SAN CARLO BASILICA IN ROME: THE RESULTS OF THE DEFORMATION MEASUREMENTS

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In this article it is briefly described the control network of the "San Carlo al Corso" Basilica in Rome. This network has the task to observe the movements and the deformations of the structure, using both automatic and non-automatic instruments. The article presents the main characteristics of the automatic instruments installed, the procedures used to define the position and the number of the control points and also some results of the deformations control.

1. HISTORICAL INTRODUCTION

The Basilica of the "SS. Ambrogio e Carlo alla Nazione Lombarda", placed in via del Corso in the very centre of Rome, is one of the most prestigious roman churches. After the canonisation of "San Carlo", the "Arciconfraternita dei Lombardi" founded in 1471 by the pope Sisto IV and that was an association made to bring together all the people coming from Milan and living in Rome, decided to built in honour of the Saint a big church. The works began in the January 1612 and finished in the period between 1685 and 1690.

The main architectural style used to build the Basilica is called Late Roman Baroque and the dimensions of the church are 72 x 34 meters. The big dome reaches the height of 60 meters and is considered the structural more important part of the church. At the moment "San Carlo" presents some structural problems shown by the great number of cracks distributed along the entire dome, in the highest parts of the arches carrying the drum and in the apse. For these reasons in 1992 it was planned an important program of structural restoration of the entire Basilica.

2. GENERAL VIEW OF THE STATIC CONTROL NETWORK

The control has the aim to describe the deformative evolution of the cracks and of the main structural elements of the Basilica in the way to contribute to a well planning and definition of the structural restoration works. The possible causes that have determined the actual static situation may be the differential movements of the foundations, mainly of the ones belonging to the 4 main pillars that have to support the dome, the material ageing and the continuos stress caused by the deformations of the structure due to the daily and the seasonal thermic variations. The control network has been planned so to check the deformations of the elements whose observation could permit to understand the contribution of each cause in the damaging process. The movements of the cracks of the Basilica present

two main components: the first one has a thermic origin and a quick evolution, the second one is caused by structural deformations, mainly coming from the foundations movements and characterised by a slower progress. These processes can be distinguish observing their temporal frequency. This operation can be done using an automatic approach at the measurements of the deformations; in this way it is possible to freely define the sampling of the measurements. The cracks along the dome, the abse and in the crypt have been observed using automatic extensometers characterised by a good accuracy to permit to distinguish also the small daily thermic deformations of the walls of the church. The thermic effects can cause not only local deformations but also more complex and general movements of entire elements of the structure and this hypothesis was verified placing six horizontal extensometers at three different levels of the dome (pictures 1 and 2), to check the deformations of the diameter, and four vertical ones along each of the four main pillars, to check the length deformations. On the other hand the slow movements caused by the instability of the foundations have been observed with non-automatic instruments; in particular it was studied the verticality of the four main pillars and the altimetric movements of the foundations with an high precision levelling network.

3. THE AUTOMATIC CONTROL

The automatic instruments observe particularly the movements and the deformations of the more badly maintained structural parts of the Basilica composed by the dome, the drum and the 4 main pillars that support the dome. In this area were installed:

- 25 automatic short-base extensometers (0.2 meters long) (the position of some of these is shown in the pictures 3, 4, 5 and 6)
- 4 vertical long-base extensometer (8-10 meters long)
- 6 horizontal extensometer (6 - 8 meters long)
- 10 transducers of temperature (thermocouples T)

Outside this area were placed only three short-base extensometers in the apse, one in the crypt and one more transducer of temperature (in the apse). The automatic instruments are composed by a mechanic part and by a transducer of displacement. The sensor used to make the automatic measurement of displacement was the linear variable differential transformer (LVDT) that is characterised by a very good linearity and stability in the time. Each LVDT works with a totally dedicated electronic conditioner that represent the more unstable part of the sensor. For this reason every transducer and its conditioner must be tested in laboratory to measure the linearity of the system and to calculate the drift of the signal with the variations of the temperature. These information are later used to clear the measurements from the unwanted drift of the signal. Both the short-base extensometers and the long-base extensometers admit a manual control measurement, so to permit the regular check of the good conditions and of the accuracy of the automatic measurement. Evidently this check could be made, every 3 month, only for the instruments positioned in a well reachable position.

