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Preservation of Newly Built and Historical Buildings

Conservation des bâtiments historiques et récents

Bewahrung historischer und neuzeitlicher Bauwerke

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Giorgio Croci, born 1936, has carried out important research, studies and projects for the strengthening and restoration of historical buildings. The Colosseum and Senatorio Palace in Rome, the Ducale Palaces in Modena and Genova, the Castle of Spoleto, the Basilicas of S. Francis of Assisi and S. Ignatio de Loyola in Spain, represent some examples of his activity.

SUMMARY

This paper deals with the preservation of existing buildings. The main problem is the evaluation of the safety level, taking into account the crack patterns, the deterioration of materials, etc. As a result of this analysis, decisions can be taken about the opportunity and the criteria for intervention. The paper illustrates some cases, referring especially to historical buildings in Italy and Spain.

RÈSUME

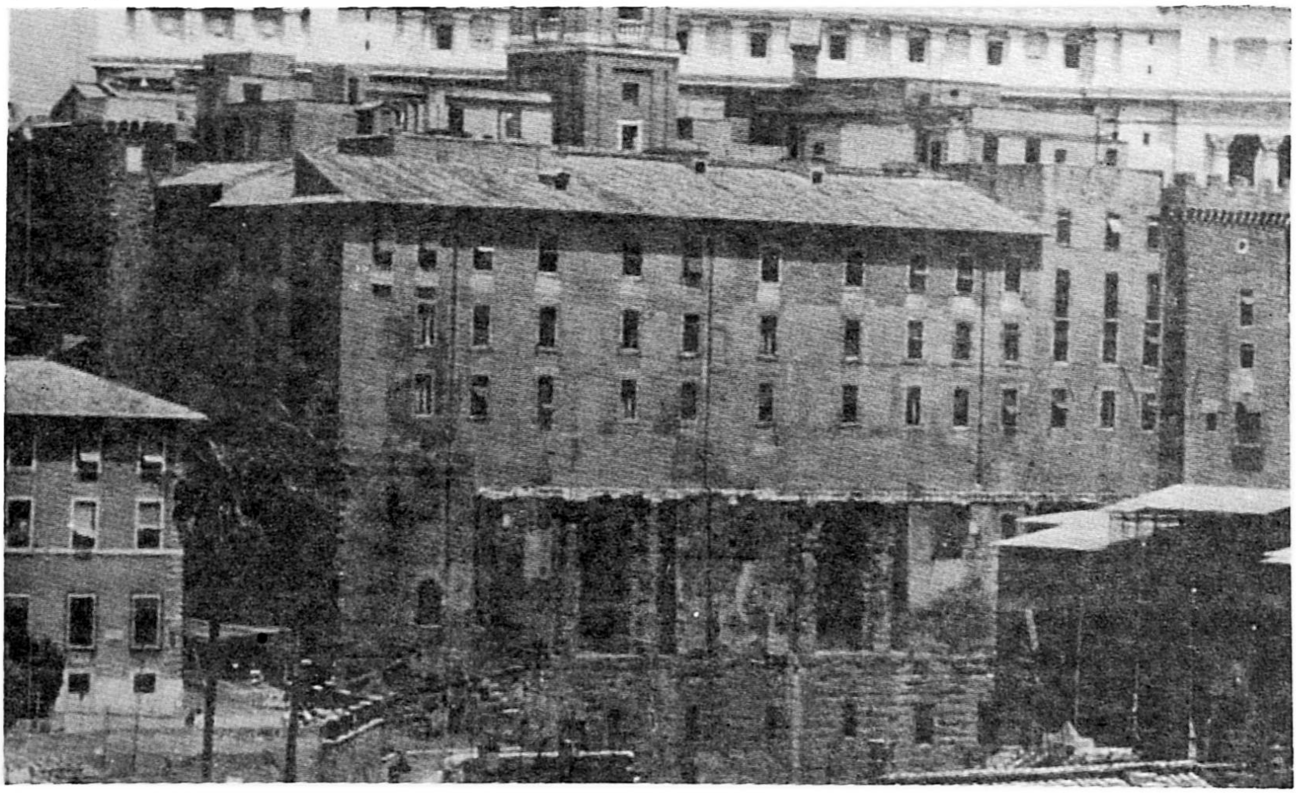
L'article traite de la conservation de bâtiments existants. Le problème principal concerne l'évaluation du niveau de sécurité, prenant en compte l'évolution des fissures, la détérioration des matériaux, etc. Cette analyse permet de prendre des décisions sur l'opportunité d'une intervention, et sur les caractéristiques de celle-ci. Des exemples de bâtiments historiques en Italie et en Espagne illustrent l'article.

ZUSAMMENFASSUNG

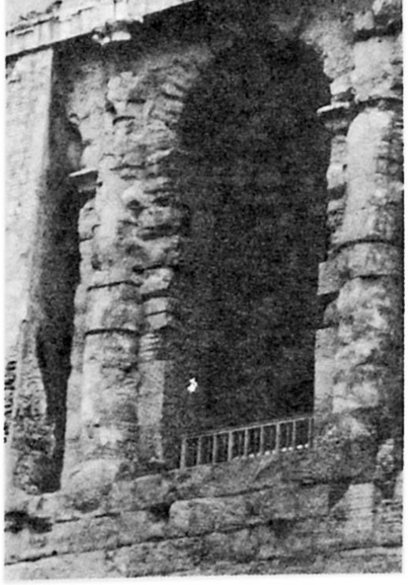
Der Artikel handelt von der Bewahrung vorhandener Bauwerke. Der Schwerpunkt liegt dabei auf der Berechnung der Standsicherheit unter Berücksichtigung des Rissbildes, der Baustoffverwitterung usw. Diese Analyse erlaubt Entscheidungen bezüglich Eingriffsmöglichkeiten und Alarmgrenzwerten. Beispiele für historische Bauwerke in Italien und Spanien erläutern den Artikel.

1. INTRODUCTION

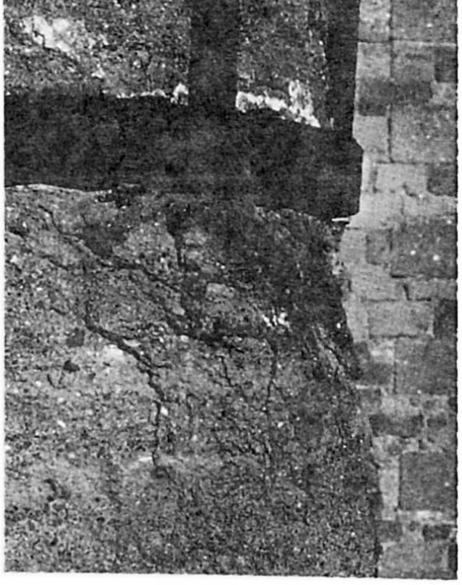
The first point to examine in the preservation of a structure is the analysis of the deterioration of the materials. This deterioration in the oldest buildings is linked not only to the chemical and physical phenomena, but also to the countless alterations, that, as in the case of Palazzo Senatorio in Capidoglio, Rome, (fig. 1) have occurred during the centuries (fig. 2), sometime stressed by incorret reinforcements (fig. 3).



