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Abstract

Structural health control is nowadays a very attractive subject in the field of civil structures. In particular, structural monitoring offers the possibility of gathering data pertaining to the structural behaviour in a continuous way and realizes the static efficiency verification of the structures, both for newly constructions and ageing ones. For existing constructions monitoring enables the technicians to ascertain the actually offered safety level and the existence of hidden resistance resources. For newly constructions continuous monitoring gives the possibility of controlling the conformity of the structure to the project and of keeping under observation the static efficiency. In this direction an impressive contribution comes from the adoption of fibre optic methods. In the present paper explained is a methodological and operative procedure to design a monitoring project of a newly reinforced concrete construction using fibre optic sensors. By means of plastic rings, these devices are anchored to the steel bars embedded in the structural elements so that they can follow the deformations of those bars. The report of such experimental values enables us to derive the stresses of the structural elements, beginning from the construction phases.

Key Words: Structural Health Monitoring, Fibre Optic Sensors, Deformation Measures

Introduction

In recent years the control of materials and structures has become a matter of central interest in the field of structural engineering. Together with the coming of calculation instruments and programs more and more powerful, it is growing the need to ascertain the safety level offered by the existing constructions. In this direction the No Destructive Techniques are most useful to the technicians because they allow to detect unknown bearing elements and to evaluate the mechanic characteristics of the materials. However, it is appropriate to underline the difficulty of executing investigations on structures in presence of fixtures and of finish elements like plasters, floors, coverings. This difficulty has a negative influence on the costs of the experimental campaigns of tests. Furthermore it strongly reduces the representativeness of the sampling and the reliability of the results. The uncertainty about the mechanic parameters of the materials at work induces the structural engineer to use high safety coefficients and in turn to design more expensive interventions both in geometric and technical terms. Despite the knowledge of these problems, they are still realized constructions that don’t allow any type of direct and periodical control, nor of the structural behaviour nor of the efficiency of the materials along the lifetime. In this way it is frustrated the possibility of planning maintenance operations oriented to the preservation of the thing.

On the base of what briefly exposed it appears clear that it is necessary to promote the use of monitoring procedures and techniques. In particular, the monitoring of newly constructions offers informations about the static efficiency levels when exceptional events occurr. It constitutes, also, a stop to the realization of structures that in the future will have unknown levels of reliability, even for simple materials degradation.

A formidable answer to such a demand comes today from resident monitoring systems based on of fiber optic methods. These techniques allow real-time acquisitions of deformation data pertaining to the principal bearing elements, as beams, columns, foundations, bridge decks. The acquisitions in point can be carried out both in place or remotely and offer the possibility of executing global evaluation of structural reliability. The control has the character of a comparison and can indicate the presence of materials degradation or incipient crisis conditions.

In this note it is presented a procedure by means of which it is possible to control the construction phases of a building, to verify the reliability of the calculation models that were adopted during the designing phase, to plan maintenance operations based on real-time acquisitions of data, periodically gathered. Such a procedure was implemented and tested on a real building. The comparison between the experimental data and the predictions of the calculation underlines the reliability of the proposed methodology.

1. The structural monitoring

The matter of structural monitoring and control can be situated in the wider field of structure maintenance, strictly related to the safety level offered in the life time of the construction.

The benefits of structural monitoring can be pointed out in relation to the construction phase, to the inspection before utilization, to all the lifetime. Structural Monitoring can improve the knowledge of the real behaviour of the structure, reducing the uncertainties on the characteristics of the materials and also on the loads. In this way they are derived parameters that are useful to design future structures with a reduced level of costs and an augmented level of safety. Structural monitoring can discover possible resistance reserves or, vice-versa, can point out the presence of structural deficiencies. In this way it is possible to optimize the maintenance and restoration interventions and to define the real costs of the construction during the life time. Furthermore, structural monitoring allows to point out the presence of damages produced by extraordinary events or by improper load conditions.

2. Structural monitoring by means of fibre optic sensors implemented to newly reinforced concrete constructions

Fibre optic sensors are instruments that gives the possibility of executing measures based on the principles of the undulatory optics and on the properties of the light. These measures gathered on some bearing elements of a structure realizes the so-called “optic monitoring”.

