The Role of Monitoring for the Knowledge of the Behaviour of Structures

Le rôle de la surveillance dans la connaissance du comportement des structures

Die Rolle der Überwachung für ein besseres Kenntnis des Bauwerken-verhaltens

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SUMMARY
This paper presents different criteria to use advantageously a monitoring system to verify the structural behaviour of constructions; three kind of functions are presented: control of the construction during its execution; control of an existing construction; control of a construction in relation to perturbations produced by external works.

RESUME
Cet article présente divers critères pour utiliser avantageusement un système de surveillance dans le but de vérifier le comportement structural des constructions; on souligne trois types de fonctions: le contrôle de la structure durant sa construction; la surveillance d'une construction existante; le contrôle d'une structure à la suite de perturbations dues à des travaux extérieurs.

ZUSAMMENGFASSUNG
Dieser Beitrag stellt verschiedene Kriterien zum günstigen Verwenden von Überwachungssystemen für das Prüfen des Bauwerkenverhaltens vor; es werden drei verschiedenartige Tätigkeiten hervorgehoben: Das Überwachen von Bauwerken während deren Errichtung; Das Prüfen von bestehenden Bauten; Das Überwachen von Störungen durch äussere Arbeiten beeinflusste Bauwerken.

1 PRELIMINARY REMARKS

The use of a monitoring system, to obtain data (strain and stresses in the material; the amplitude ofcracks, and joints; temperature; movements of the foundation; inclinations, ...), represents a very usefull way to verify the structural behaviour. This facility appears of particular interest in the following situations:

1) Control of the construction's behaviour during its execution;
2) Control of an existing construction, that is interested by damages, which can be related to ciclic or progressive phenomena;
3) Control of the construction's behaviour in relation to perturbations produced by external works of different kinds.

In this Note are presented some examples, that illustrate the three situations which we described before, and the criteria on the base of which it is possible to correlate the experimental data with the analytical models representative of the construction.

2 CONTROLS DURING EXECUTION

2.1 General aspects

This type of controls allows to verify the correspondence between the reality and design, either during execution of new constructions, or during interventions of strenghtening or consolidation; the analysis of the results can be usefull not only to modify the design in relation with the obtained data, but also like a testin during the works.

2.2 A prestressed concrete bridge on the Tiber River

The monotoring was related with the control of the bridge during its execution (fig. 1), and in particular it regarded the verticals displacements (due to elastic strains, creep shrinkage and temperature variations) for comparing theorical and effective phenomena. The difference between them were analyzed by a computer program in order to correct the elevation of the structural elements before to cast them.
The vertical displacements were correlated to the level of a liquid (mercury), contained in some small vases (fig. 2), designed by the Author in 1970, and connected between them with a net of tube. The level was measured by a inductive transducer that trasmitted the signal to a computer. The diagrams of the displacements' evolutions, for different sections of the bridge, are shown in fig. 3. and 4.

2.3 Santomarco tunnel in the Paola -Cosenza railway.

The behaviour of the tunnel lining depends from the radial pressure distribution, from the value of these pressure and their variation with time increasing. The definition of the rules and parameters governing this problem is always affected by uncertainty related with the indispensable extrapolations of the results of tests to complexes situations. In these extrapolations an important rule is assumed by the anisotropy of the rock and by the alterations due to exavation. In order to obtain more complete informations on the real behaviour of the soil-structure system, and to have the capabiity of adjust during

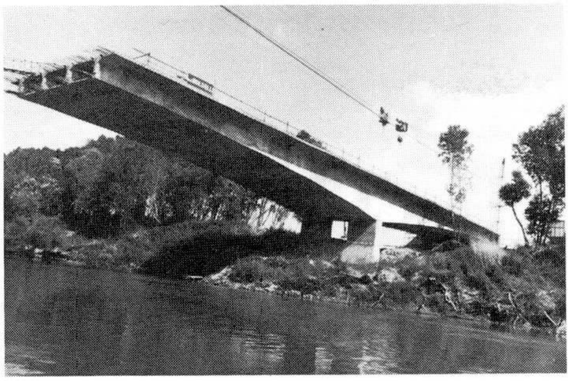


Fig.1 The bridges on the Tiber River during its ececution.

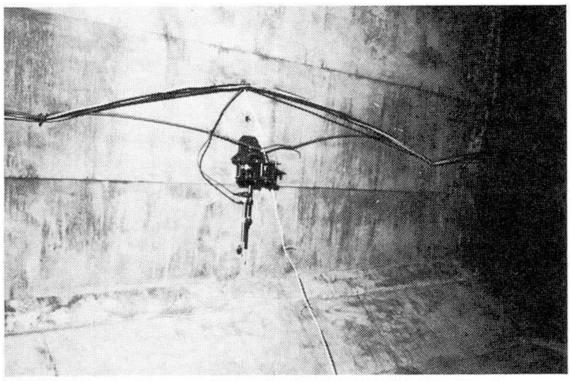


Fig. 2 Levellometric vases.