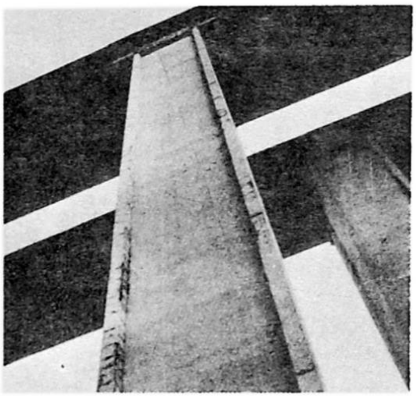
Pic.1: General view of Palazzo Senatorio and Tabularium in Campidoglio from the side of the Roman Forum



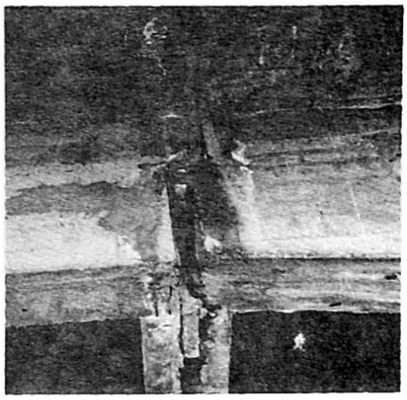
Pic.2: Alterations and deteriorations of Palazzo Senatorio



Pic.3:Effect on the columns of Tabularium

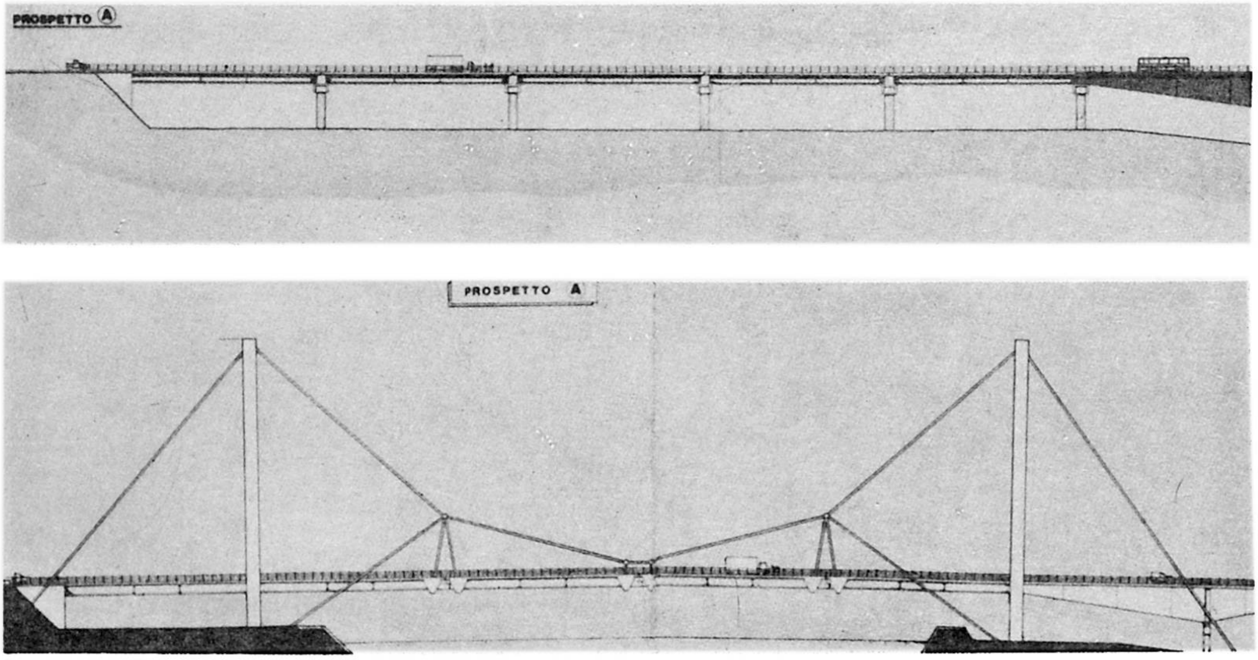


Pic.4: Concrete motorway bridge



Pic.5: Deterioration in a bridge deck

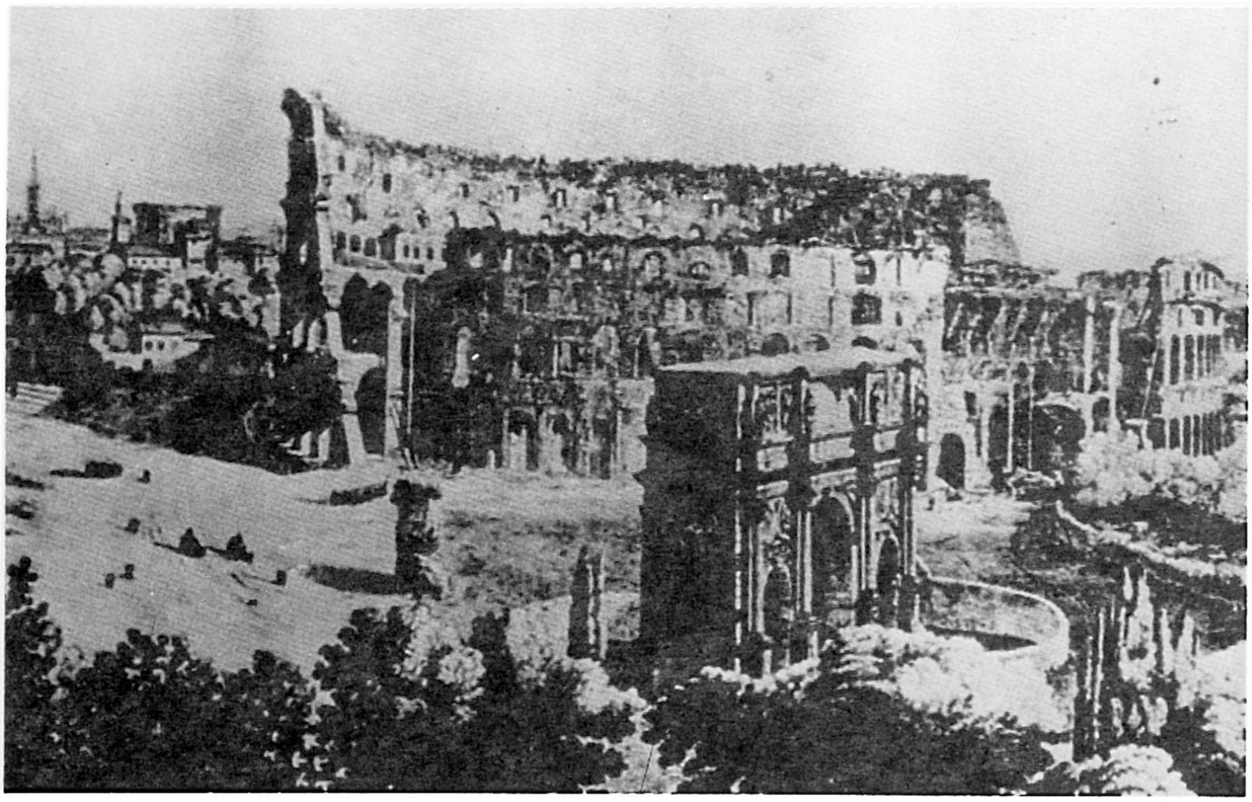
For newly built constructions, unluckily, the situation is often worse, despite the support offered by science and modern technology. It is not uncommon to find in some bridges (fig. 4) high levels of deterioration due to lack of maintenance, insufficient protection of the steel, bad quality concrete, imperfect design of details. (fig. 5) Repairing and strengthening will be an important activity for the future.
The second point to consider is the assessment of the structural capacity. This evaluation, which will be examined in the following paragraphs, related to historical buildings, is often very difficult and always delicate, because it involves the decisions and criteria of interventions. Structural interventions, however, are not only related to insufficient bearing capacity. In some cases, new requirements can suggest a substantial change in the original behaviour; this is the case, for example, of a bridge (fig. 6) where it was decided to remove the pillars, substituting the support of the beams with cable, transforming in this way the old structure, to a new suspended bridge (fig. 7), satisfying the need for a free area below.



