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Monitoring of a piling wall by means of FBG

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ABSTRACT: Pile long term stability characterization will provide key information about pile design for a specific geological ground structure. The installation of fiber optic strain gauge sensors (FBG) and data acquisition campaign on some piles during the construction at the "Parco della Memoria" in San Giuliano di Puglia, allow the verification of the evolution of deformation of steel bars. FBGs have been installed in two piles. In each pile 12 sensors have been deployed onto the reinforcement bars directly, before the concrete casting. The data acquired allow verification of the evolution of iron tools deformation. A preliminary analysis of the results of acquisitions of one of the two testing piles has shown a different behavior of two steel rebars, with increasing values at all levels, with respect to the previous reference measurements acquired shortly after full concrete cure.

1 INTRODUCTION

Any structure undergoes many changes during its lifetime. Knowing its health status is very important for the prevention against natural disasters. In fact, we always strive to save lives in emergency situations and to improve overall quality of life for people who use the structure. Recent advances in sensing and network technologies, like fiber optic strain gauge sensors (FBG), make it possible to collect a multitude of various data, in and around the structure, and to establish its health status in a much more comprehensive manner than ever before, by integrating these data (Rinaldis et al. 2009). The goal of this structural sensor data repository is to conceptualize, develop and implement a prototype of a framework for gathering, classifying, and integrating structural data collected in and around a structure, and to enable effective visualization and fusion of such data to define the state of a structure. The research activities in the following are dealing with analysis of long term stability characterization of reinforced concrete piles. This research is part of a wide program, in which the seismic monitoring of selected structures, such as base isolated buildings and bridges, will be performed by installing seismic arrays with FBG and force-balanced accelerometers (FBA). The data obtained will also be integrated by data from vertical arrays deployed in and on the ground surrounding buildings foundation (Rinaldis et al. 2010).

With these objectives, the Coordinator Office for the reconstruction of San Giuliano di Puglia (Ministry of Infrastuctures) asked ENEA to install FBG optical fiber sensors in some piles and to perform a data acquisition campaign during the construction of a trench at the "Parco della Memoria" in San Giuliano di Puglia (Italy). This has allowed the analysis of the evolution of deformation of steel reinforcing bars and could provide key information about pile design for a specific soil. In particular, FBGs have been installed in two piles. In each pile 12 sensors have been deployed along the reinforcement bars directly, before the concrete casting. It is worth reminding that FBG sensors are provided in the form of strain gauges, suitable for application on structural resin with reinforcing steel and subsequent incorporation into the casting. In the proposed configuration, the installation system allows the monitoring of pile deformation, discriminating between axial strains and bending.

2 INSTRUMENTED PILES AND SENSORS POSITION

2.1 Sensors specifications

The installed sensors consist of eight optical strain gauge chains. Each chain is composed of three optical strain gauges. It has an external shield (maximum external diameter Φ = 16 *mm*), made of reinforced PVC flexible sheath with helical rib. Sensors are arranged along the chain, spaced of about 4.0 *m*. The flexible sheath is interrupted at each sensor, which is encased in epoxy molded block, 50*3*3 [mm^3] size, with a concave surface for optimal grip on the reinforcing steel bars (with a diameter of Φ = 20 *mm*). The axial dimension (50 *mm*) of the shaped block defines the gauge length of the sensor. The four chains installed on each pile are terminated at ground level in a rugged waterproof technical container 50*50*50 [mm^3] which houses a patch panel with optical connectors for data taking.

The sensors provide measurement signals encoded with optical spectroscopic strain sensitivity rating, stated by the manufacturer for ‘bare’ sensor (FBG sensor on not embedded optical fiber):

- Strain sensitivity = 1.20 *pm / microstrain nomimal*, bare sensor

From calibration measurements performed in the laboratory at ENEA on 3 sensors installed and produced with the same procedures and technologies as the chains in this report, is:

- Strain sensitivity = 1.18 *pm / microstrain*, actual sensor installed chain.

2.2 Provision of sensors

The eight sensor chains were mounted on 2 piles (Pile No. 95 and Pile No. 17). Each chain has been installed along a longitudinal reinforcement steel bar of a pile. The four chains of the same pile are angularly spaced of π/2.