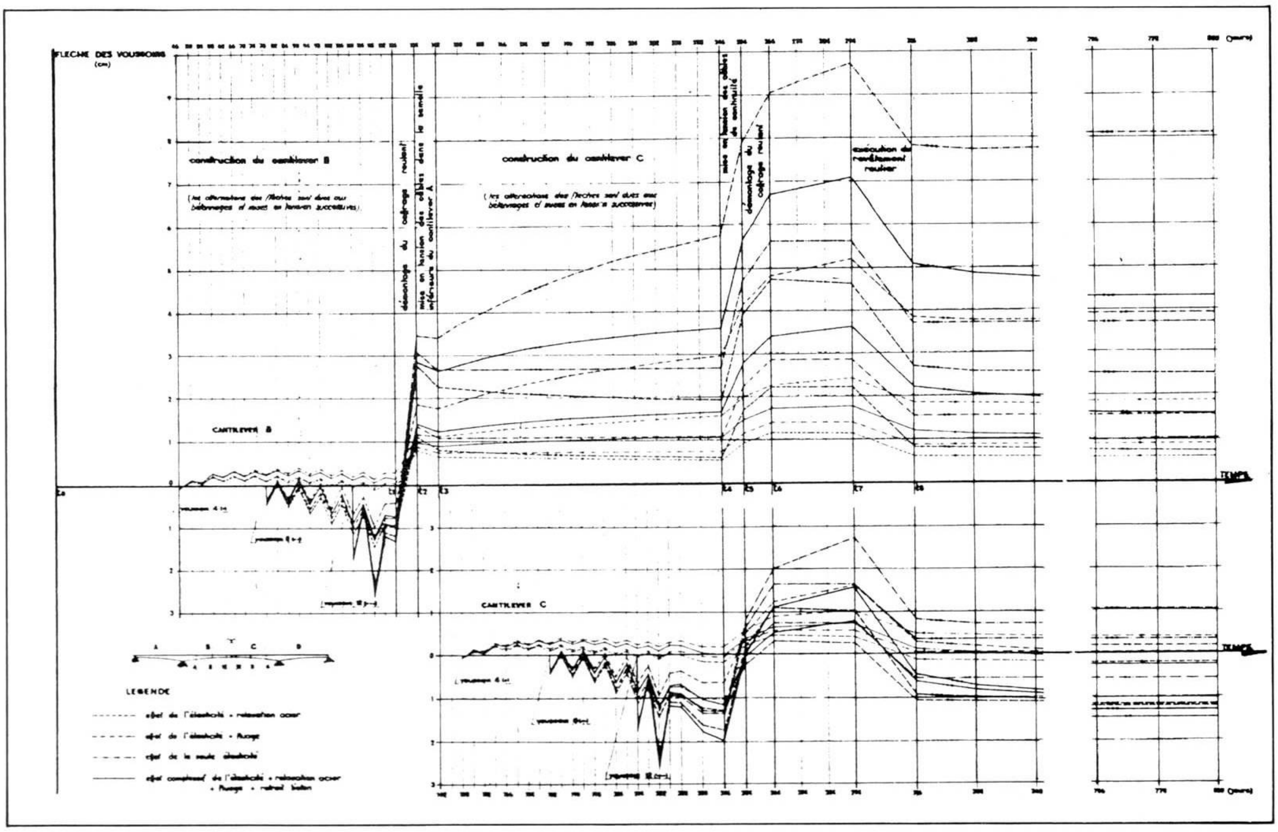
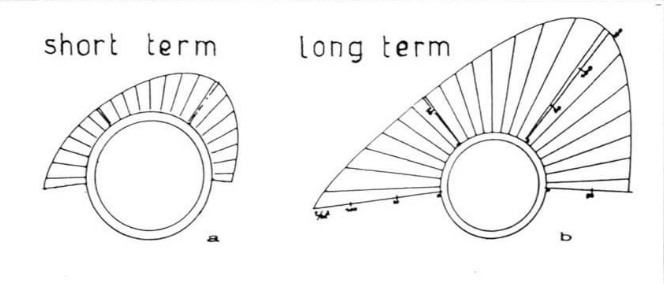


Fig. 3-4 Diagrams of the displacements' evolution for different sections of the bridge.



Diagrammi polari di sollecitazione sul rivestimento dopo 2.5 mesi dalla posa in opera (a) ed a situazione stabilizzata (b).

Fig. 5 Diagram of the soil-liner interface pressures at short and long term.

the works the construction modality in relation with situations different by the design assunptions, was planed an instrumentation system, that was composesed by:

- pressure ganges to determine the rock-liner interface pressure;
- strain ganges into the concrete segments and into the additional centres;
- rock extensimeters placed in radial direction from the liner, anchored in the rock, with different lenght (6,9 and 15 meters), to control the width of surroinding soil yelded, in consequence of exavation. The figure 5 shows,

for one of the instrumeted rings of the liner, the diagram of the soil-liner interface pressures at short and long term. In the figure 6 is showed the evolution of the average pressures with the time increasing. It appears the comparison among the theorical exponential curve (a), the curve related with the graphic extrapolation of the adimensional curves (b) and the experimental exponential interpolation curve(c). The concordance among the results is goood at long term, while in the first months the theorical previsions had under-estimated the phenomenon. The experimental control has pointed out the necessity of gear up the times of insertion of the strengthening steel centres, that in the design assumptions should have been inserted in place more later. The applied methodology can be considered from a general point of view. Infact, every time there are complex problems, and phenomena based upon highly uncertain parameters the experimentation during the construction is a rational and convenient way in a more large evaluation costs-benefits. The best knowledge in fact, not only permit to receive the allarm warning and then operate in safety conditions, but also let the engineer to develop the design in a more flessible and articulate way. Many unfavorable situations are not unforeseeable, but only more one less probable conditions: a correct methodology of design must anticipate at the begin the possibility to adjust the solutions in consequence of the progressively pointed out situations, without engage in undiscriminately conservative intervetions, and then unjuistifavely expensive

