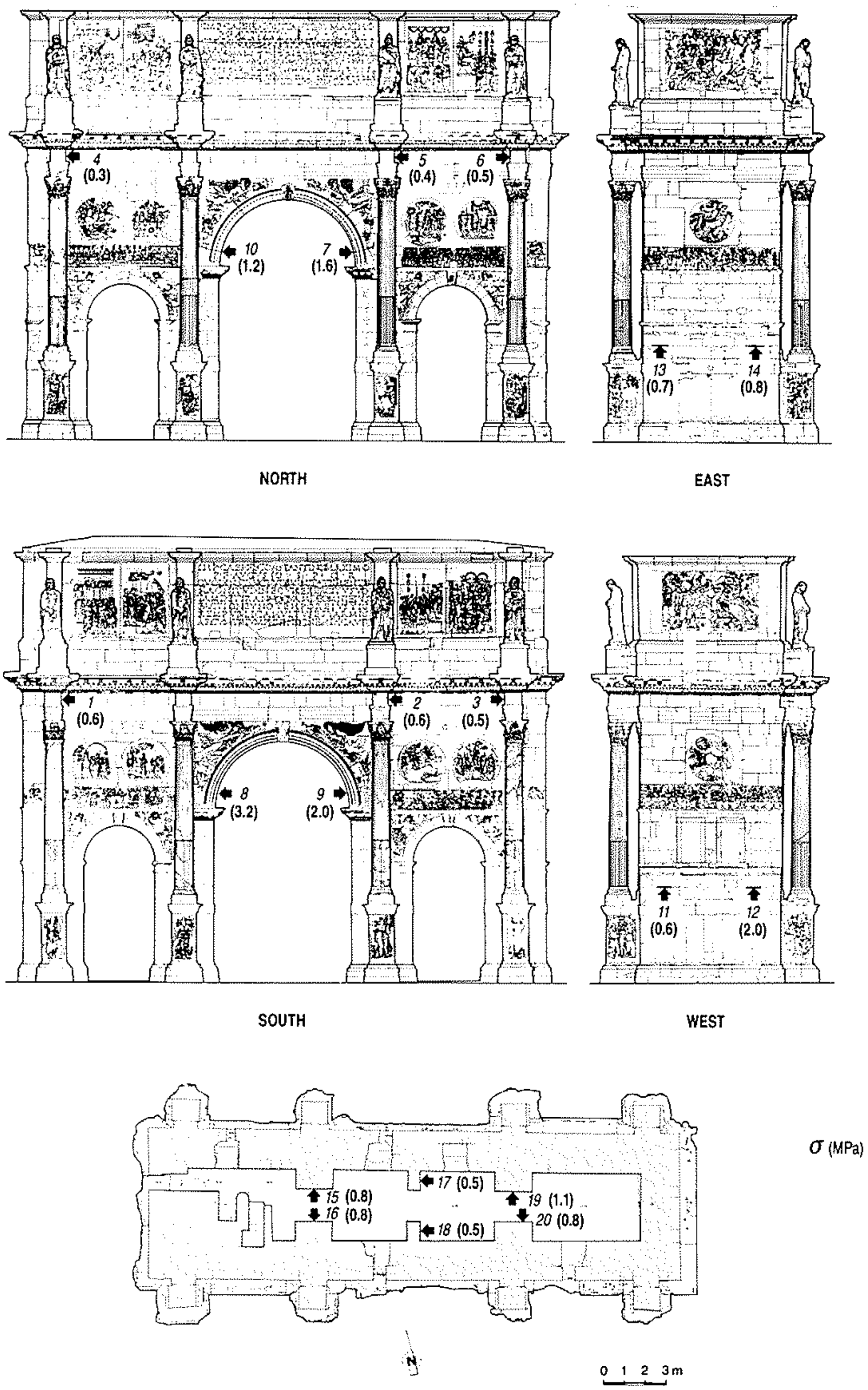

Fig. 3: The state of stress (experimental tests)

4. THEORETICAL SURVEY OF THE TENSIONAL STATE

The tensional state was examined by means of a polar Finite Element numerical procedure. Conventional moduli of elasticity, using a different one for each material, were set up in order to describe mechanical behaviour.