Figures 1a and 1b specify arrangement and classification of chains installed in Pile 95 and Pile 17, respectively, in the transversal section. Figures 1c and 1d specify the exact location of the sensors installed in Pile 95 and Pile 17, respectively, in the longitudinal section. The depths of sensors are referred to as distance from the top of the steel bar. The figures specify the nominal wavelengths of the individual sensors in each chain, which is used during data acquisition to discriminate the signal of each sensor in the chain.

2.3 Installation and wiring

The application of sensors on the steel bars has been carried out by means of epoxy resin, following a pre-established codified procedure, thus ensuring the applicability of the strain sensitivity factor set for the sensors. The installation of sensors on the bars of the steel cage took place before their positioning into the hole.

For both the piles, the installation of the sensors did not require any significant modification of the procedure normally adopted for the positioning of the steel cages inside the hole. The chain ends were housed in a box at the top of each pile, in the beam, which links all the piles at their tops.

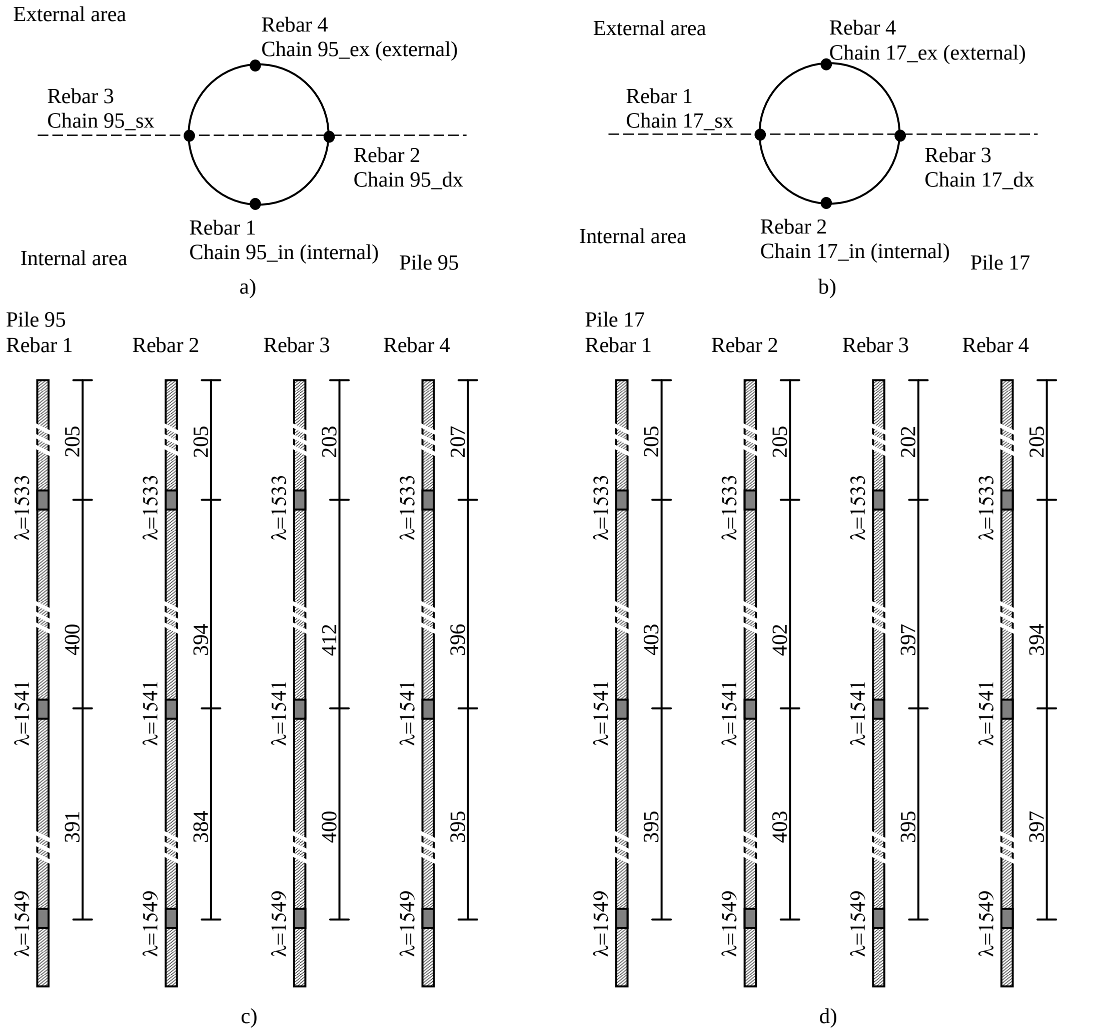

Figure 1. Nomenclature and arrangement of sensors in Pile 95 and Pile 17. Distance between sensors and distance of first sensor from rebar upper end are given in *mm*.