2.4 The intervetions in the Major and Minor Council hall into the Ducal Palace of Genova

The Vaults of the two halls see to Figure (7 and 8) presented important deformations, that are probably appeared since during his erection and successively and unlarged in spite of the intervetions made in threee centuries. The characteristics of the Vaults, conformed as barrel Vault in the central part, much lowered and thin (about 1/120 of lenght of the span) make the structure much deformable; and are sufficient little displacements and rotations of the facade to preduce the great present deformations (more than 40 cm of relative vertical displacement between the two anterior and posterior portons, Figure 9). Such as interpretation of the vault's behaviour is confirmed by the theorical analysis of a finite element model of the structure (Figure 10). The design choices to a final recovery should consider the two following requirement:

- create a global connection between the two facades of the two halls;
- create a strtucture to support the vaults, without to intervent directly on the vaults, as to mantain the effective characteristics. The structural solution is reperesented by a system of stell beams jointed theirselves and

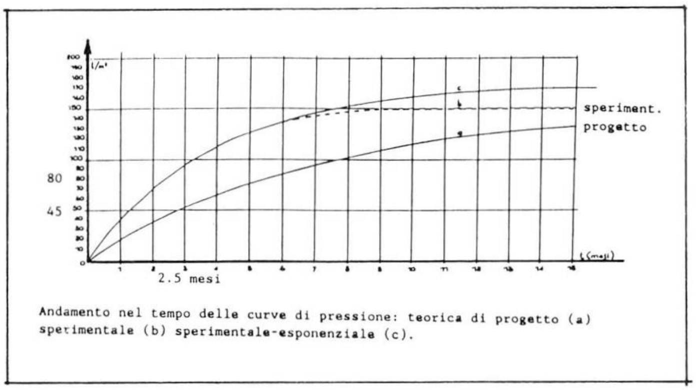


Fig. 6 The evolution of the average pressure with time increasing.

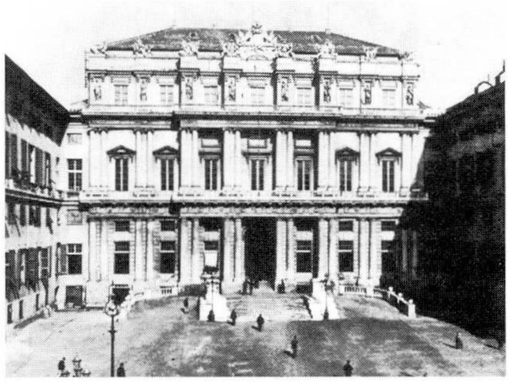


Fig. 7 View of the Ducal Palace of Genova.

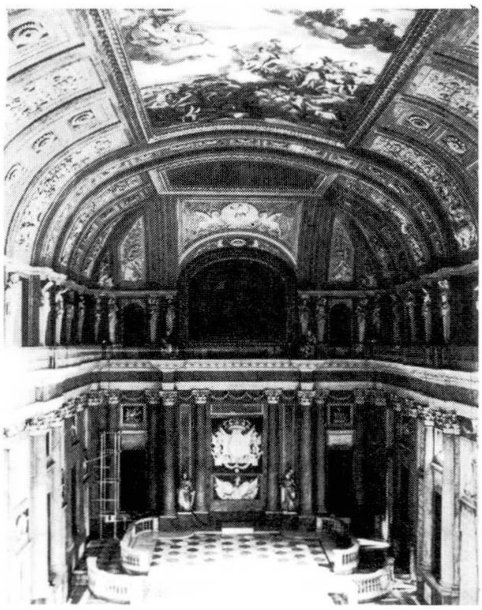


Fig. 8 The Major Council Hall.