In the reinforced concrete structures the fibre optic sensors are embedded in the bearing elements by means the anchorage to the steel bars. For each one of the elements to be instrumented, both foundational ones (strip footings, plinths, piles) or elevation ones (beams, columns), the sensors have to be situated on the steel bars before the pouring phase. In this way the sensors can register the deformations of the bars from the concrete maturation phase on, and, therefore, the deformations of the bearing element.

The realization of a fibre optic monitoring system on the reinforced concrete structures allows to get important objectives, represented in the sequel of this section.

- To control the correct execution of the different parts of the structure and to evaluate the real task of the materials during the different phases of the realization of the structure. In this way it is possible to carry out a systematical control of the construction in relation to its design.
- To verify the maturation levels of the reinforced concretes and particularly the effect of the shrinkage, directly in terms of deformations and in turn, by means of calculation, of the induced stresses. In this way it is offered the possibility of acquiring informations specifically related to the structures subjected to investigation.
- The instrumental data acquired at the start of the service life of the construction constitute a constant reference respect to the analogous data acquired along the entire life time. These comparisons allow to identify possible materials degradations or redistribution of stresses in the structure. In this way it is possible to plan interventions of ordinary or extraordinary maintenance on the basis of objective data.
- All the informations acquired by means of the resident monitoring system constitute a fundamental reference to be able to control the static conditions of the construction after extraordinary events as earthquakes, landslides, inundations.
- To reduce the costs of the activities related to the test before the beginning of the operational life of the construction. The resident monitoring system allows the direct registration of the static task of the different structural parts without the need of executing the typical operations connected with the load tests.

3. A fibre optic based control methodology of the static efficiency of newly reinforced concrete constructions

It is proposed a methodology for the structural control during the construction phases, during the test before the beginning of the operational life and along the entire life time of a reinforced concrete building. It can be depicted as a procedure subdivided in well distinct operational phases, identified in the sequel with the letters A, B, C.

A. DESIGN OF THE MONITORING SYSTEM

- Analysis of the architectural and structural terms of the building.
- Identification of the structural elements to be monitored by means a “Zone Criterion”.
- Choice of the points where the registration devices are to be placed.
- Time definition of data acquisition as short, medium and long term acquisitions.
- Drawing-up of graphic papers and execution specifications.

B. SYSTEM INSTALLATION DURING THE CONSTRUCTION PHASES

- Installation of the fibre optic sensors on the steel bars – Active Part of the Sensors.
- Setting of the connection cables to the acquisition box – Passive Part of the Sensors.
- Functionality control of the sensor – Control Data Acquisition.

C. EXPERIMENTAL ACTIVITY

- Acquisitions of the deformation data in the hours following the pouring. These acquisitions allow to evaluate the shrinkage effect on the reinforced concrete, particularly for the columns which are isostatic before sustaining the floors. The ones in point are short term acquisitions.
- Programmed acquisitions during the execution of the construction directed to verify the variations of the stresses on some bearing elements as an effect of the realization of parts of structure (as floors, ceilings, …). The ones in point are medium term acquisitions.
- Acquisitions of data when the construction is complete, during the test before the beginning of the service life and also at the beginning of the service life. They are acquisitions useful to define a “zero” reference so that, subsequently, to effect comparative controls. The ones in point are medium term acquisitions.
- Acquisitions of data to be executed in the first year of life of the construction so to evaluate how the operational life modifies the stress conditions. These data acquisitions are to be considered as medium term ones. They allow to refine the “zero” values registered at the beginning of the service life. They will constitute the ultimate reference for the periodical control of the construction along the life time.

- Acquisitions of data along the life time to be executed every two years, directed to verify the static functionality, to control the degradation of the materials and to define the operations of ordinary maintenance.
- Acquisitions of data subsequently to exceptional events as earthquakes or related to the occurring of improper load conditions, not predicted in the design phase. These acquisitions, directed to verify the integrity of the structure, are long term ones.

The operational phases depicted above are not fully comprehensive of all the activities that it is necessary to execute in the implementation of the monitoring system in point. For example, in the design phase it will be necessary identify areas without singularities where the fibre optic sensors can be placed. In this way it will be possible to ensure reliable acquisitions of the deformation data of the steels. Furthermore, the experimental activities of data registration can be directed both locally, to verify the quality of the materials, both globally, to control the structural behaviour.

