MONITORING OF A PILING WALL BY MEANS OF FBG: PART 2

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FBG optical fiber sensors were installed in two piles and performed a data acquisition campaign during the construction of a piling wall at the "Memorial Park" in San Giuliano di Puglia (Italy). This allowed the analysis of the evolution of deformation of steel reinforcing bars. In each pile 12 sensors were deployed along the reinforcement bars directly, before the concrete casting. The installation system allowed the monitoring of pile deformation, discriminating between axial strains and bending. Measurement campaigns were planned between April 2010 to October 2010. The observation to temporal intervals of the order of the months of the deformation of irons in poles 17 and 95 to several quotas allow us to inside study of eventual dislocation phenomena of the ground of the "Park of the Memory". Irons left and right of pole 17 show an increment of the deformation to all the quotas: in compression in the iron left in traction in the iron right. In the iron left, the compression increases until to the tests of 25 of May, in order then to decrease slightly in the tests of July and October. The amount of the deformation assumes values 5 times (period 15 opens them - 6 October 2010) respect those found in the previous year (period 23 September - 22 Decembers 2009). Looking at geotechnical project, deformations do not seems caused by differences of soil characteristics in the piles deploying but could be caused by geological evidences. An attempt in order to analyze what happens at pile 17 can be to insert, in the hole where the borehole accelerometer will be installed, a metallic bar to which connect a series of sensors FBG opportunely distanced so as to record the deformations near contacts between soil layers that may generate an elevated variation of stiffness (and therefore of speed of the shear waves) with possible inversions and eventually to measure with the FBG the permanent ground deformation induced by teleseismic (low energy) events.

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ABSTRACT: FBG optical fiber sensors were installed in two piles of a piling wall at the "Memorial Park" in San Giuliano di Puglia (Italy), and a data acquisition campaign was performed during the construction. This allowed the analysis of the evolution of deformation of the steel reinforcing bars. The installation system allowed the monitoring of pile deformation, discriminating between axial strains and bending. Measurement campaigns were carried out between April and October 2010. The long time measurements, lasted some months, of the deformation of irons in piles 17 and 95 at different quotas allowed us to inside study of any dislocation phenomena of the ground of the “Memorial Park”.

1 INTRODUCTION

FBG optical fiber sensors were installed in two piles and performed a data acquisition campaign during the construction of a piling wall at the Memorial Park in San Giuliano di Puglia, Italy (Rinaldis & al., 2011). This allowed the analysis of the evolution of deformation of steel reinforcing bars. In pile 12 sensors were deployed along the reinforcement bars directly, before the concrete casting. The installation system allowed the monitoring of pile deformation, discriminating between axial strains and bending. 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 and any possible perturbation cause. The data acquired in September and December 2009 allowed the verification of the evolution of deformation of steel reinforcing bars (Rinaldis et al., 2011). The trends identified in the pile testing seemed to indicate a correct behaviour of the bulkhead. However, constant monitoring of the deformations at regular intervals may well test more informed basis for the presence of any abnormal behaviour. 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. Measurement campaigns were planned between April 2010 to October 2010. The observation to temporal intervals of some months of the deformation of irons in piles 17 and 95 at different quotas allowed us to inside study of any dislocation phenomena of the ground of the “Memorial Park”. Left and right bars of pile 17 show an increase of the deformation at all the quotas: in compression for the left bar and in traction for the right bar. In the left bar, the compression increases up to the tests of May 25th, and then decreases slightly in the tests of July and October 2010. The amount of the deformation assumes values 5 times (between October 6th and 15th 2010) than those found in the previous year (between September 23rd and December 22nd, 2009). Looking at geotechnical project, deformations do not seems caused by differences of soil characteristics in the piles deploying but could be caused by geological evidences (e.g. dislocation of the fault system).

It is to remind that the Memorial Park is the site of the old Jovine school that collapsed during the 2002 earthquake. In a parallel project, two triaxial accelerometer sensors will be installed at this site, one on the surface and the other about 30 *m* under the surface, in order to analyze the input at the bedrock and the amplification. This could be the occasion for the installation, in the same hole, a metallic bar to which connect a series of sensors FBG opportunely spaced, to record the deformations near contacts between soil layers that may generate an elevated variation of stiffness (and therefore of speed of the shear waves) with possible inversions. The permanent ground deformations induced by teleseismic (low energy) events could also be measured.