While bearing in mind that the actual behaviour of the structures under examination is more complex than the theoretical linear one, the absence of relevant tensional states due to traction suggests that results obtained are fairly significant.

Figure 4 gives the tensional state in a transversal section, and Figure 5 the tensional state in a longitudinal section.

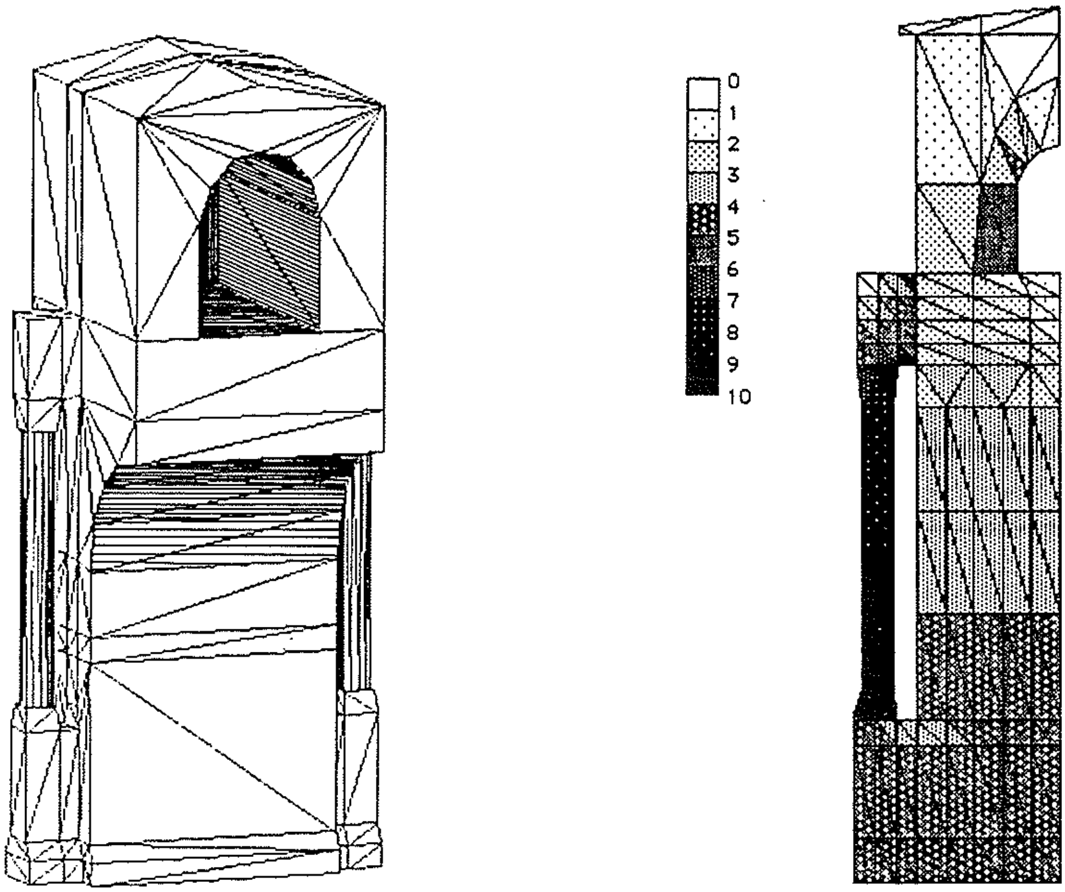

Fig. 4: Numerical model: Tensional state in a transversal section

A comparison between the theoretical values of the tensional states and those obtained experimentally reveals a high rate of correlation; especially worthy of note is the correspondence between the areas of the model revealing greatest tension and areas of demage in the monument.

It thus seems reasonable to conclude that the information given by the numerical model provides a valid indication of the present tensional state.

It should however be noted that the tensions revealed both by experiments and on the model, even in the areas under most strain and where cracks have revealed, although worthy of remarks, are not such as to explain the fractures completely.