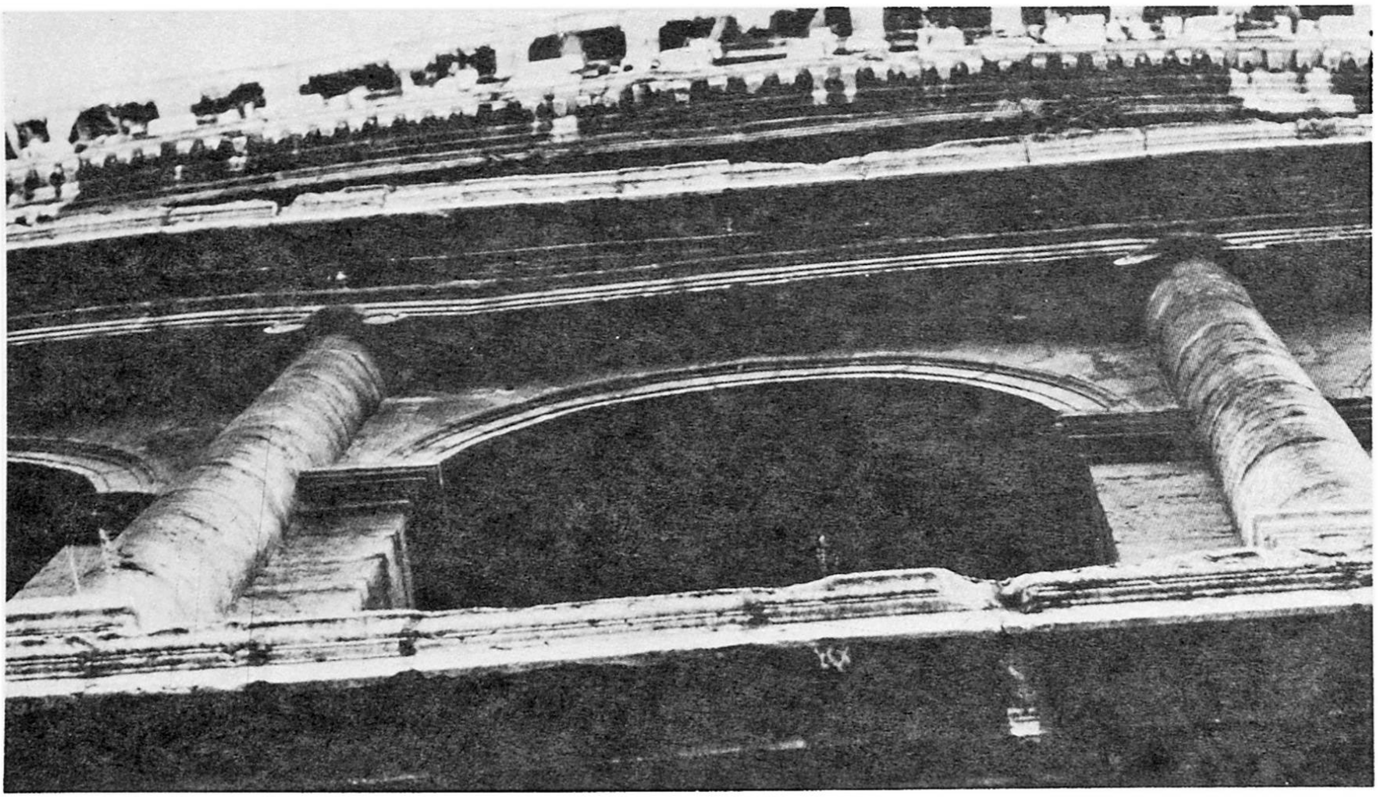
Pic.6,7: The same bridge before and after the substitution of the pillars with cables

2. THE ASSESSMENT OF THE RESIDUAL CAPACITY

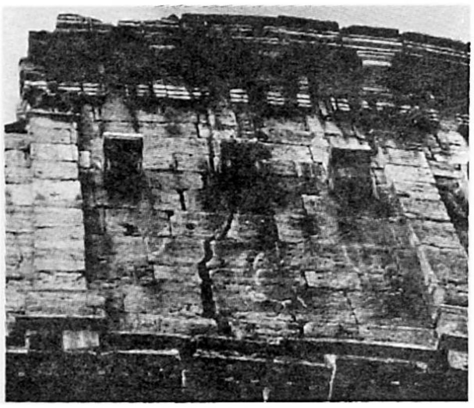
The evaluation of the safety level, expecially for historical buildings is not an easy task and, as a general rule, it is necessary to follow simultaneously three different routes or criteria.
The safety assessment, should thus result from the synthesis of the best information obtainble from the following different approaches:
I - historical survey (historic-critic method) which consists of the systematic reading and interpreting of historic documents;
II - in situ observations (or empirical-qualitative method), often with the support of investigations and monitoring systems, which consists of the survev of the crack patern, the quality of materials, and so on;
III - structural analysis (theorical quantitative method), that is an abstraction of the reality, reducing the complexity of the Monument's behaviour to simplified mathematical schemes.
The study of COLOSSEUM can be seen as a significant example of this methodology, following a continuous feed-back process.
The historical survey has pointed out the role of the earthquake in the failure and collapses that have been occurred in 443, 801, 1347, 1703 (fig. 8).
As a initial result of the historical survey there appears to be a discrepancy between the quantity of crumbled portions, as seen today, and the description of historical collapses related to the earthquakes that have been recorded
We will see later the mechanical behaviour which has caused spontaneus collapses a long time after the earthquakes have occurred. The second congitive process, the in situ survey, shows sinusoidal deformations of the external wall, (fig. 9) clearly due to the seismic effect, and considerable out of plumb.