2 INSTRUMENTED PILES AND SENSOR LOCATIONS

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 of the piling wall at the Memorial Park in San Giuliano di Puglia, allowed the verification of the evolution of deformation of steel bars (Rinaldis et al., 2010). The map in figure 1 shows the position of monitored piles as well as the sections considered to verify the landslide stability. Unperturbed layer, landfill and altered layer are shown in the sections. As one can see from the different sections, piles 95 and 17 were partially inserted (about 30% of their length) in the unaltered soil.

The eight sensor chains were installed in 2 piles (Pile No. 95 and Pile No. 17). Each chain was installed along a longitudinal reinforcement steel bar of a pile. The four chains of the same pile are angularly spaced of $\pi/2$. Figures 2a and 2b specify arrangement and classification of chains installed in Pile 95 and Pile 17, respectively, in the transversal section; sensors were positioned at -4.0 *m*, -6.0 *m* and -10.0 *m* from the top of the bar (Rinaldis & al., 2011). The application of sensors on the steel bars was 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 took place before their positioning into the hole.

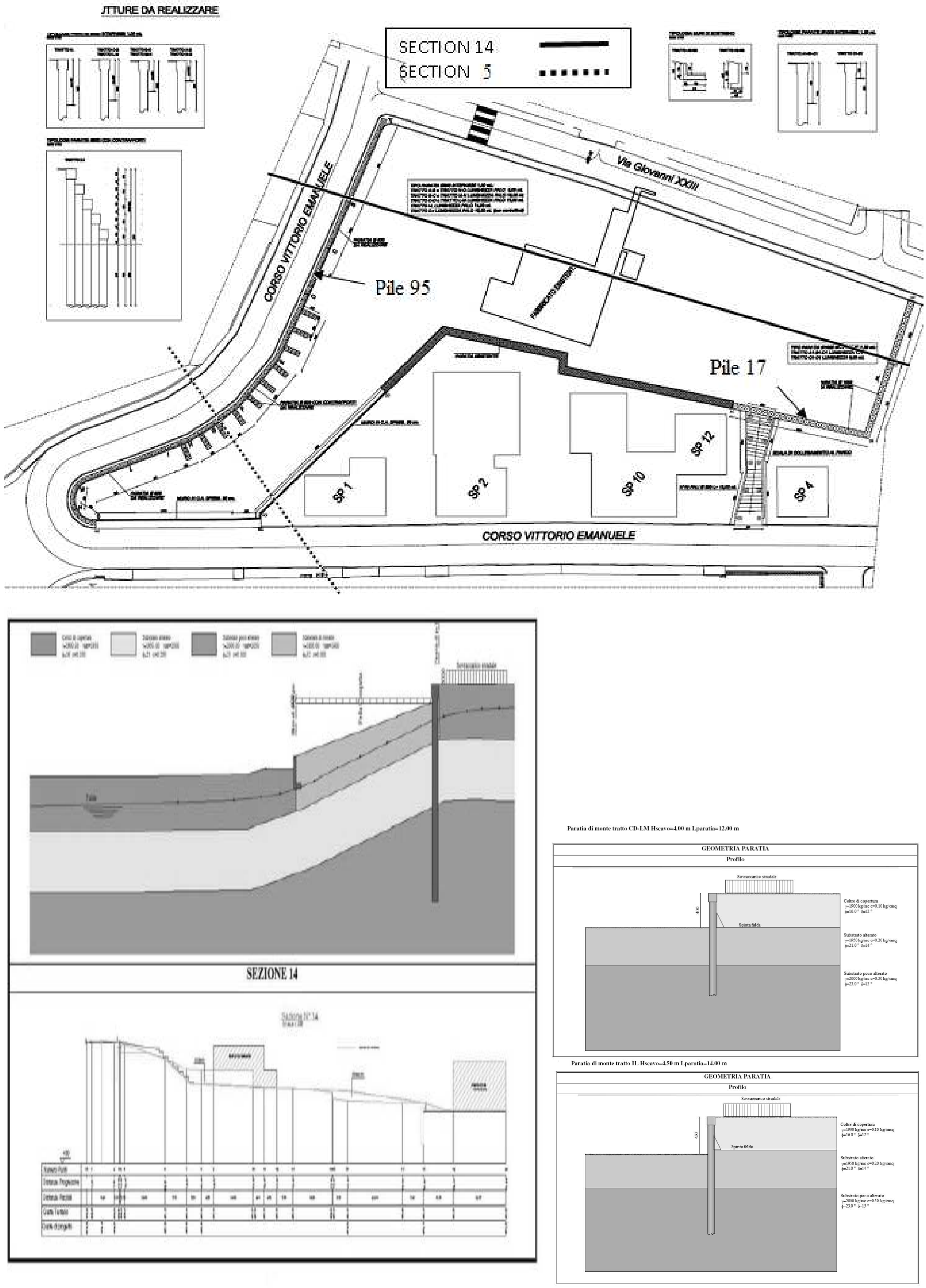


Figure 1 Map of “Memorial Park” in San Giuliano di Puglia (Italy).