3.1. The automatic instruments

The automatic instruments, short-base extensometers and long- base extensometers, use the same type of LVDT sensor to measure the movements. The pictures 7 and 8 show respectively the short-base extensometer and the long-base extensometer. The main part of the horizontal extensometer, composed by a metallic and plastic casing, by the LVDT and by a metallic mechanism, is firmly fixed to the wall and is connected through an invar wire to the opposite part of the Basilica's structures. In this way can be easily measured the movements between elements of the Basilica having a relative distance of some meters.

The "heart" of each automatic instrument, the transducer, is directly connected to one of the three dataloggers and to an energy supply station. Each datalogger can store 960 Kbyte of measurements and admit 24 channel in input (both from the LVDT and from the thermocouples); the data can be downloaded by modem or by personal computer using a RS-232 connection. The functions of the dataloggers can be defined by software using a personal computer that can also be used for on-line measurements. Each datalogger is characterised by 4 output alarms. The automatic measurements are collected by the dataloggers every 6 hours, in the way to observe also the daily deformations of the elements controlled. The accuracy of the deformation measurements made by the short-base extensometers is 0.02 mm; the long-base extensometers have a lower accuracy caused by the presence of the thermic dilatation of the invar nail. The bigger part of this effect is calculated and adjusted, measuring the temperature in the very near area of the extensometer; the accuracy cannot be considered better than 0.1 mm.

4. THE NON-AUTOMATIC CONTROL

The levelling network is composed by 57 control points placed on the main walls of the Basilica (picture 9). The measurements are made every three months using a Zeiss Ni1 automatic level and are adjusted using a least squares approach. The accuracy of the height definition of the control points is about 0.1 mm. Also the measurements of the variation of verticality of the 4 main pillars is made every three month with an accuracy of 0.1 mm.

5. RESULTS OF THE CONTROL

The control began the 3rd of April 1992 with the first measurement of the levelling network. The start of the automatic control began on the 29th of July 1992 and has been carried on until the October 1993. The analysis of the altimetric movements shows that there aren't important differential movements in progress; to highlight the smallest deformations it is necessary to control the movements for, at least, three or four more years.

On the other hand the automatic control is already giving good results regarding the yearly and daily deformations of the structural elements of the Basilica. All the extensometers show a syclic seasonal deformation. After one year of control the geometric configuration of the structural elements seems to return to the same initial status and for this reason it is reasonable to adfirm that the Basilica is not near to a structural collapse. On the other hand both the daily and seasonal deformations reach, in same cases, very important values.

In the upper part of the dome the cracks have a seasonal deformation of 1-1.5 mm and a daily movement of 0.2-0.3 mm. The trand of these deformations follows very well the outside temperature with a delay of few hours (2-3 hours).

Also the results coming from the long-base horisontal extensometers show an important seasonal deformation that reaches a maximux excursion of 3-4 mm.

The picture 10 show the deformations of some cracks (101 and 103) placed in the abse and the variations of temperature measured inside and outside the Basilica, as an example of results representation;