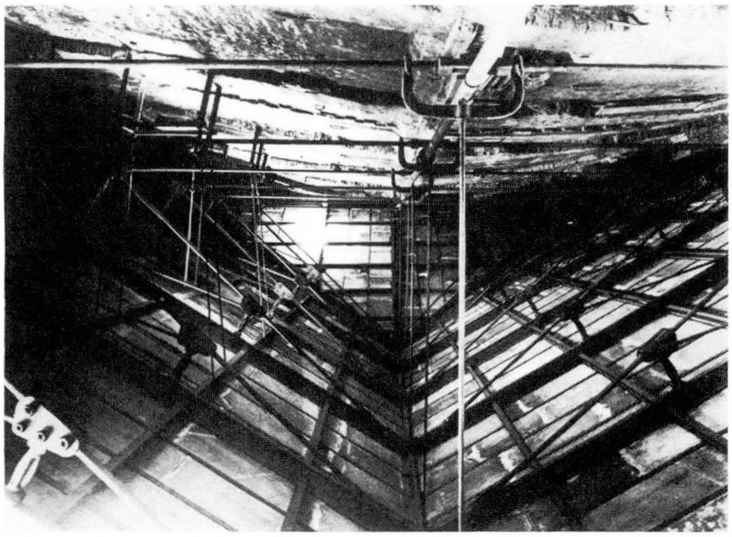
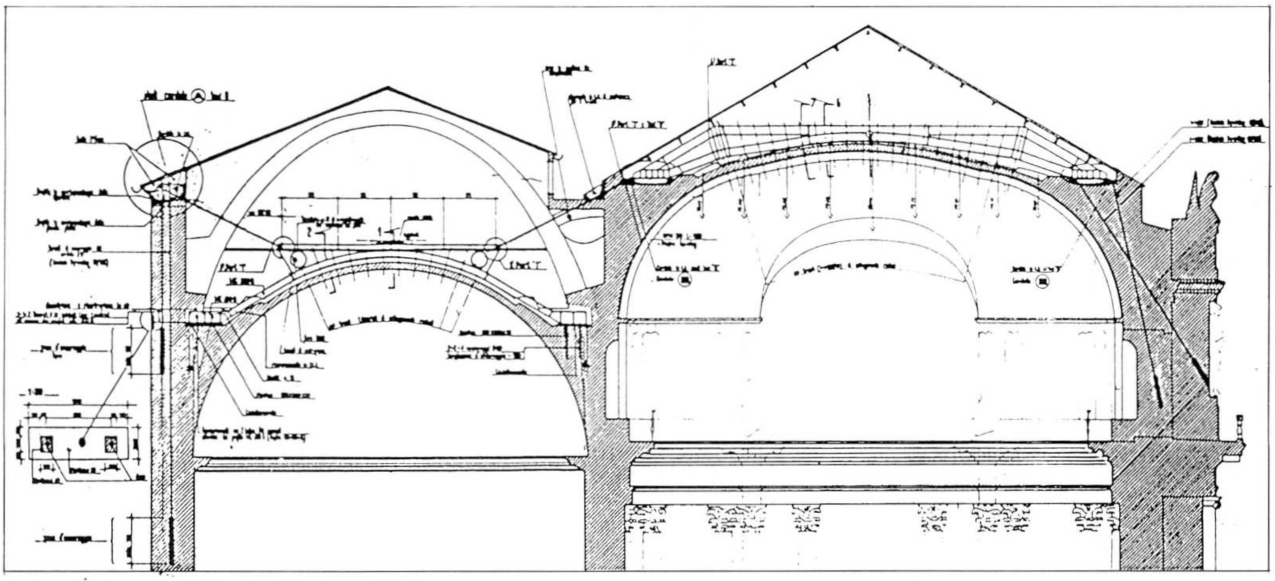
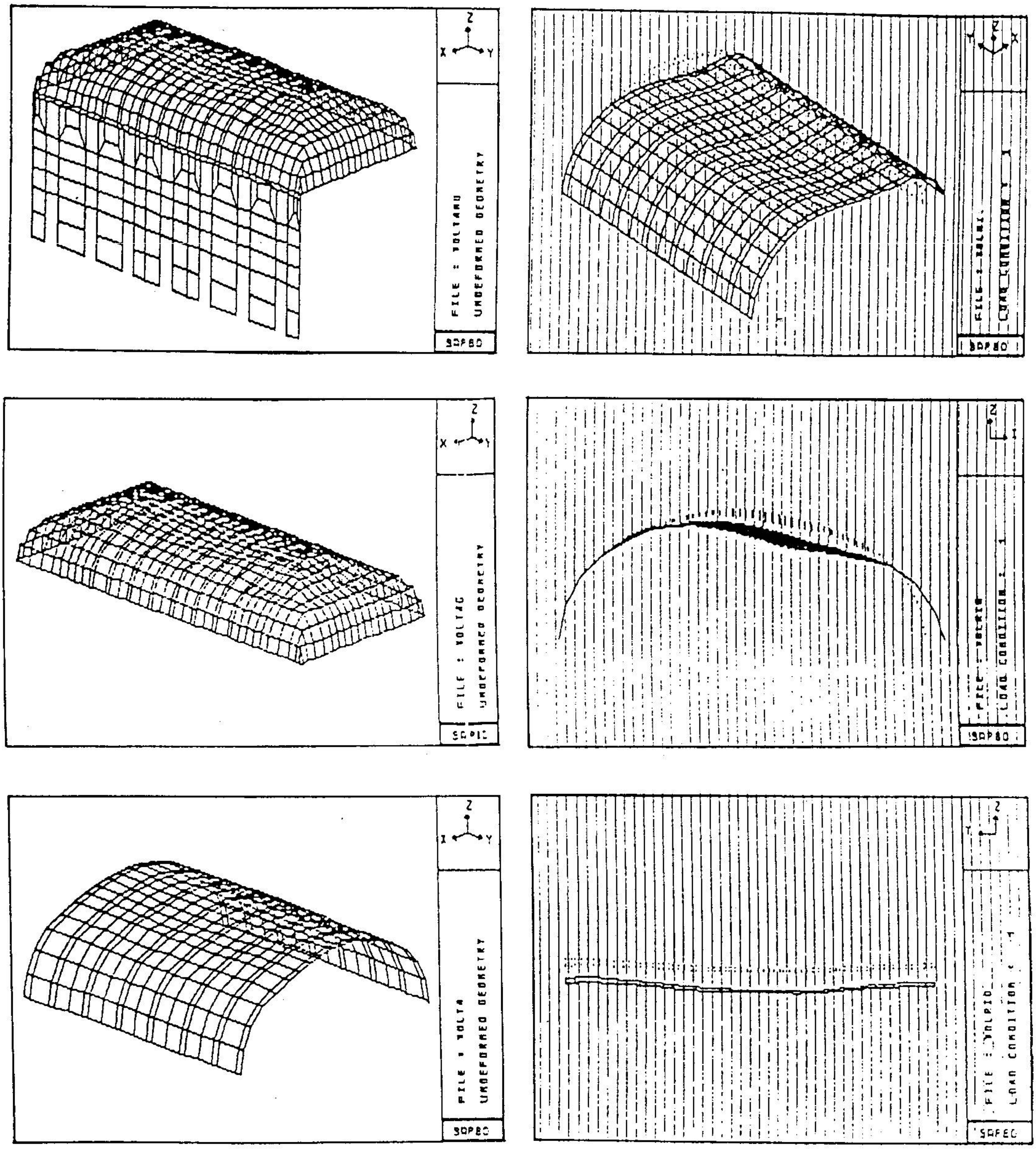


Fig. 9 The extrados of the Vault of the Major Council hall.