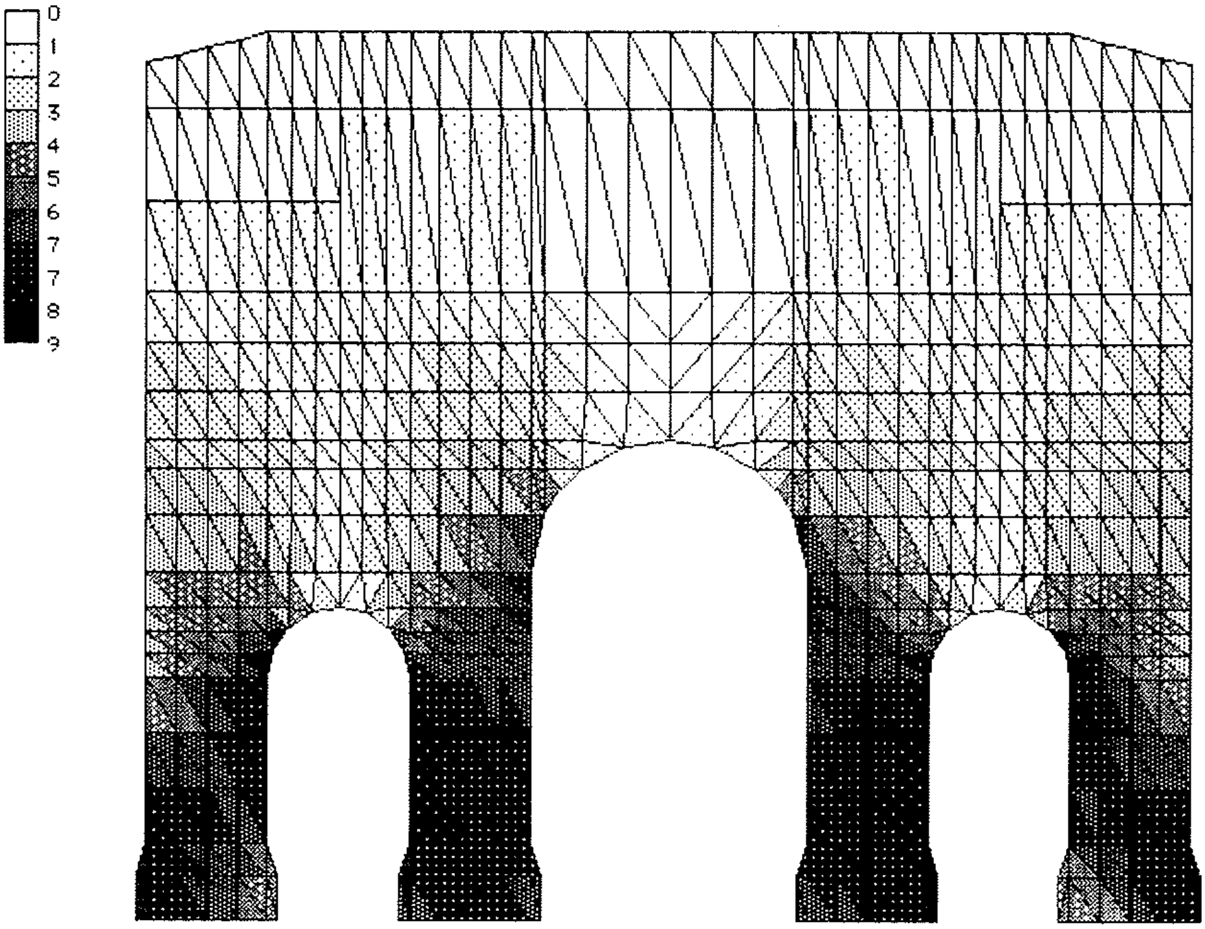

Fig. 5: Numerical model: tensional state in a longitudinal section

Further increases in tension should therefore probably be attributed to local factors.

In particular, with regard to the corners at the abutments of the main arch, it is reasonable to assume that the more careful working of the exposed surfaces of the marble blocks has resulted in points of increased adherence and hence of greater concentration of tension in these areas.

Finally, the traumatic events the monument certainly underwent (earthquakes, demolitions, etc) should not be forgotten: these could have increased the tensions beyond the limits of resistance at particular points, such as the corbels, the columns or the masonry rubs in the internal cella.

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