3 DATA ACQUISITION SYSTEM

A first data acquisition took place just after the end of the installation in order to test the system (on July 16th, 2009 for Pile 95, and on July 29th, 2009, for Pile 17). A second preliminary experimental campaign has been carried out on Pile 95 on July 29th. Finally two experimental campaigns have been completed on both the piles: between September 21st and 24th, and between December 22nd and 23rd.

The first acquisitions during the testing phase were carried out in about 8 hours after completion of the concrete casting. The spectrum of the optical signal has been plotted for each chain of sensors (Fig. 2). The bias modulation of signal chains derived from interference phenomenon due to the wiring of the provisional line of sight, run with the launch into the air of the signal from the optical cable system acquisitions. The presence of three peaks in the spectrum of the signal of each chains shows the proper functioning of the individual sensors comprising each chain. The values of the wavelength at each peak correspond to the expected nominal values before specified.

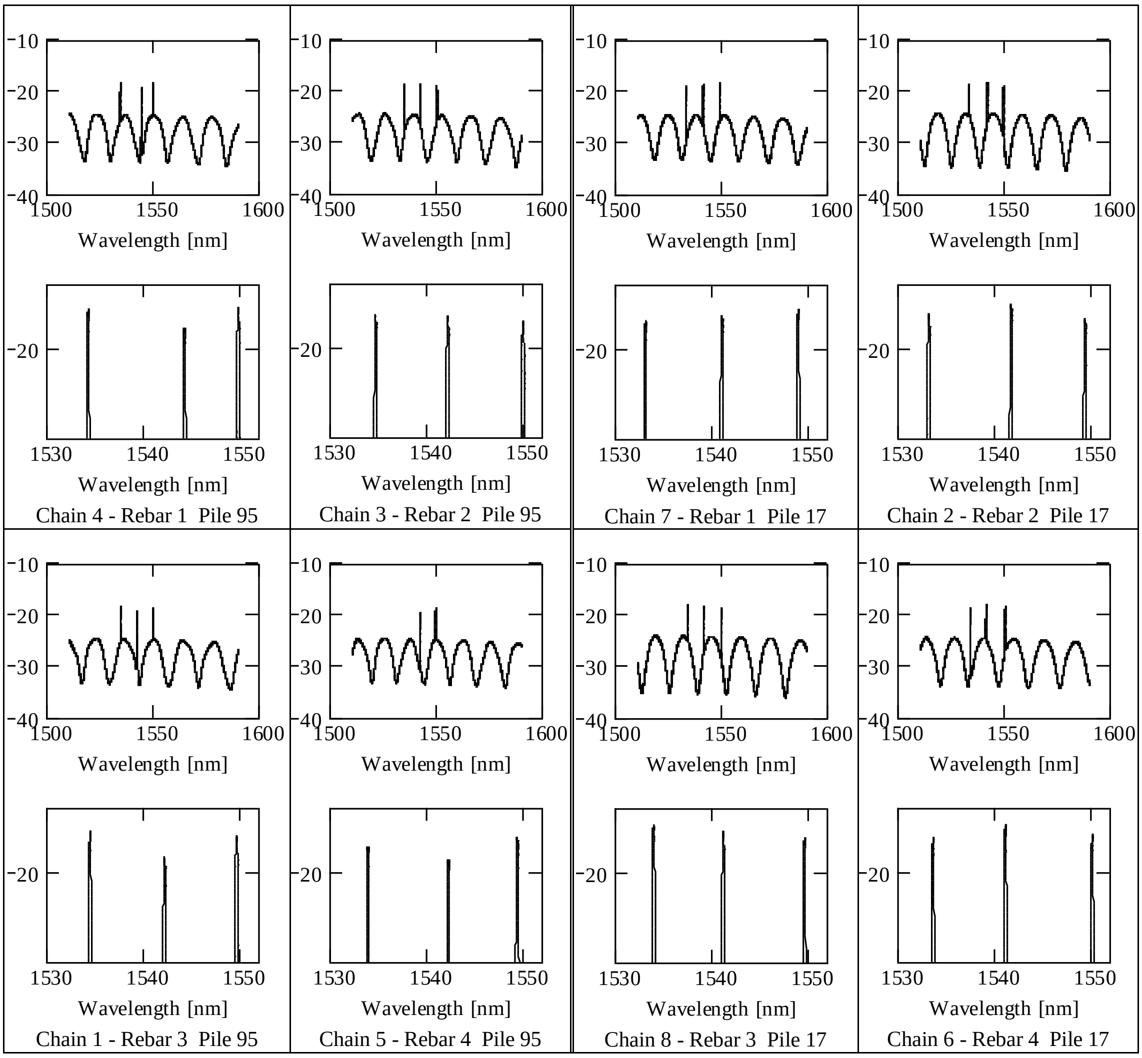

Figure 2. Signal Amplitudes (db) in the first acquisition, after the end of the concrete casting.

4 ANALYSIS OF THE ACQUIRED DATA

In Figure 3 time histories of deflection, measured during the campaigns of September 2009 and December 2009, are shown; the value of the deformation is relative to that measured at the beginning of the campaign in September 2009. In Figures 4 the time histories of the deformation of all the sensors installed in Pile 17, obtained in September and December 2009, are compared. Figure 5a) and 5b) show as an example the distribution of deformation on the steel bars of Pile 17 and Pile 95, respectively. These values correspond to the deformation measured at the end of the campaign in December 2009, the “zero” reference measure being reported to start campaign in September 2009.

The data acquired in September and December 2009 have allowed the verification of the evolution of deformation of steel reinforcing bars.