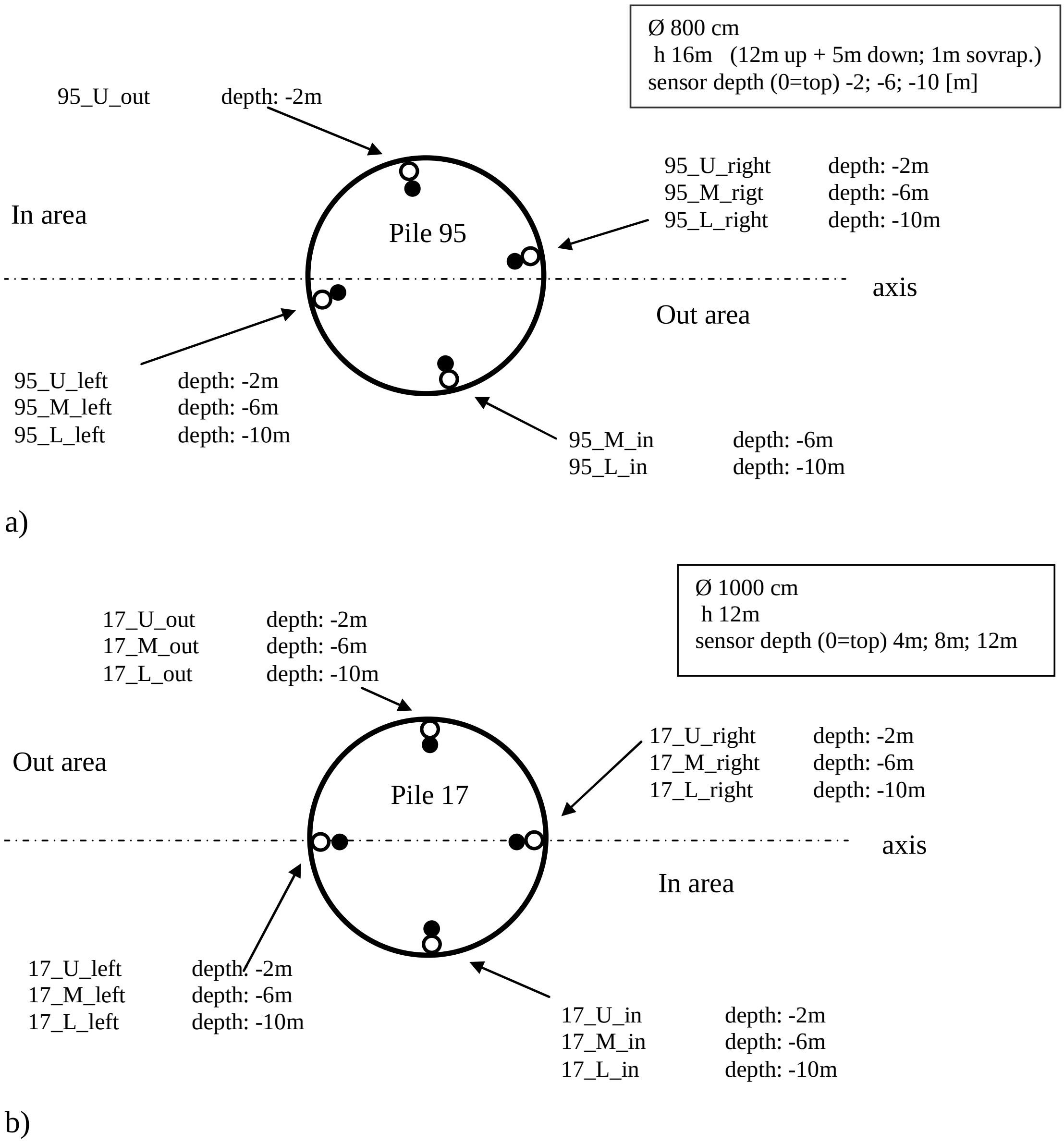


Figure 2. Arrangement and classification of chains installed in Pile 95 and Pile 17.