Pic.8: the Collosseum in the XVIIIth Century

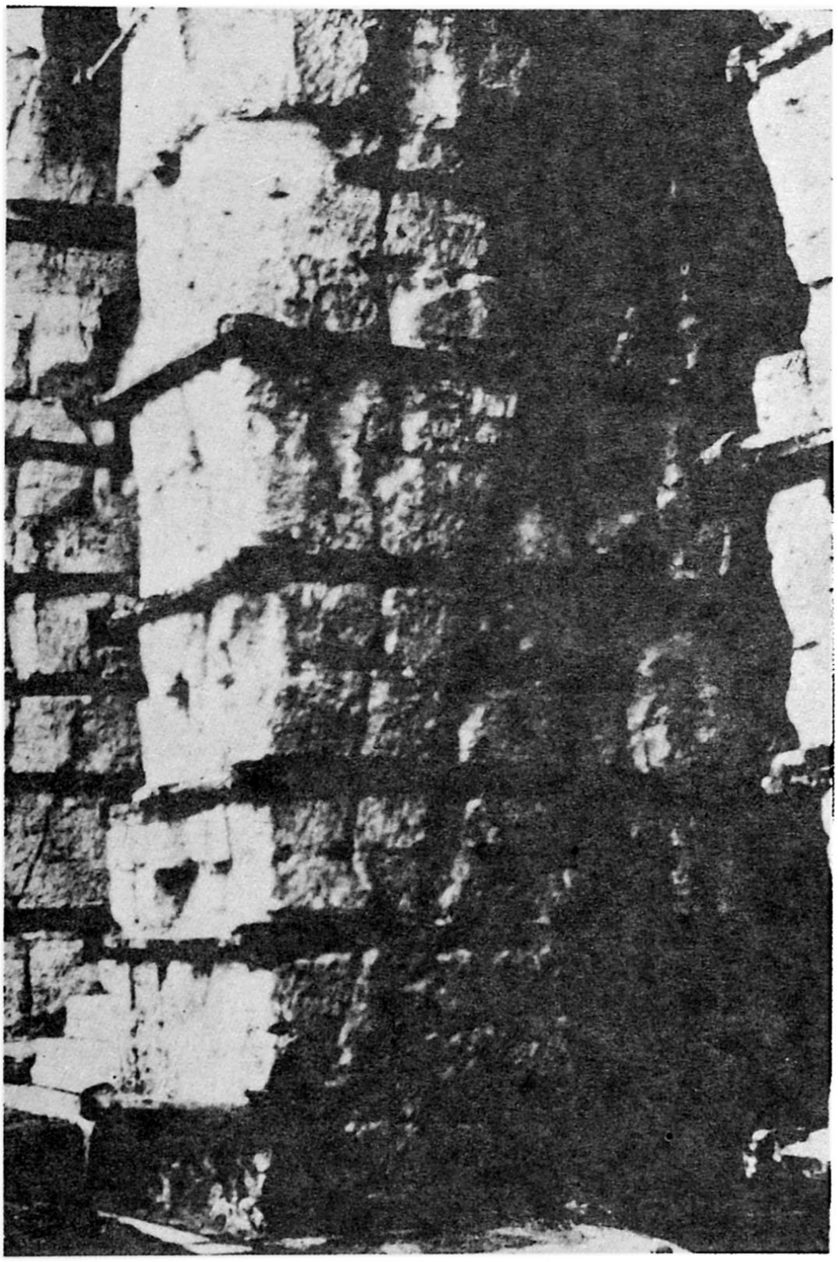


Pic.9: Sinusoidal deformations of the external wall showing the signs of the earthquake



Pic.10,11: Displacements and discontinuities in the structure of Collosseum

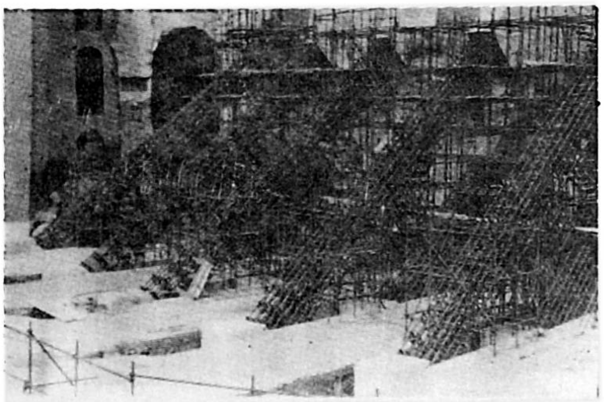
Consequences of this outward movement are relative displacement of the blocks (fig. 10) and discontinuity between the outer elliptical structure and the radial masonry (fig. 11).
The corresponding increase of the stress level has been the cause of the worrying signs of collapse present in some pillars ten years ago (fig. 12). This occurred in such fast evolution that the pillars had to be shored urgently (fig. 13).
We will see later why the Colosseum arrived at a situation of collapse two centuries after the last important earthquake, without apparent motivation.
The third criterion, the mathematic analysis (fig. 14), has shown that the foundation dishomogeneties caused a different amplification of the seismic action and have been the cause of the wellknown assymmetric collapse of Colosseum.
The mathematical analysis has also shown the importance of the dissipative behaviour under dynamic actions linked to the dry friction coefficent between the blocks.



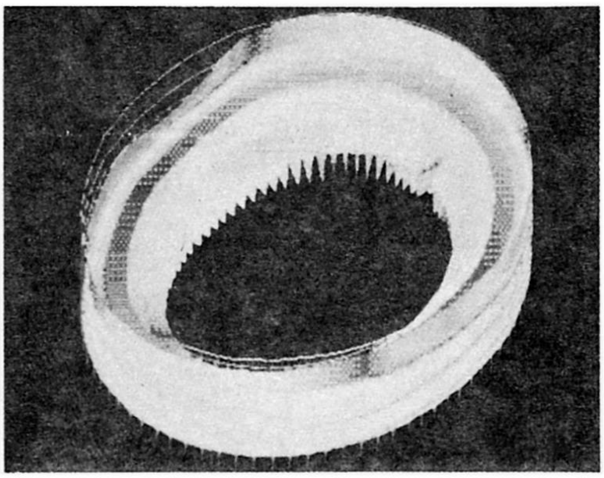
Pic.12: Warrying signs of collapse in some pillars of Collosseum 1979

On the basis of all the information obtained (historical survey, in situ observation and mathematic analysis), we can try to explain what has happened: due to the seismic actions the cylindrical outer surface suffered a loss in shape, with an increase of the elliptical length that caused out of plumb. The increase in the stress level caused the first collapse; at the same time the adjacent structural elements were left weaker because of the lack of circumferential continuity.

Once the stability had been in such a way compromised then, even weaker earthquakes, slow decay and deterioration of materials, the pushing of iced water in the small fractures caused by the high stress levels, ... generated, years, or even centuries after, the "spontaneous failures". A situation of this kind occurred, (I was witness to it), in 1979.