4. Experimental campaign of data acquisition: the control of a multi-floor building with a reinforced concrete framework

The procedure in discussion was applied in the design and implementation of a fibre optic monitoring system on a building located in Cosenza , Italy, entirely made with reinforced concrete structures [Figg. 1, 2, 3].

The objectives put at the basis of the experimental campaign are the following ones:

- To verify the reliability of the materials.
- To control the evolution of the stress conditions in the bearing elements during the construction phases.
- To provide the building with reliable data equipment by means of which to execute static efficiency controls all along the life time of the construction.

FIG. 1 THE BUILDING BEING MONITORED

In this work they are reported the experimental results pertaining only to the second point, for the sake of brevity and considering that the experimentation is still in progress.

The building presents 23 floors of height and one level completely underground which has a greater extension respect to the overground floors. The loads produced by the superstructure are distributed on a number of piles solidarized by a foundation plate. At the moment they are completed the realization phases of the reinforced concrete parts and the finishing works are in progress.

FIG. 2 IV ORDER COLUMNS – SENSORS INSTALLATION

FIG. 3 REALIZATION OF THE XVII FLOOR

Referring to the proposed procedure, it was drawn the monitoring system design. According to a “Zone Criterion” they were identified in plan the bearing elements that present the load conditions more representative for vertical or horizontal [i.e. earthquake] loads. With an analogous method, at the different levels they were identified the horizontal bearing elements to be instrumented. In the building they were integrated n. 52 fibre optic sensors in all, both in the foundation elements and in the elevation ones, according to the following list: 4 sensors in the piles; 4 sensors in the strip footings; 44 sensors in the columns and beams of several elevation floors [Fig. 4]. Each group of sensors pertaining to certain floor were conducted to a connection box from which it is possible to acquire the data registered by the fibre optic devices embedded into the columns and beams of the entire level [Fig. 5].