Fig.11 The intervetions on the masonary structures.





The finite element models used to analyze the vaults.

anchored at the facades (Figure 11); the Figure 12 shows the stell beams, placed at the extrados of the vault of the Major Council Hall. The connection between the steel structures and the vaults is provided by prestressed bars. The value of the pretension has been accurately evaluated ; in fact the bar can provide two different functions: (A) to provide support forces, (B) to impose deformations that allow to partially ricovery the old displacements and to reinstate then into the vaults a bearing capability due to curvature. The installation of an instrument net, integrant part of the restore intervetion, was necessary to evaluate which of the two behaviours should be spontaneansly established in dependence of the actual vault's stiffness.
The maintenance in activity of the instrumentation system for a suitable period, permits to verify the behaviour in the time increasing and then the final validity of the intervetion.
The monitoring system is composed by an automatic remote data acquisitor connected with a computer (Figure 13) in which are recovered the values measured by the different instruments: strain gunges on the bars to evaluate the stresses (Figure 14), transductors into the vault to measure the crack's width, and the deformations of the vault's intrados (Figura 15) and at least termometers placed on the steel strucuture and on the mansory vault.

2.5 Monitoring during the construction of the great concrete buildings

The construction of the great concrete buildingseven emphasizes the opportunity to control the corrispondence between the actual behaviour and the design hipothesis that can be of particular importance for the constructions that use precast structural elements, stiff as a whole and weak in the assembly; more subject then the other to the effects of the indirected actions, as the soil deformations and the thermic variations. For this purpose, have been placed some instrumentation system in threee Service Centers and Offices of the Ministry of Finance in Venice, Genova and Alessandria (Figura 16, 17). There are the most delicate problems in the center in Genova, where are been erected impressive retaining structures (Figure 18 ;the load cells placed on the rear of the retaining structures and the load cells placed on the head of the anchorage bars permit, in particular,to have ever the effective values of the earth thrust and any relaxation of the anchorage bars with time increasing.

3 MONITORING OF AN EXISTING BUILDING, IN WHICH ARE PRESENT FAIULERS DUE TO CYCLIC AND EVOLUTIVE PHENOMENA.

3.1 General aspects

Such as kind of controls permit to have usefull data to a better understanding the actual phenomena. So it's possible to make a reliable diagnosis and operate a choise about the intervetion criteria.
This stage of the study is of particular importance in the case of the monuments, in which an accurate preventive cognitive investigation makes it possible to optimize the intervetions in respect for the historic-artistic value of the building.

Fig. 12 The steel beams placed at the extrados of the vault of the Major Council Hall.

Fig. 13 The monitoring system

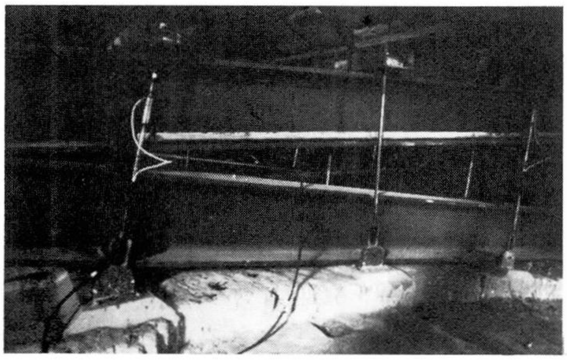


Fig. 14 The strain-gunges on the bars to evaluate the stresses.

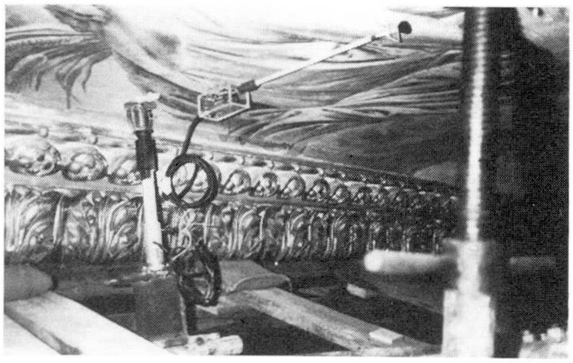


Fig.15 The instruments placed at the intrados of the vault.