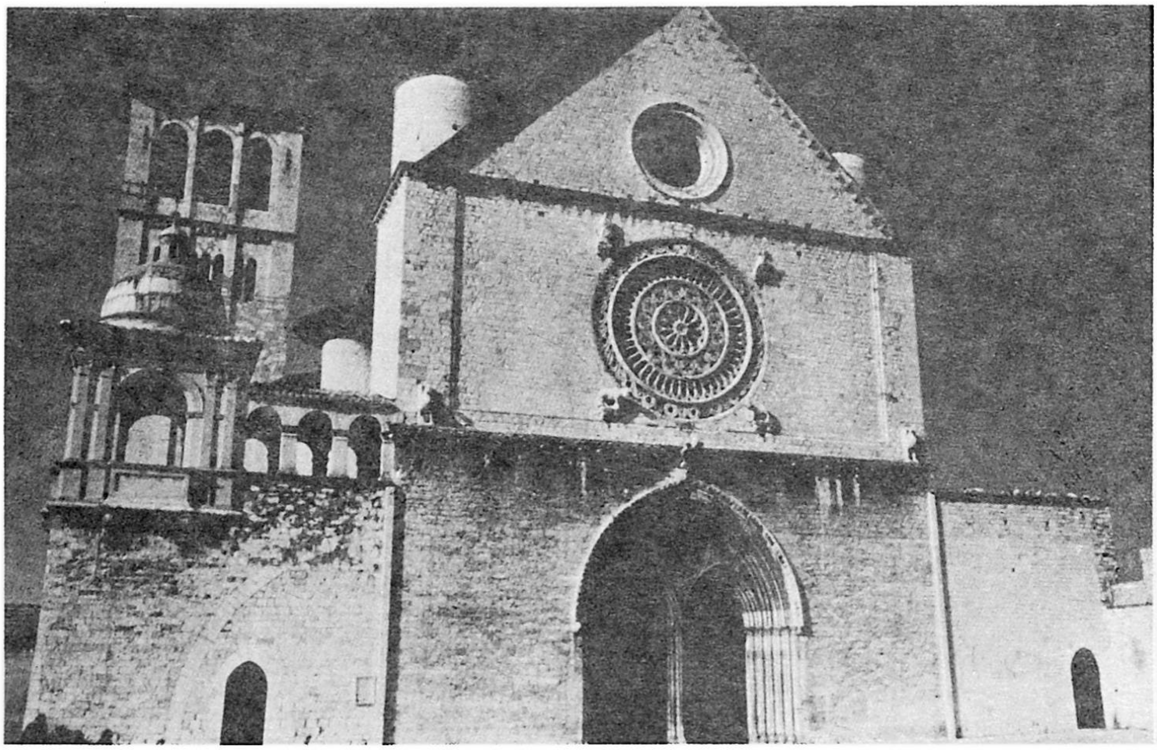
Pic.13: Shoring put in place in 1979



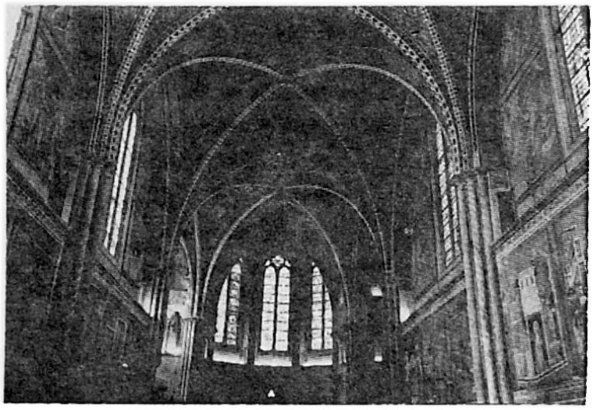
Pic.14: Mathematical model

3. INTERVENTIONS IN MONUMENTS RELATED TO EARTHQUAKE EFFECTS

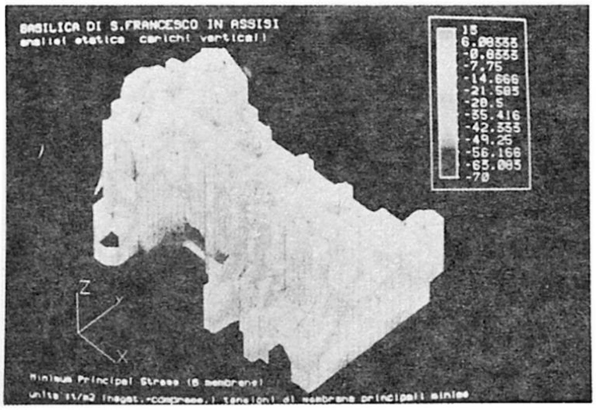
The earthquake has been also the main cause of damages in the Basilica of S. Francis of Assisi (fig. 15). Many signs are visible, the cracks in the central columns of the large windows and the damages that in the centuries have effected Giotto frescos (fig. 16).
The mathematical model shows the general stress distribution (fig. 17). In the wall that supports the Giotto frescos we can see in further detail the tensile stresses in the inner surface, and the compression stress in the outer surface, corresponding to bending moments; these stresses change sign many times during the sinusoidal seismic action, causing the cracks that we have observed. In order to reduce these effects, a steel trussed beam will be placed over the internal cornice (fig. 18, 19). This beam is connected to the masonry by oleodynamic dampers in a position to allow thermal deformations, but to react rigidly under the effect of dynamic impulse due to the seismic action.



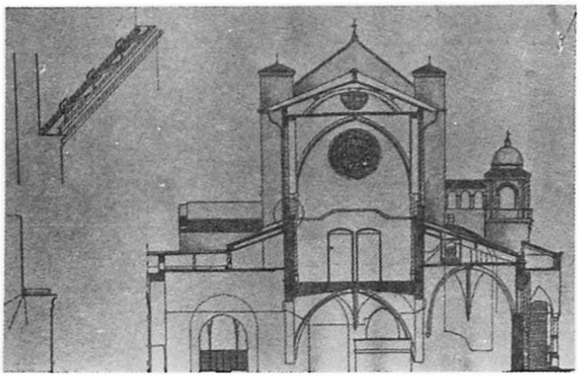
Pic.15: The Basilica of St. Francis in Assisi

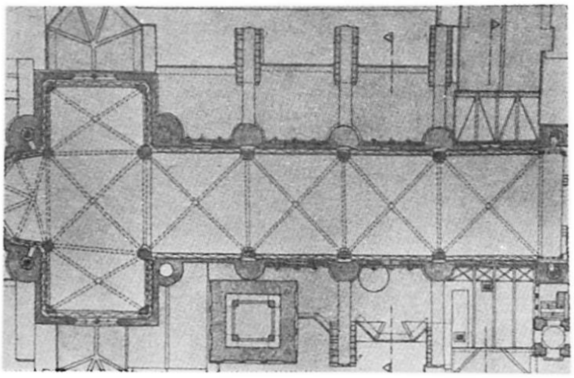


Pic.16: Damages in the Giotto frescos



Pic.17: Mathematical models of Basilica of St. Francis in Assisi

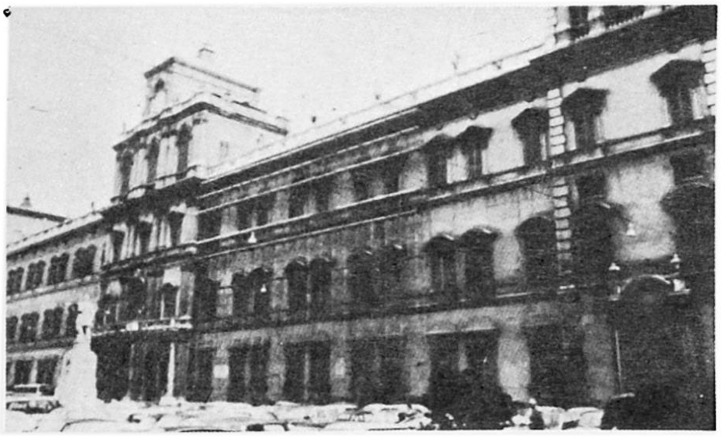




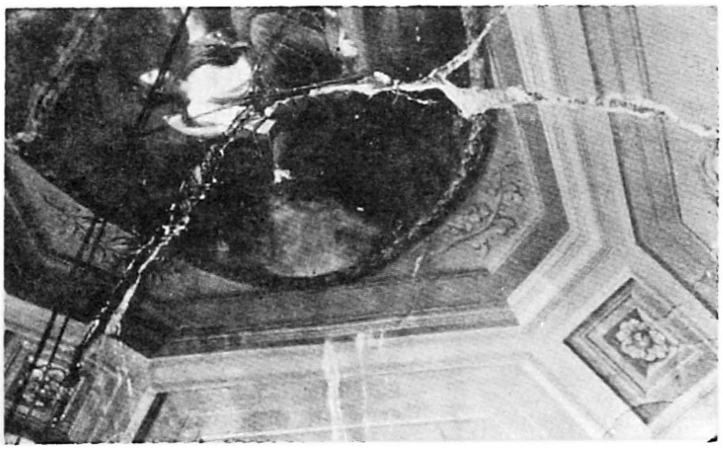
Pic.18,19: Steel trussed beam placed the internal cornice of Basilica of St. Francis in Assisi