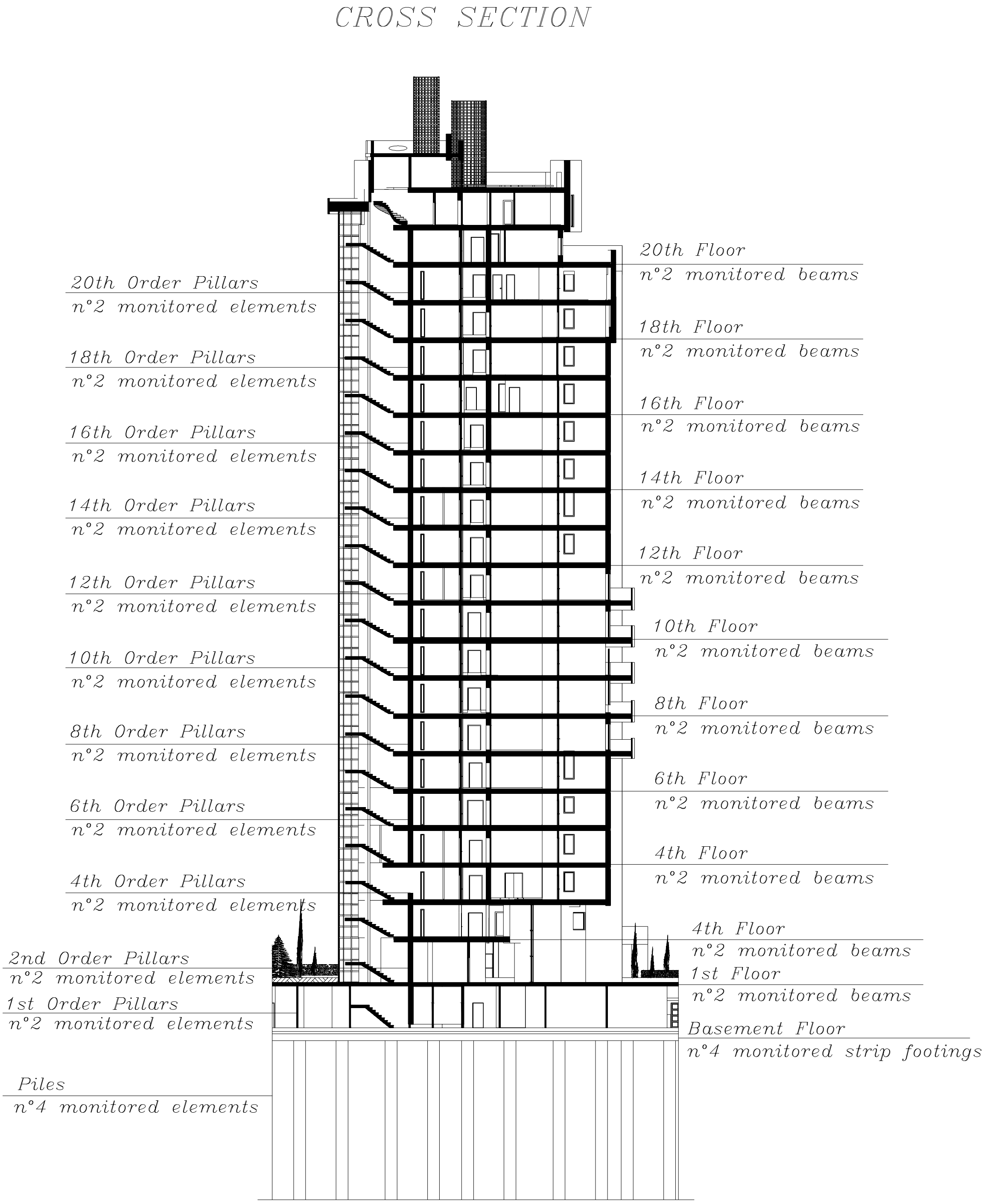

FIG. 4 MONITORED BEARING ELEMENTS

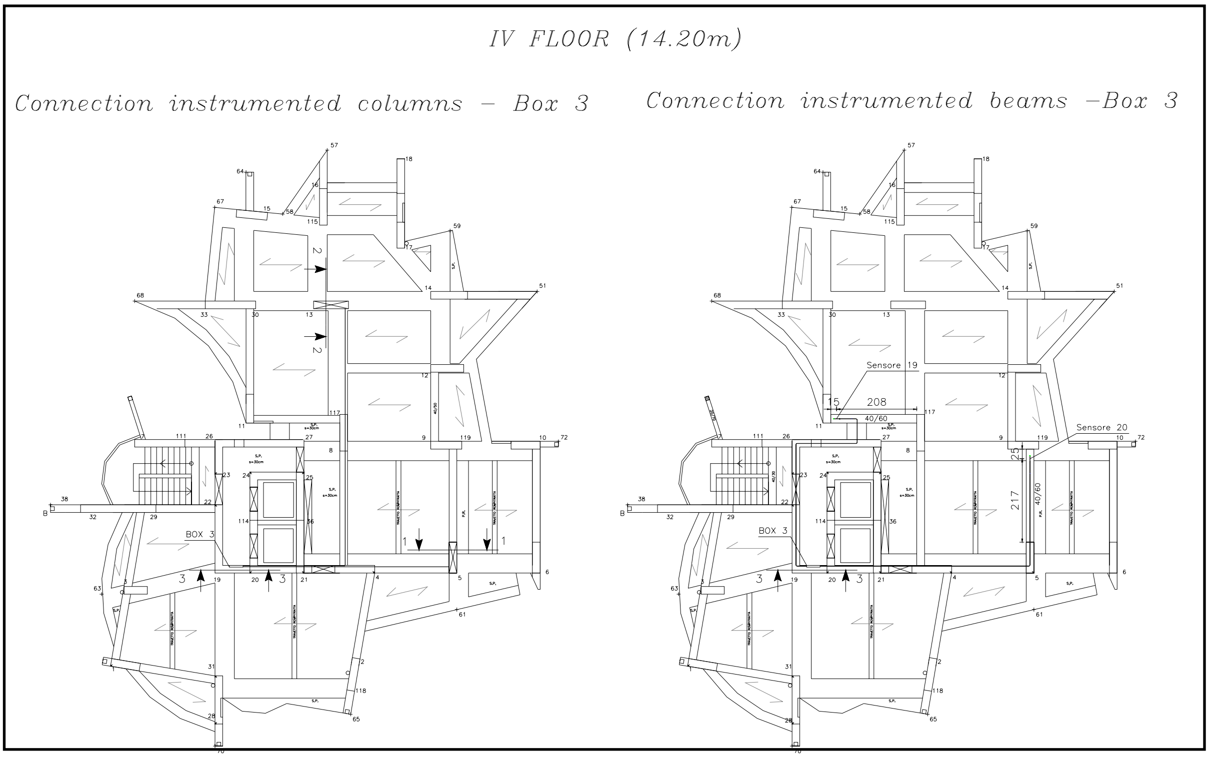

FIG. 5 IV FLOOR - MONITORED BEAMS AND COLUMNS

In the first part of the experimentation they were executed data acquisitions of short term and partially of medium term, while they are still in a completion phase the medium term acquisitions and they were programmed the long term ones.