Fig. 16 The Service Center in Venezia

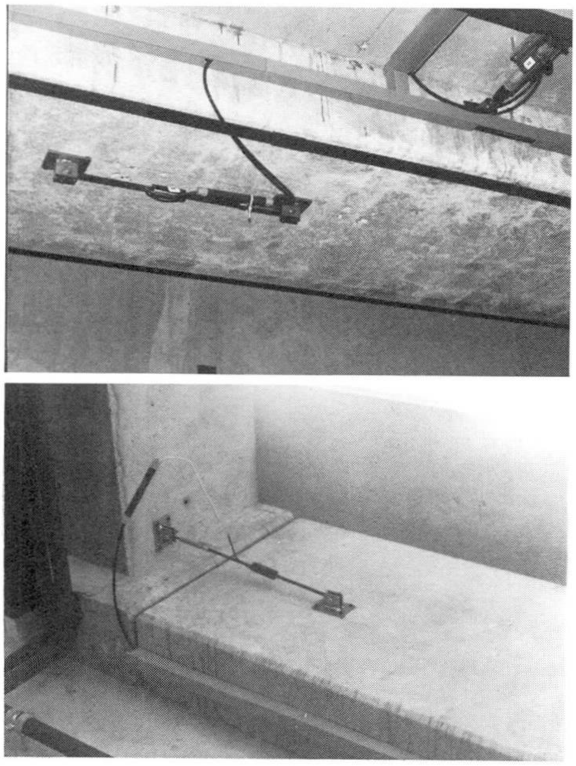


Fig. 17 Some of the instruments placed into the Service Center in Venezia.

3.2 The monumental building of the Tabularium - Senatorial Palace in Campidoglio

The monument present serious damages and it's now in very dangerous conditions. The first part of the study was concerned individualization of the phenomena with the ascertainment of the causes (Figures 19 and 20).
Apart from the investigation to ascertain: the connection between walls and slabs (assaies), the sthrenght (test with flat jacks), the diffusion of cracks (ultrasound, ...), ecc. are been carried out other measurement on time increasing, to understand the effects of the temperature and of the soil settlements. The results of these measurement are shown in the following Figures:
Figure 21: Temperature distribution through the Facade wall looking on the Roman Forum;
Figure 22: variations of the span of the archs that are in perpendicular direction with respect the Facade of the Figure 19, due to the temperature variations;
Figure 23: development,on time increasing, of the out of plumb of the bell tower that now presents at the top an horizontal displacement of about 50 cm. These deformations not only depend, on the season's differences of temperature, but also due to settlements of the foundations. The settlements are probably a consequence of the excavations carried out in the first half of our century, to uncover the temple of Veiove.

3.3 The bridges of the Roma-Viterbo railway

These bridges present, apart from a widespread state of decay, some important longitudinal cracks that have disconnected the archs from the external walls (Figure 24 and 25). The monitoring in the time domain of this phenomennon was carried out by the use of joint-gunges and extensimeters and permitted to acertain the stabilization of the relative displacements.Then it was possible to plan out, for the successive bridges, a much simple consolidation intervetion: instead of empting out all the bridges and create a reinforced concrete caisson, working together to the masonry structure (Figure 26), the design was restricted to carried out an effective connection between external walls and archs, inserting a prestressed Dywidag bars system (Figure 27).

4 CONTROL OF BEHAVIOUR OF AN EXISTENT BUILDING RELATED WITH THE DISTURBANCES DUE TO EXTERNAL WORKS

4.1 General aspects

This is the case in which excavations are carried out or other buildings are erected in the closeness of the considered building. In these problems the monitoring can minimize the preventive intervetions, planning out an action strategy thet will be carried out gradually depending by the evolution of unfavorable events (removal of the people, insertion of cribs or chains, close to traffic, ecc...). An instrumentation net has, in these cases, its

Fig. 18 Service Center in Genova, the retaining structures.

Fig. 19 The facade looking on the Roman Forum, in the present state.

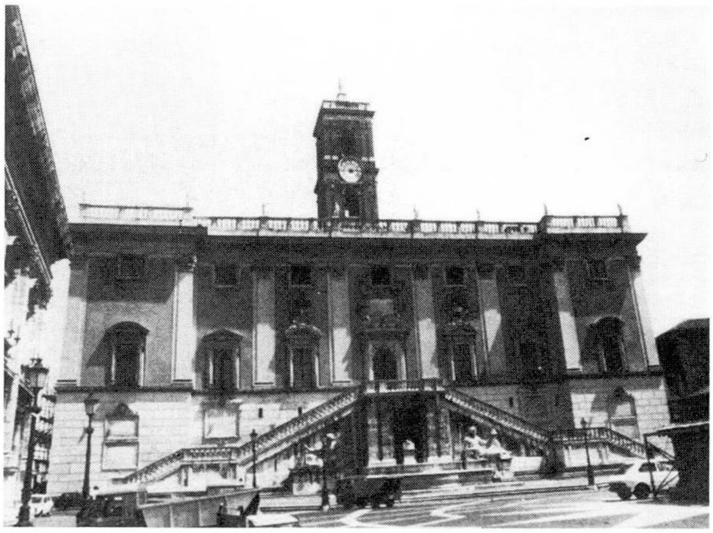


Fig. 20 The facade looking on Campidoglio square in its present state.

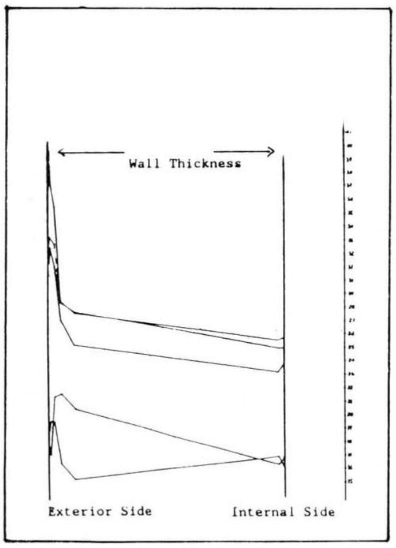


Fig.21 Temperature distribution trough the facade wall looking on the Roman Forum.