4. INTERVENTIONS IN MONUMENTS RELATED TO SOIL PROBLEMS

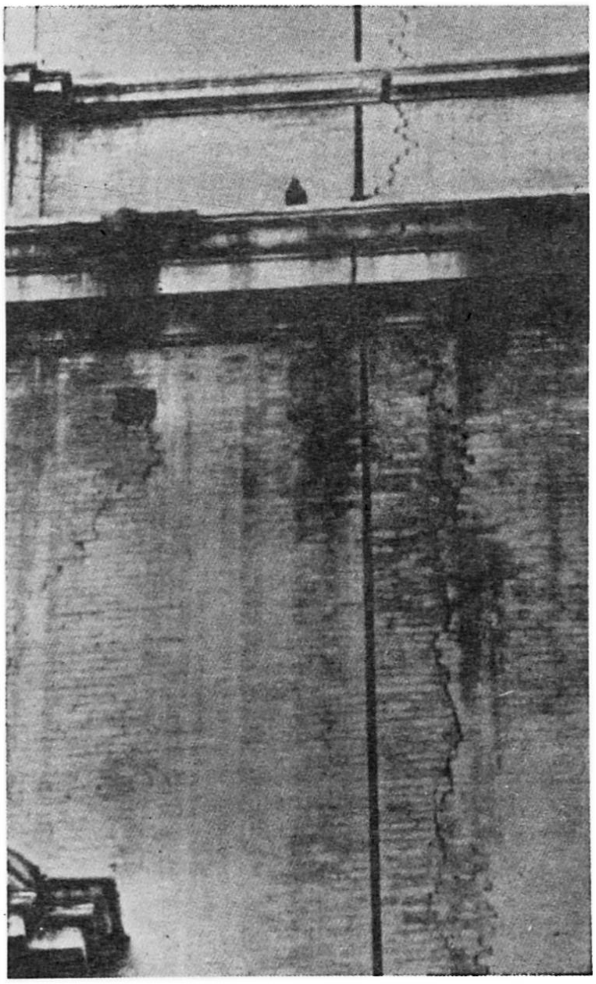
Soil deformations represent a further group of phenomena that often effect old buildings. The solution is not only in improving the bearing capacity of the foundations (underpinning, ...) or in strengthening the building as a whole. It is often better to use different solutions: in the Ducal Palace of Modena (fig. 20), where important cracks due to soil rettlements effect the walls, floors and vaults (fig. 21), we have proposed to make joints (fig. 22), to allow differential settlements to occur without inducing significant stresses in parts of the Palace.



Pic.20:Ducal Palace of Modena

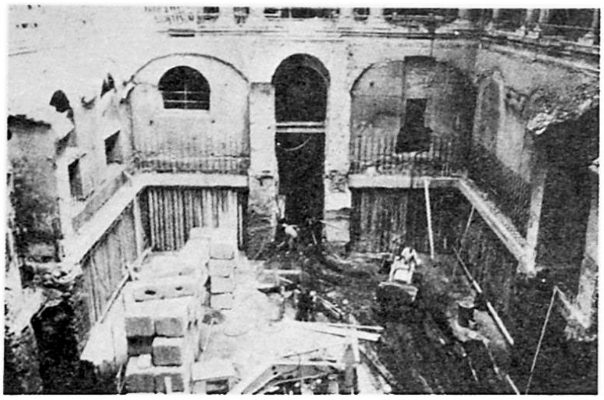


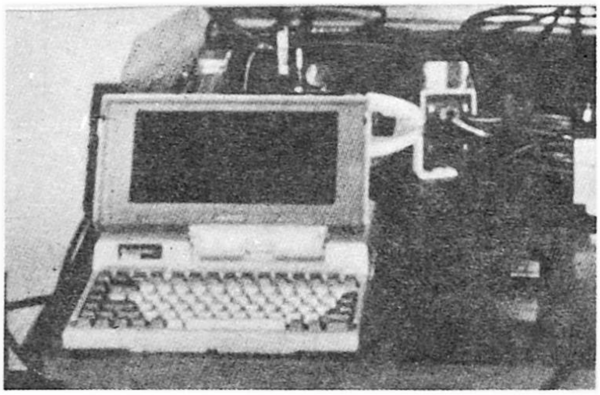
Pic.21: Cracks in the voults of Ducal Pala ce of Modena



Pic.22: Joints realized by cutting the walls, following the main crack pattern

In other situations the repairs to foundations are related to the buildings current needs.
This is the case of Palazzo di Istituto Massimo in Rome, where it was necessary to make important excavation works to obtain new space for a permanent museum, containing old coins of the Roman Empire (fig. 23); a monitoring system has been set up in order to control the settlements of the foundations and, if necessary, to take corrective measures (fig. 24).