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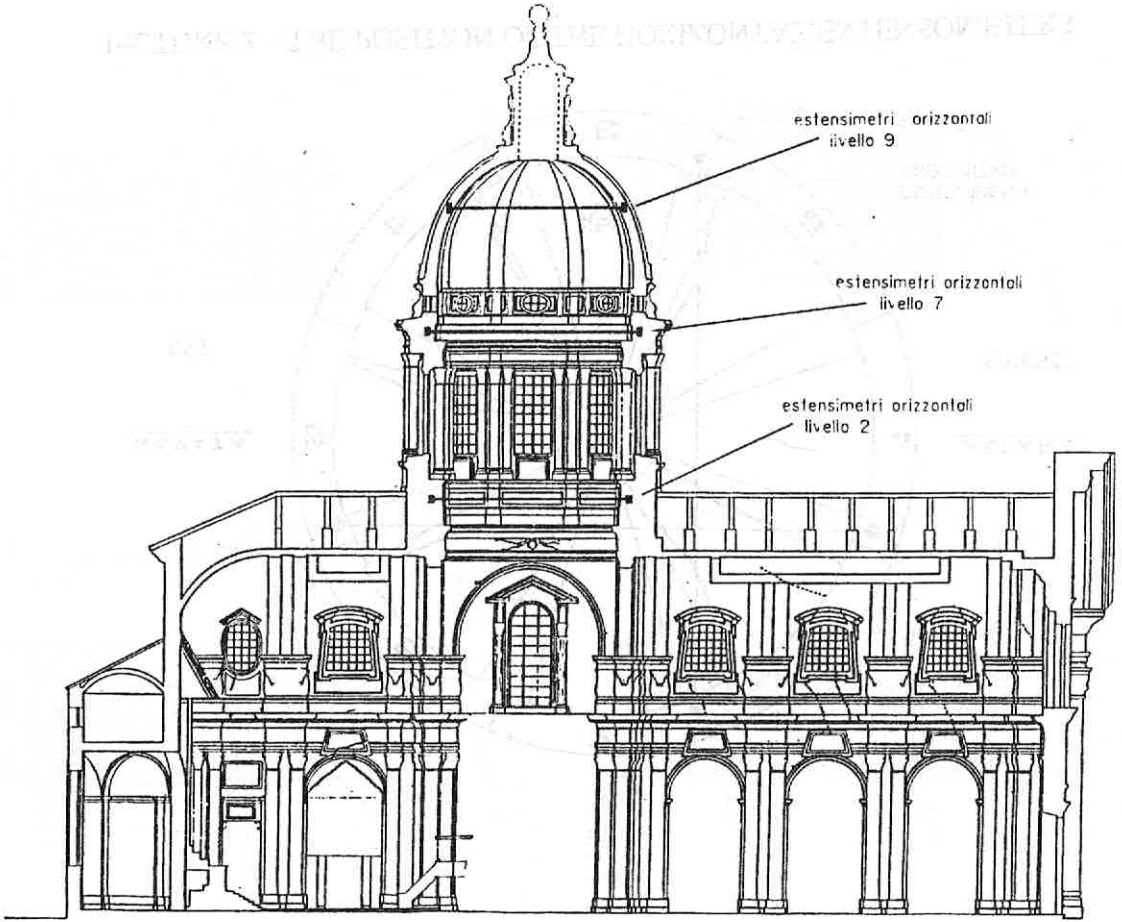
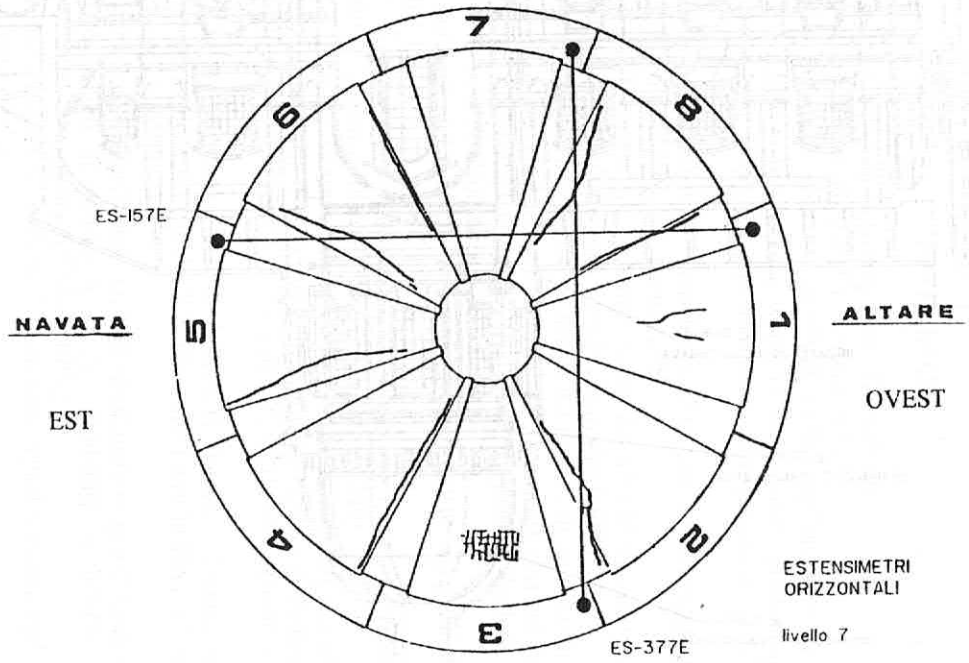
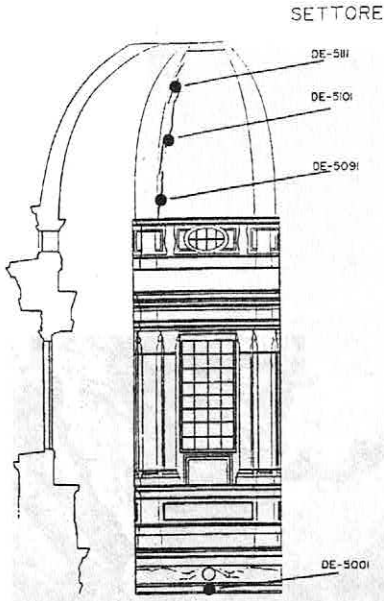
PICTURE 1 THE POSITION OF THE HORIZONTAL EXTENSOMETERS