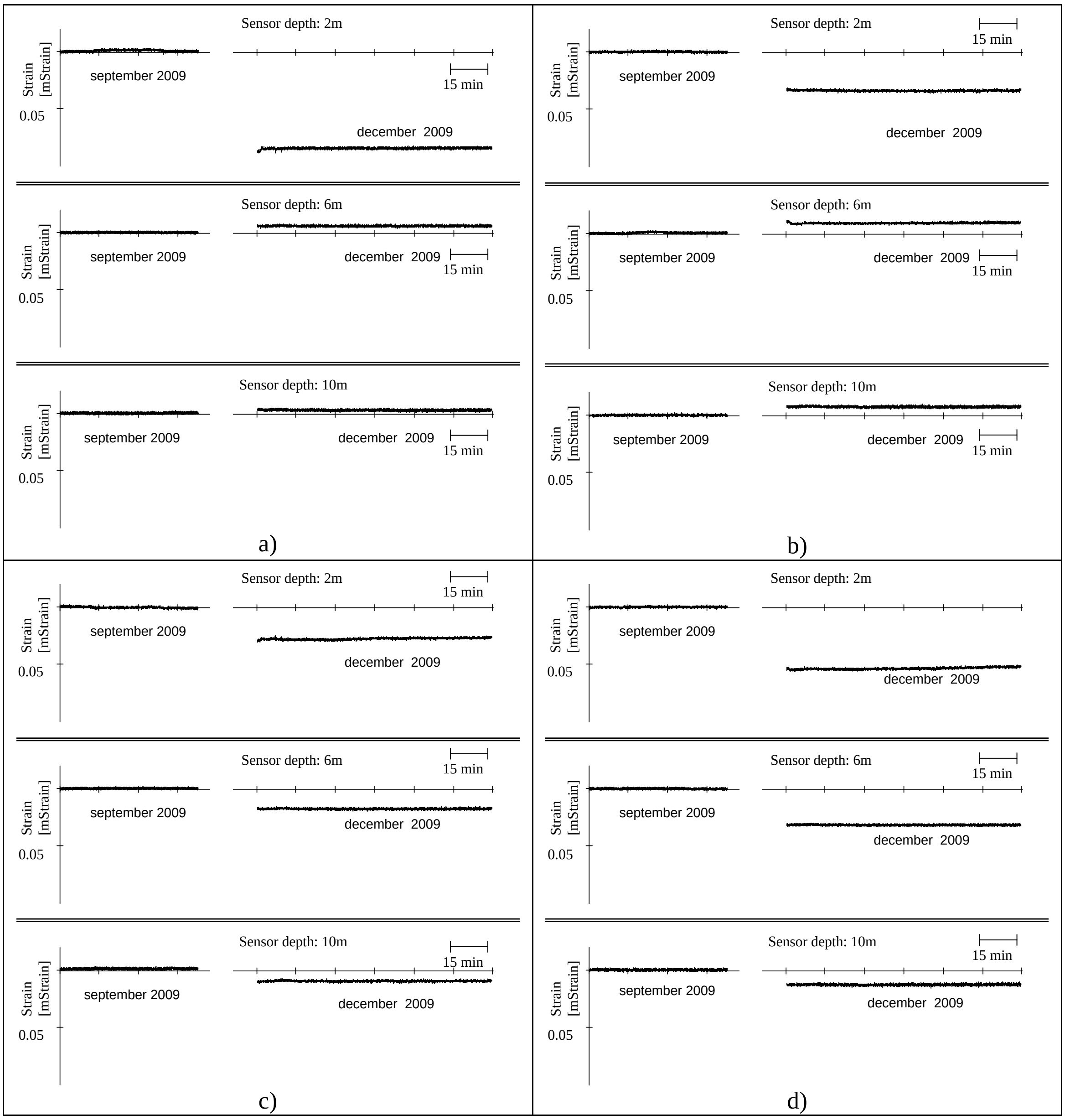

Figure 3 Strain Time History of Pile 17: a) Bar No.1; b) Bar No.2; c) Bar No. 3; d) Bar No. 4.

Preliminary analysis of the data, shows a different behavior between chain 1 and chain 2 of Pile 17, with increasing values at all levels compared to baseline measures of September 2009. We note a negative average value (compression) of the strain of the recorded strains measured in sensor at -2 *m* and sensor -6 *m*; the average values of strain becomes positive at -6 *m* and -10 *m* (traction). Figure 5a shows the stress states in the reinforcing bars of all four chains: although the absolute values of deformation are negligible, there is a tendency to compression in the pile in correspondence of rebar 3 and rebar 4. The comparison between chain 3 and chain 4 shows decreasing values of strain compared to the reference ones of September 2009, except for the sensor at -2 *m* of chain 1 that seems to be much more stressed than others. Figure 5b shows the strain of Pile 95. It seems to be much more stressed than Pile 17 at -6 *m* and -10 *m*. This is probably related to the ground movements and the different lengths of the two piles.