For the sake of brevity, in this work they are illustrated the stress results obtained for two columns of 4th order [n. 5 and n. 13] on the basis of the deformation values gathered during the construction phases of some of the above floors. In detail, they are illustrated the stress increments deduced subsequently to the realization of the levels from the 11^{th} to the 17^{th} one. The stress variations on both the considered elements was evaluated considering as a reference the stress level that is supported upon the realization of the 7^{th} floor. These results are illustrated in comparative terms respect to the ones we deduced, for the same elements and the same load conditions, with a numerical estimate performed by means computer and a finite elements program. The two series of results show a good agreement, with differences that don't exceed a variance of 20% [Figg. 6, 7]. The concordance between the calculation predictions and the experimental results certifies that the construction corresponds to the design prescriptions and that the theoretical model is able to represent to a good extent the behaviour of the actual structure.

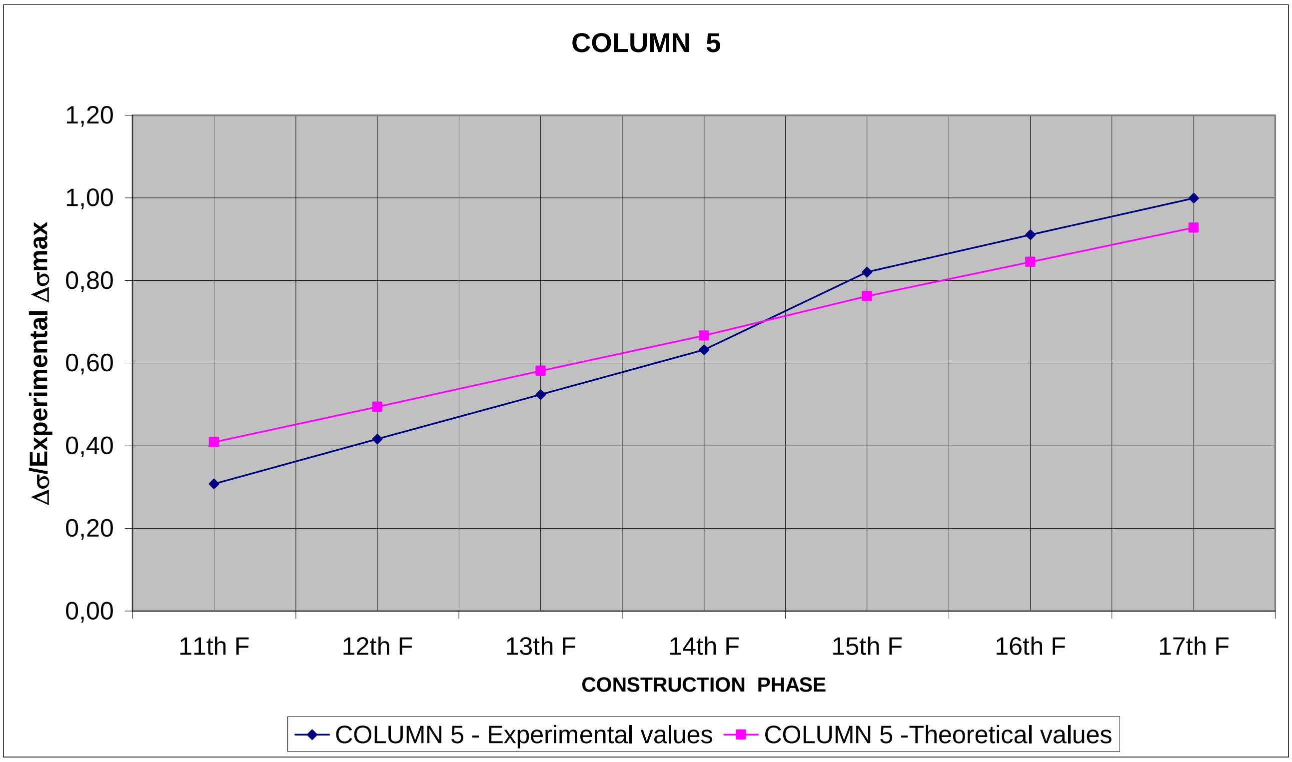

FIG. 6 COLUMN 5: THEORETICAL AND EXPERIMENTAL STRESS INCREMENTS IN DIFFERENT CONSTRUCTION PHASES