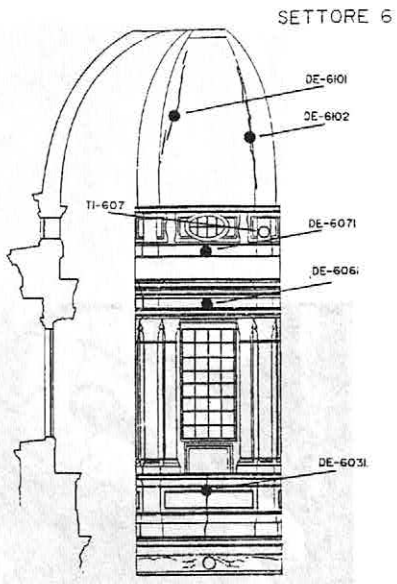




PICTURE 2 THE POSITION OF THE HORIZONTAL EXTENSOMETERS



Picture 3



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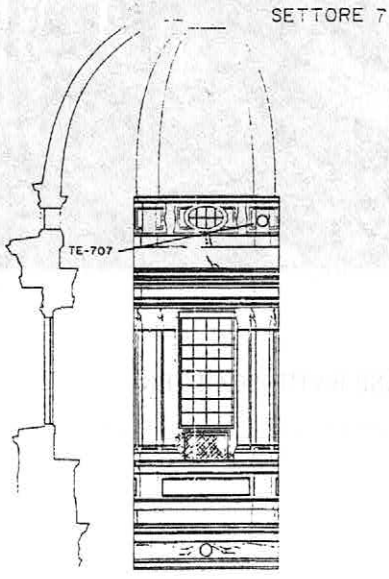

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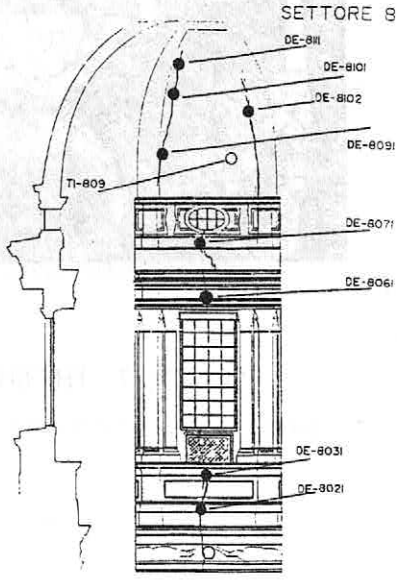
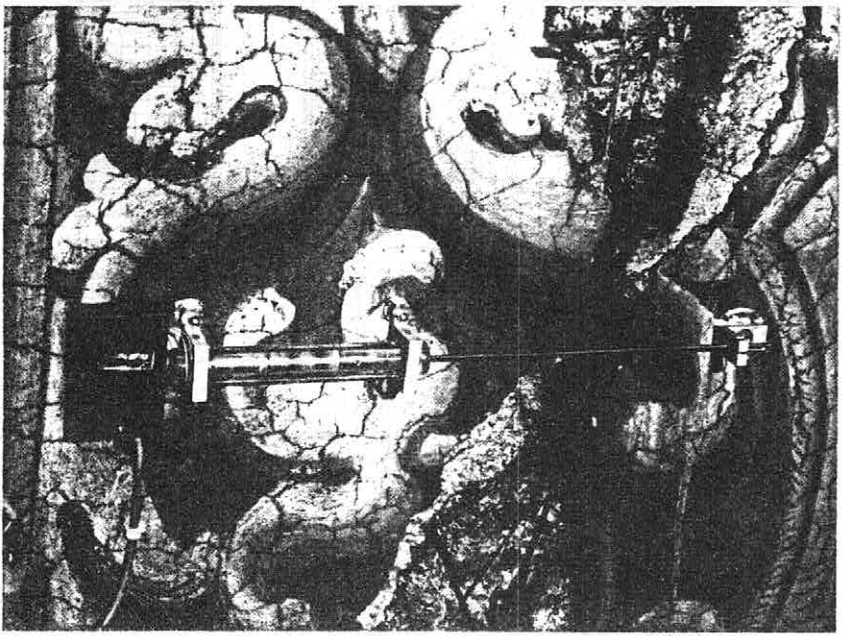
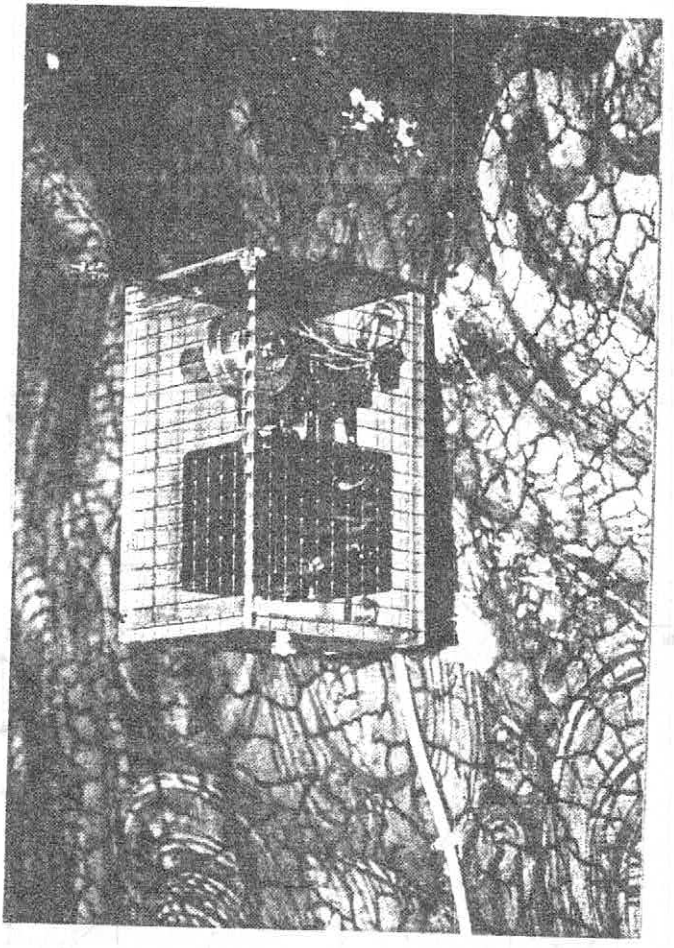