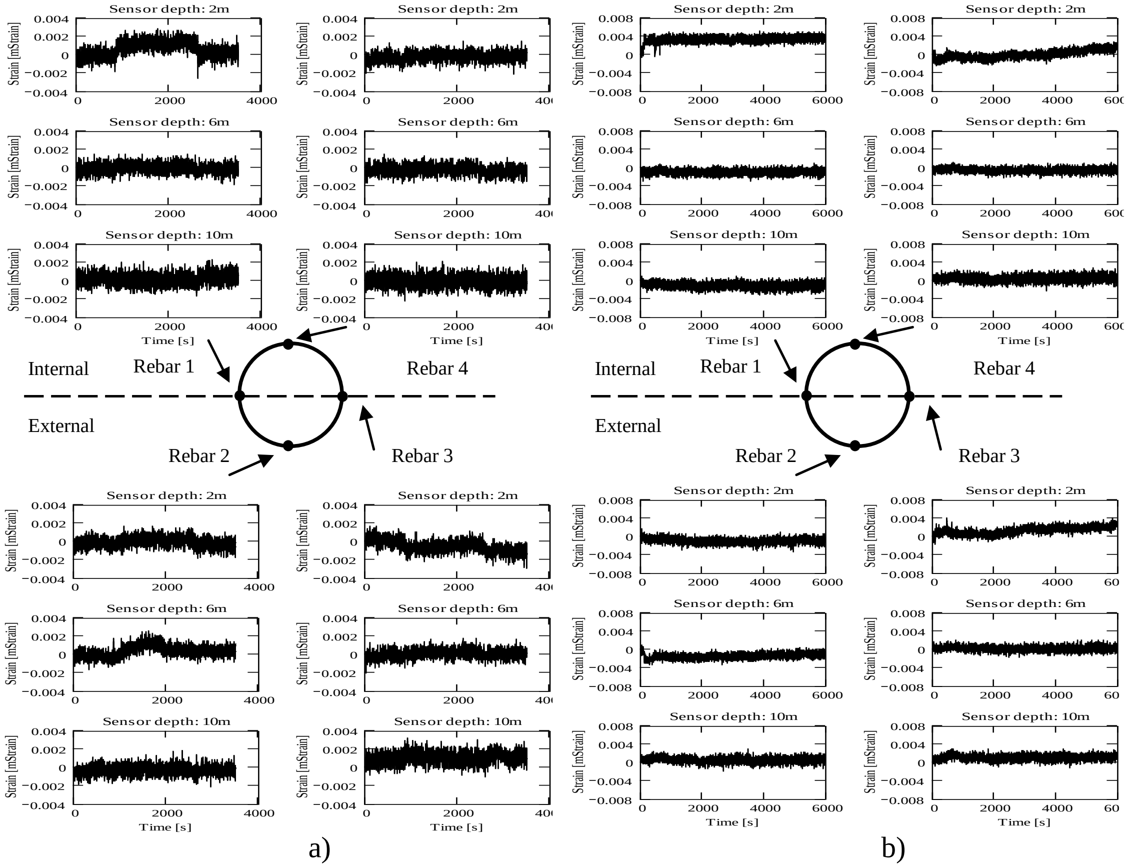

Figure 4. Comparison between deformations of a) September and b) December in Pile 17 in the rebars at all the depths.

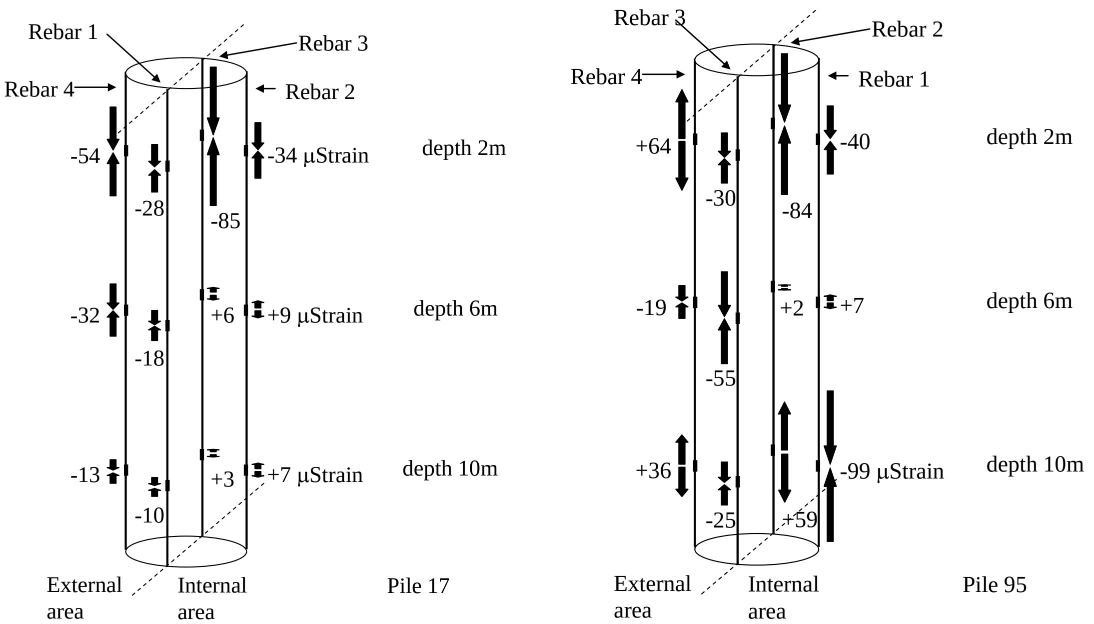

Figure 5. Distribution of deformation in Piles 17 and 95 at the end of the campaign in December 2009.

5 CONCLUSIONS

FBG optical fiber sensors have been installed in two piles and performed a data acquisition campaign during the construction of a trench at the "Parco della Memoria" in San Giuliano di Puglia (Italy). This allowed the analysis of the evolution of deformation of steel reinforcing bars. In each pile 12 sensors have been deployed along the reinforcement bars directly, before the concrete casting. The installation system allows the monitoring of pile deformation, discriminating between axial strains and bending.

The trends identified in the pile testing seems to indicate a correct behavior of the bulkhead. However, constant monitoring of the deformations at regular intervals may well test more informed basis for the presence of any abnormal behavior. It would also be suitable to provide a schedule of operations from which they can derive significant changes in the stress field near the tested piles, so plan well in advance of the measurement campaigns.

The proposed technology allows the monitoring of piling walls and other retaining structure deformation, with reference to global mechanism and to the different load conditions. The monitoring becomes very important in the test phase and in the control of the service conditions in order to verify the health status of the structure.

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