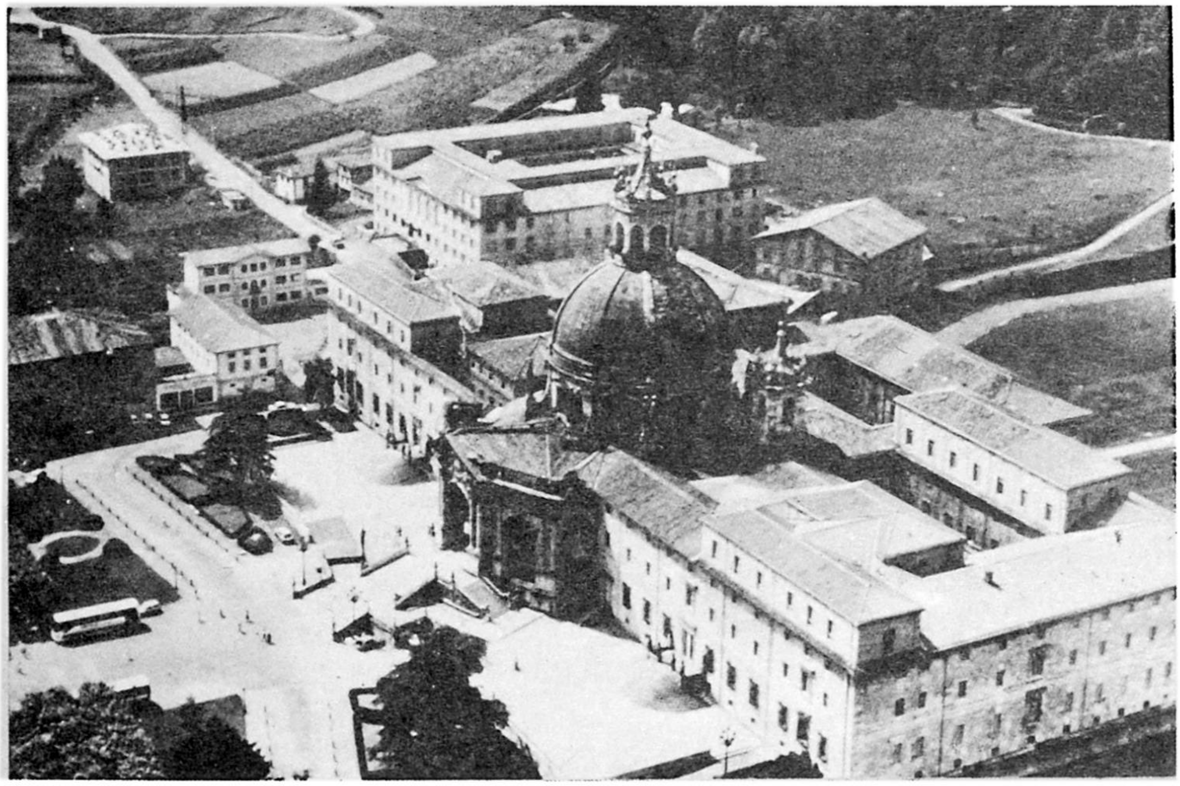




Pic.23,24: Excavation works under the foundation and monitoring system

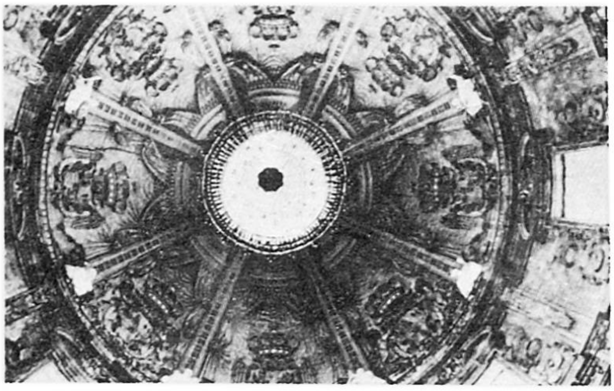
5. INTERVENTIONS IN MONUMENTS RELATED TO IMPERFECTIONS IN THE ORIGINAL CONCEPTION

A third category of problems are due to the direct forces, namely the dead load. In the Basilica of S. Ignatio de Loyola in Spain (fig. 25), this has been the cause of important cracks that effect the dome (fig. 26).

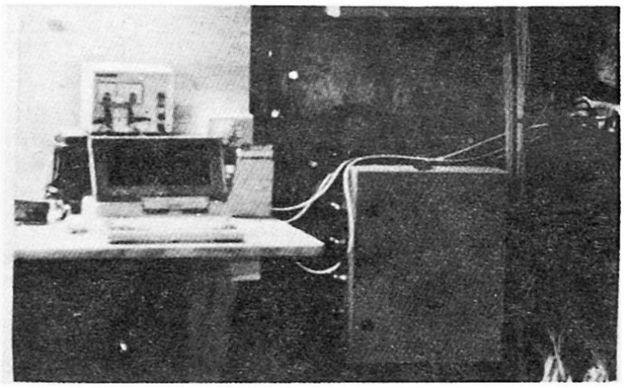


Pic.25: Basilica of St. Ignatio de Loyola in Spain

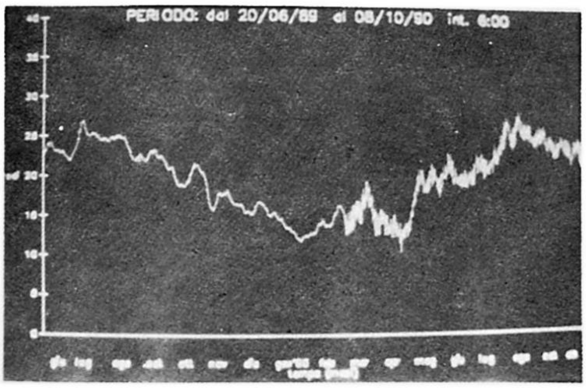
A monitoring system has been installed (fig. 27) to assess the evolutionary character of the phenomena; the results show the dependence on temperature and a low trend of the width of cracks to increase (fig. 28, 29).