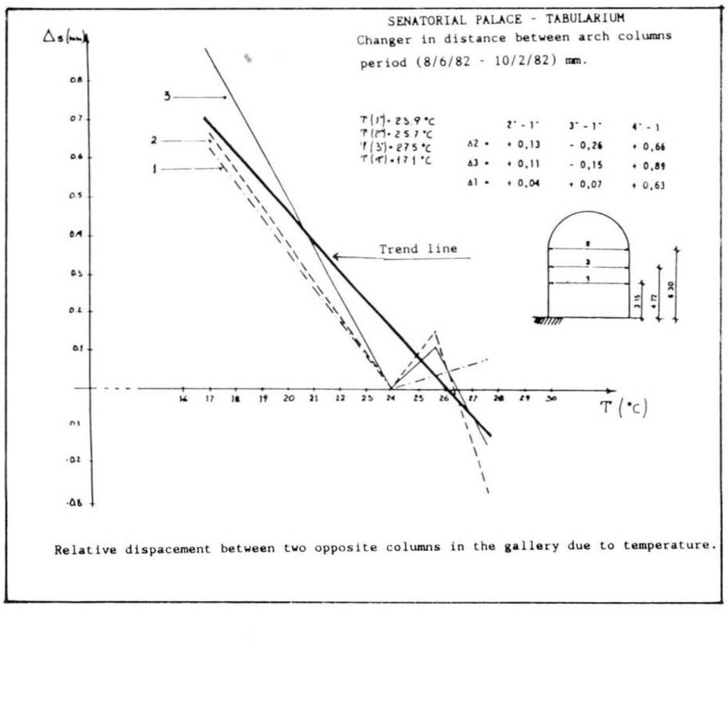


Fig. 22 Variations of the spans of the archs, due to temperature variations.

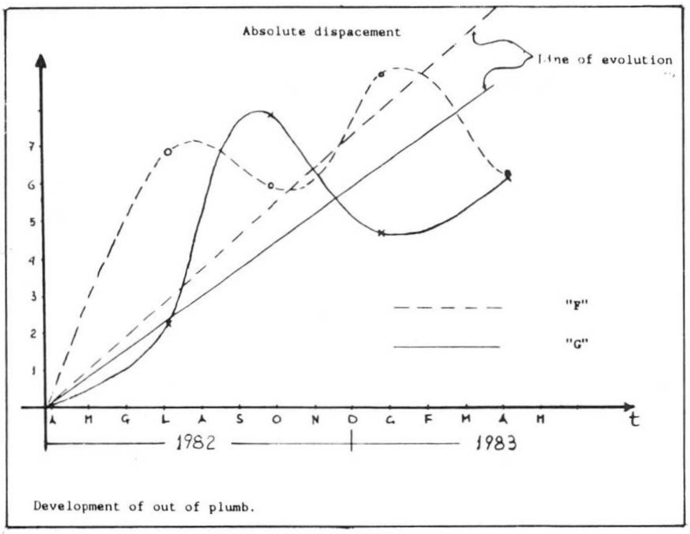


Fig. 23 Development, on time increasing, of the out of plumb of the bell tower.

Fig. 24 A bridge of the Rome-Viterbo railway

Fig. 25 The lesion in the masonary structures of the bridge.

Fig. 26 The realization of a reinforced concrete caisson.

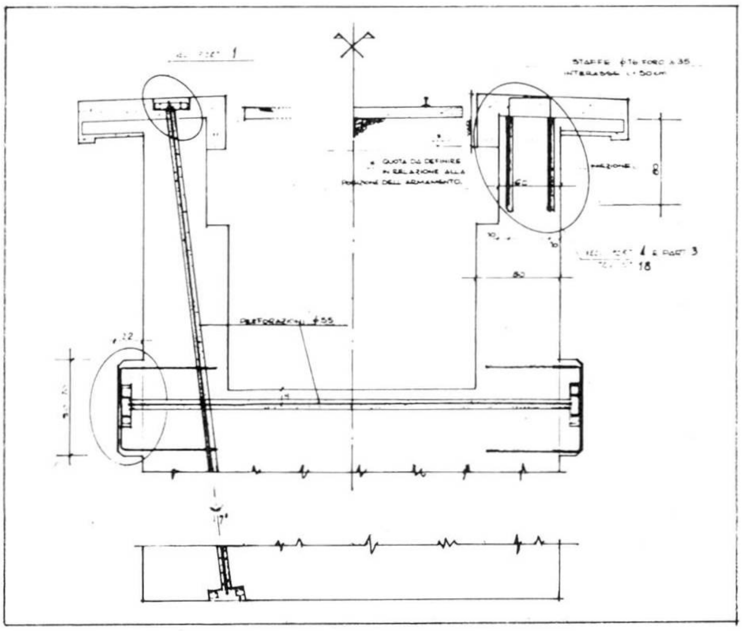


Fig. 27 The intervetions based upon the insertion of prestressed Dywidag bars.

independently by the data measured and by their scientific significance, assuming the role, in a sense, of an insurance policy; it can be represent, in fact, a warning bell that intervenes only in case of unfavorable or risks events.