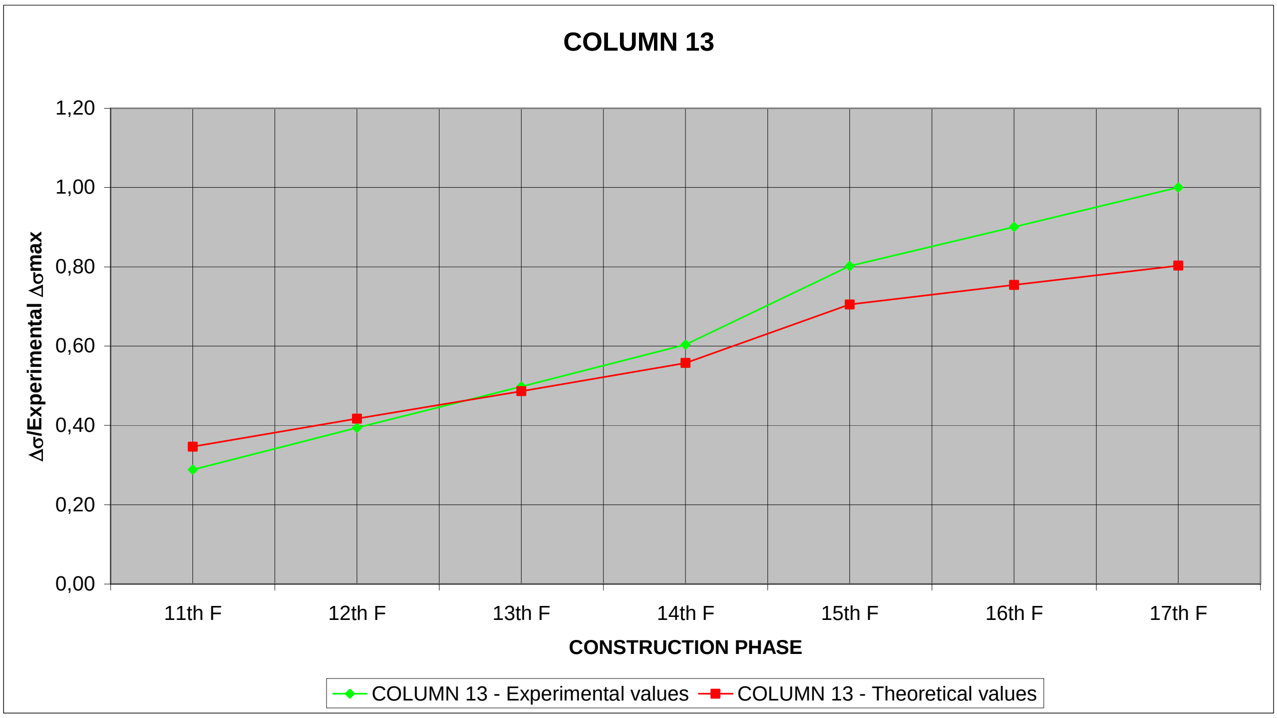

FIG. 6 COLUMN 13: THEORETICAL AND EXPERIMENTAL STRESS INCREMENTS IN DIFFERENT CONSTRUCTION PHASES

Conclusions

In this work it is presented a methodology based on the employment of fibre optic sensors as an instrument to control the static efficiency of newly reinforced concrete constructions. Particularly, the implementation of a resident monitoring system allows to verify the reliability of the constructions subsequently exceptional events, as the earthquakes, or upon improper load conditions. The resident systems offer the possibility of programming acquiring data operations of short, medium and long term in relation to the life time, beginning from the realization phases. It is also possible to follow the maturation phases of the concrete for some bearing elements and to evaluate the effect of secondary actions as the concrete shrinkage on the stress conditions. Furthermore, the increment of stress conditions produced by the realization of parts of the building, is illustrated by the experimental results on beams and columns. In this way it is possible to control the correct realization of the structure and to verify the distribution of stress predicted in the design phase.

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