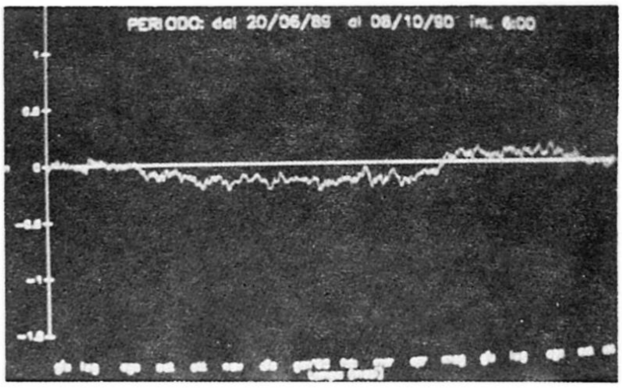
Pic.26: Cracks on the dome



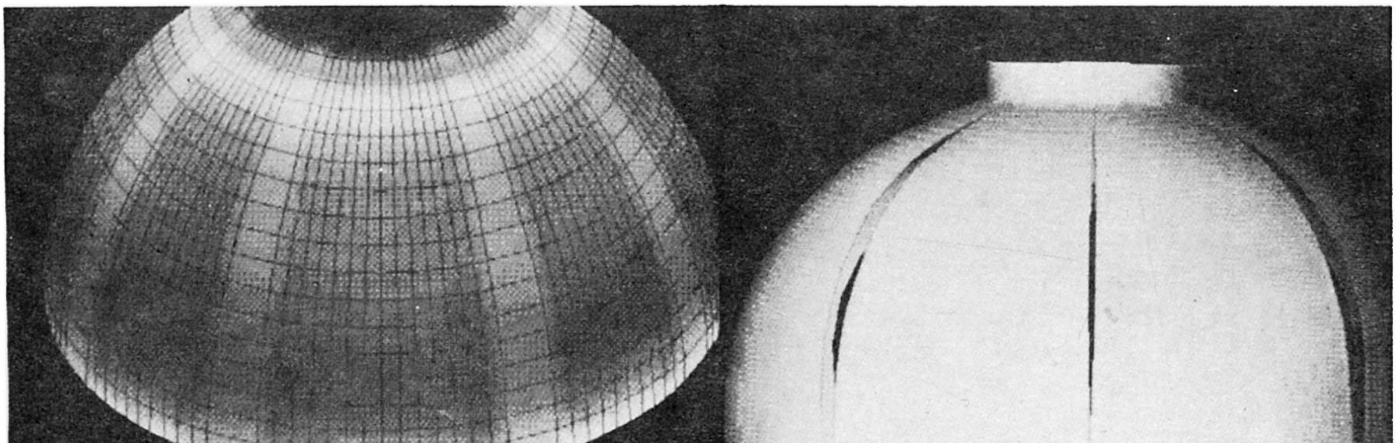
Pic.27: Monitoring system



Pic.28: Diagram of temperature evolution

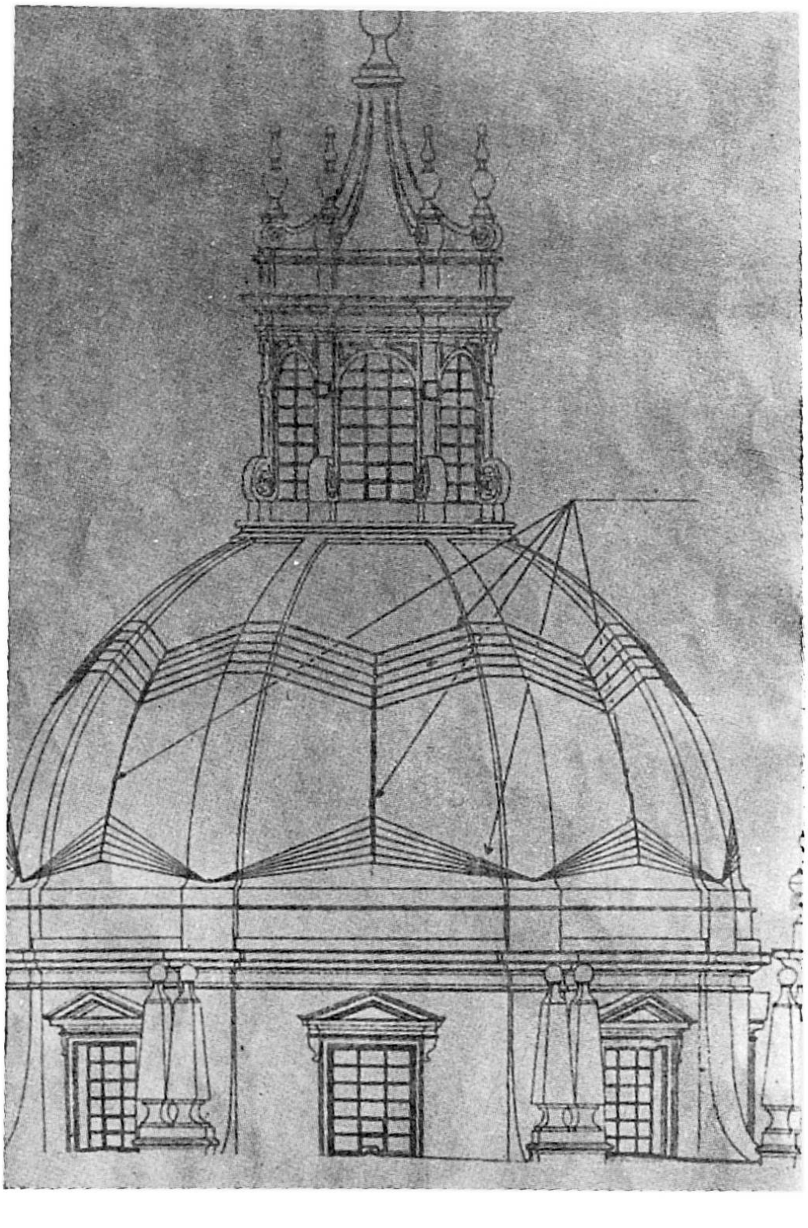


Pic.29: Diagram of crack evolution

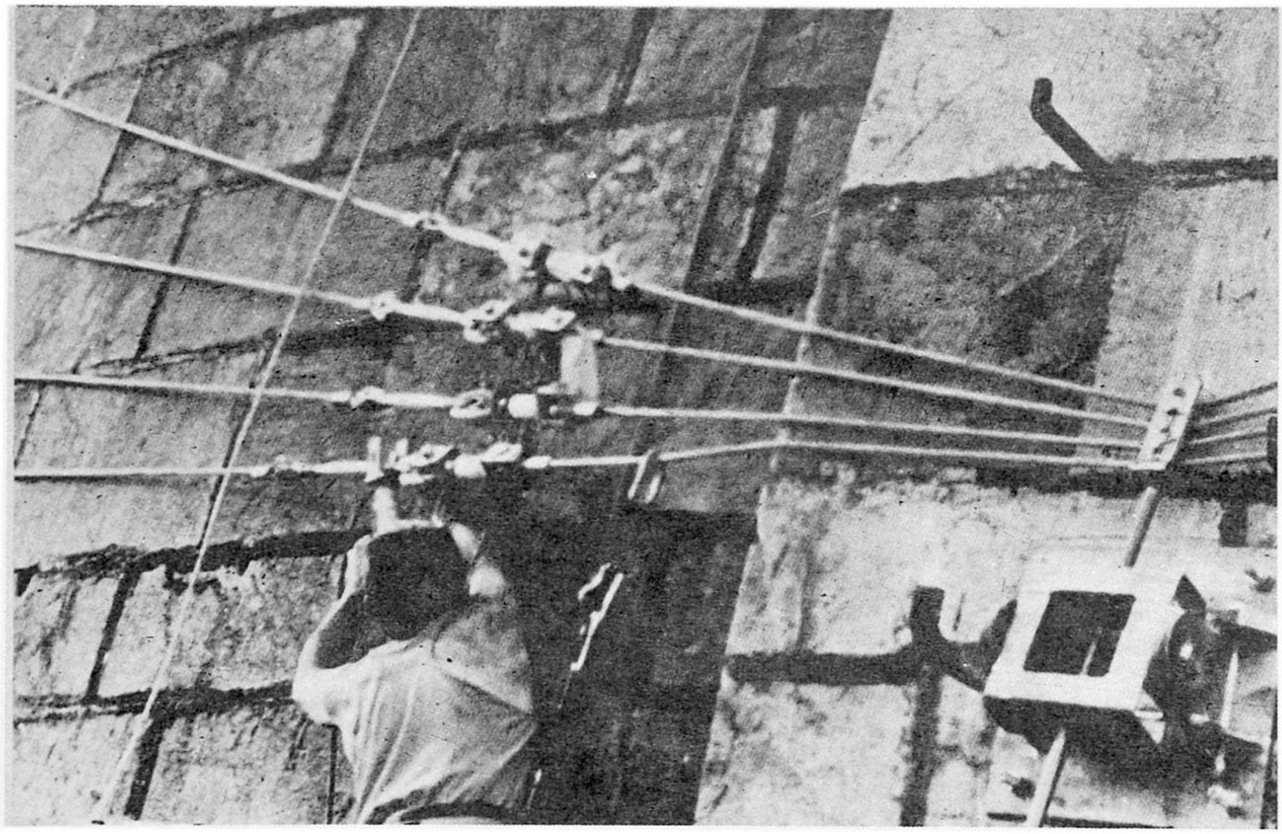


Pic.30 : Mathematical model of the dome

A preliminary mathematical model (fig. 30) shows that the shape of the dome, bein quite hemispherical, is the cause of important tensile stresses in the parallels and, consequently it has led to the crack pattern that we have observed.
A second mathematical model, taking in account the discontinuites represented by the cracks, has shown that now the equilibrium is assured only by important bending momentes in the meridians, represented by tensile stress and compression stress, on the inner and outer surface of the dome.
In this situation the margin of safety is very low.
The reinforcement that we proposed consisted of prestressed cables of the same kind usually employed to sustain the masts of sailing boats (figg. 31, 32). The advantages of this solution are economy and durability.
The stainless steel cables have been put in place by "escaladores" (fig. 33) and the phase of pretensioning has been monitored (fig. 34).

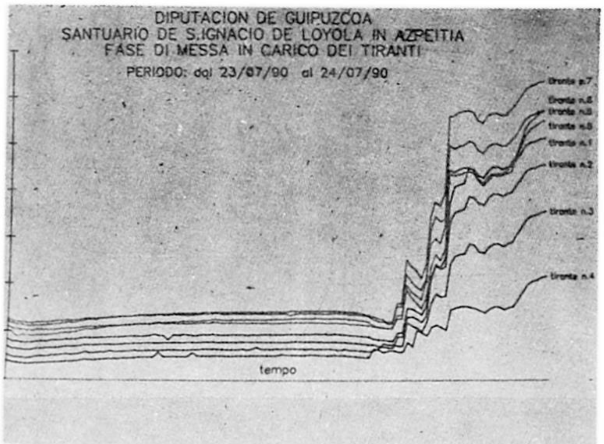


Pic.31: Prestressed cables for the reinforcement of the dome



Pic.32: The cables for the reinforcement of the dome

Pic.33: The operations to place the cables



Pic.34: Monitoring of the phases of prestressing