4.2 The construction of a tunnel of the subway of Rome, under some building the Castro Pretorio area.

The instruentation net, that is composed by temperature sensors, cracks and strain meters, was placed in the most signifative locations on the buildings (Figure 28, 29 and 30); the remote for the data recording was connected with an alarm system. The good course of the works had avoided, in any case, the trasmission of alarm signals by the system, because nothing of the quantities measured, exceeded the preset alarm levels. So the buidings could remain occupied during all the work time without any risk.
The measurement carried out also revealed theirselves of great scientific interest permitting the clear knowledge of happened phenomena; the comparison between these phenomena and those theorically foreseable by a finite element model, was soddisfacent (Figure 31). A more detailed study is reported on another paper (1).

4.3 The excavations into the court of Ex Massimo Institute, to realize a bunker caveau containing artistical and archeological finds of the Superintendence of Rome.

The realization of a great excavation (Figure 33) in the court of the building (Figure 32) to realize a bunker caveau, obliged to several precautionary measures during the excavation (chains ...). Nevertheless the importance of the excavation and the values of the forces related with the work recommended to strictly control all the stages of the intervention,by a monitoring net, to opportunely determine differential soil settlements, wall rotations, changes of tension in the chains, ecc... The Figure 34 showes some of the installed instruments.
The monitoring system, still upon office, showed an actual stationary situation and so permitted a quick work development.

REFERENCE.

1 CANGIANO M., CROCI G., Control and detecting system apllying to some buildings located in Rome and connected with works relating to the construction of the underground line.

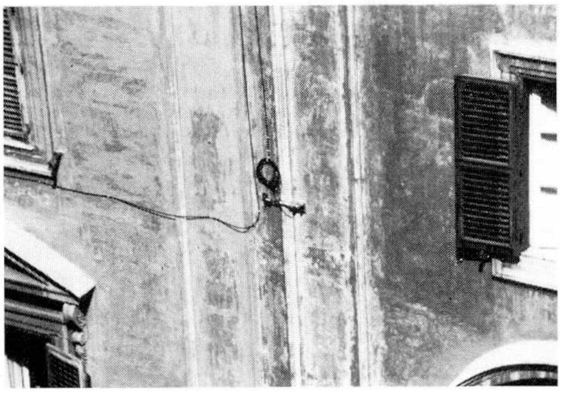


Fig. 28

Fig. 29

Fig. 30

Fig. 28, 29, 30 The instruments installed on the most significative locations on the building.

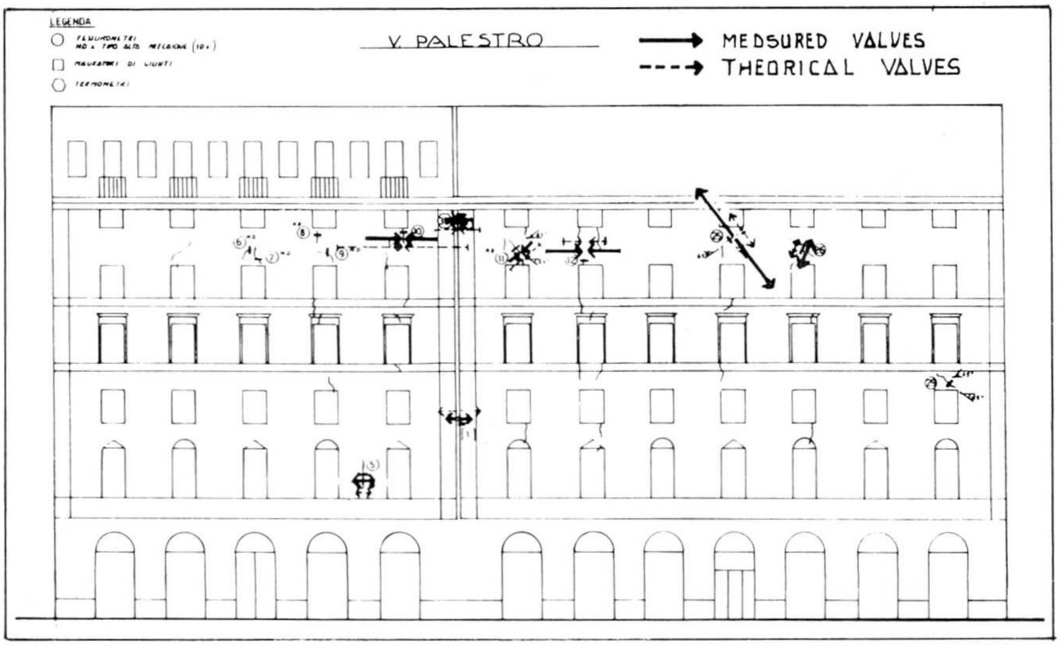


Fig. 31 Comparison between measure of phenomena and the results of theorical analysis.

Fig. 32 View of the Ex Massimo Institute

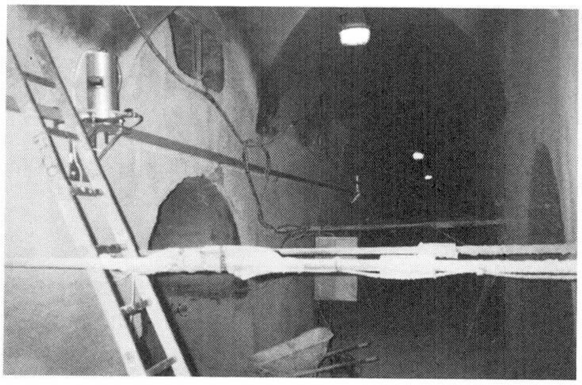


Fig. 34 Some of the installed instruments.

Fig. 33 The realization of the excavation to realize a bunker caveau in the court of the building.