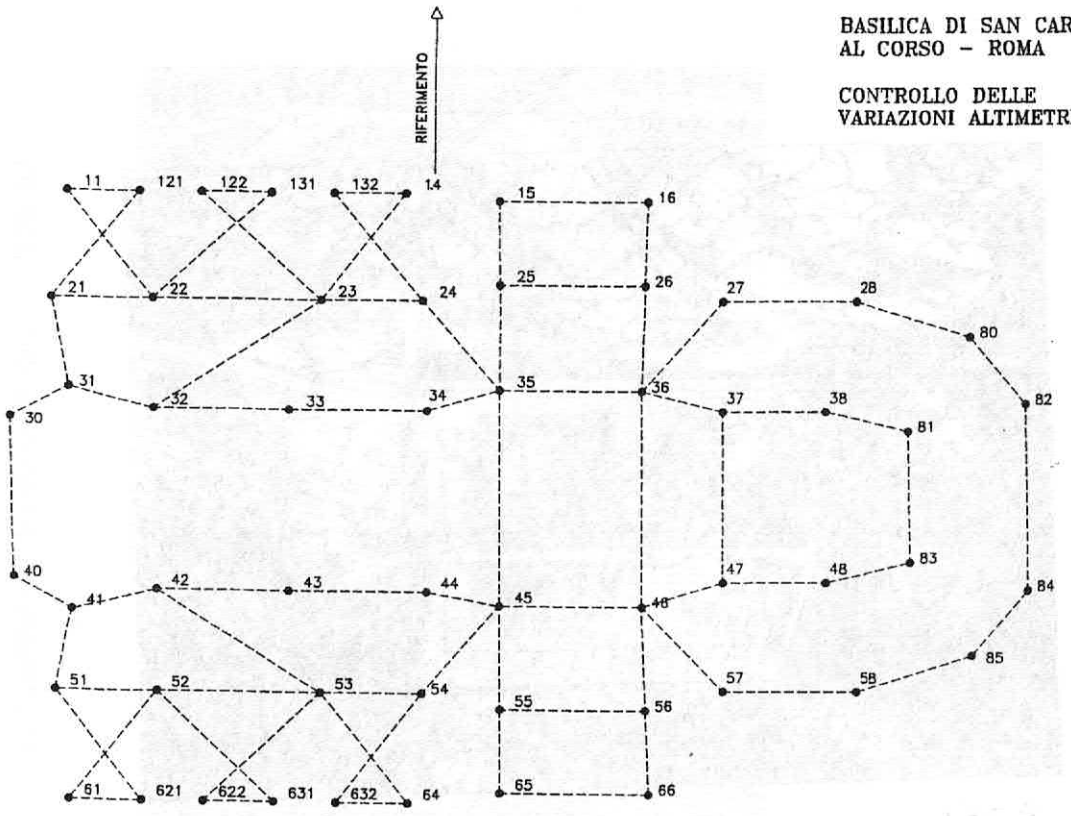
Picture 6



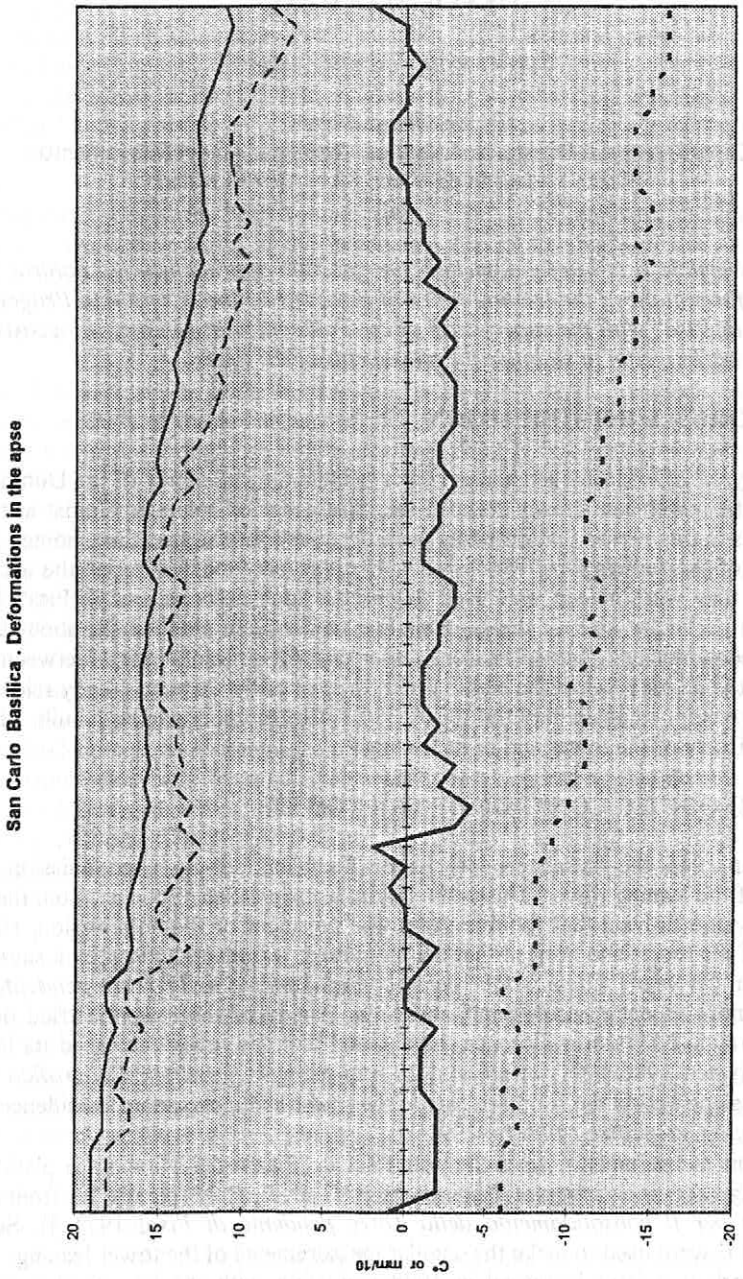
PICTURE 7 THE SHORT-BASE EXTENSOMETER



PICTURE 8 THE LONG-BASE HORIZONTAL EXTENSOMETER



PICTURE 9 THE LEVELLING NETWORK


San Carlo Basilica . Deformations in the apse
C° or mm/10
20
15
10
5
0
-5
-10
-15
-20
time (days)
Temp. In.
Temp.Out.
Def. 101
Def. 103

PICTURE 10