3 ANALYSIS OF RECORDED DATA

Before proceeding with the analysis of measurements taken between April and October 2010 we should first summarize the results of the previous measurements (Rinaldis et al., 2011). These measures, especially those made in September 2009, also contain information on the stresses caused by ground movements that overlap, however, human actions such as excavation, drilling for the installation of piles near the castings for the construction of piling wall etc., and therefore they may be somewhat masked. So greater importance is given to the most recent measurements because the influence of human activities in this period was negligible. The graphs in both figures of annual summary (Figure 3a and 3b) and those related to the measures of October 2010 (see e.g. Fig. 4a and 4b) show a clear increase of stress in the rebars for pile 17 but more visible in pile 95. In particular, the left and right chains of pile 17 show an increase of strain at all levels, in compression at left (negative values) and in traction at right (positive) (Figure

3a). In fact, as regards the left rebar, the compression increases until the tests of May 25th, then decreased slightly in the tests of July and October 2010.

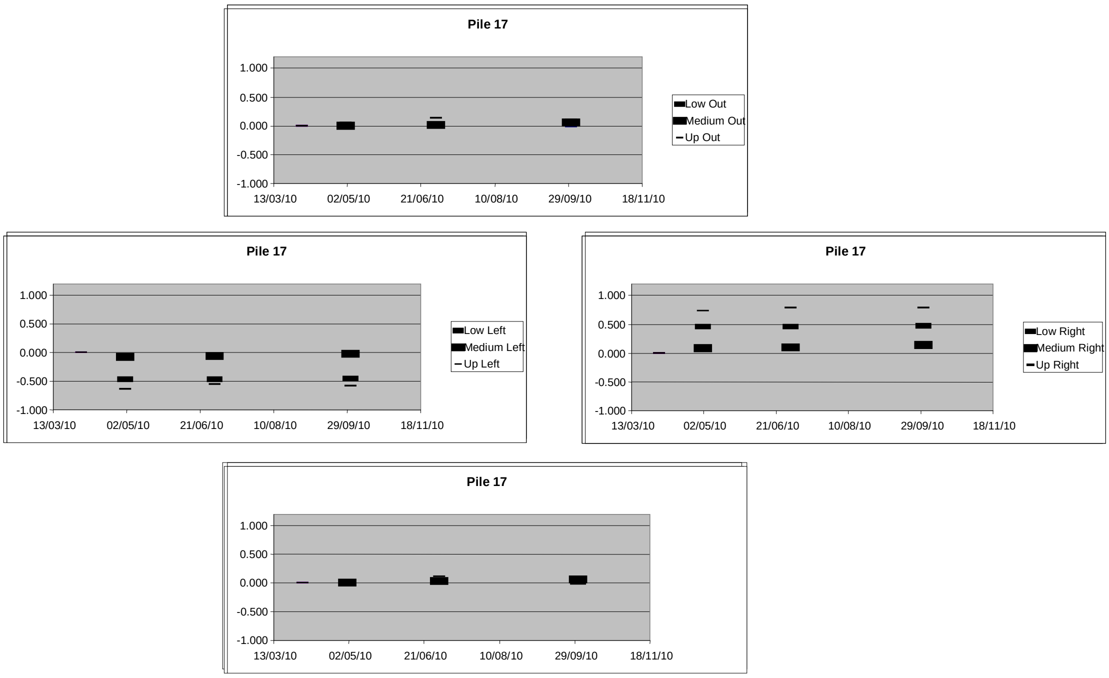
It is important to note that the amount of deformation increased to values five times higher (between April 15th and October 6th, 2010) than those seen in the previous year (between September 23rd and December 22nd, 2009). Most of this increment occurred between April 15th and May 25th (approximately 90% of total for rebar in traction and 100% for rebar in compression). The measurements carried out on pile 17, from October 5th to 6th, 2010, exhibited a phenomenon at a time scale much smaller than hitherto revealed. Such measures were suspended during the night and the value of the strain in right rebar at lower level, at the resumption, was positive (traction). No appreciable changes occurred in the other rebars. In addition to this one, the phenomena of cyclic deformation at low frequency could be observed, always at the maximum depth of measurement, with the measurement of deformation in the long run.

Figure 3b shows that the deformation in pile 95 is less than in pile 17. Moreover, measures of average values seems to ensure that the most stressed bars are "in" and "out" (Figure 2) and the both of them are is traction. The measurements of October 5th and 6th, 2010, show a stress drop at a time-scale shorter than that observed in the previous ones. Besides, stresses in the rebar of piles 17 and 95 may be caused by sliding or other phenomena caused by the geological evidences.

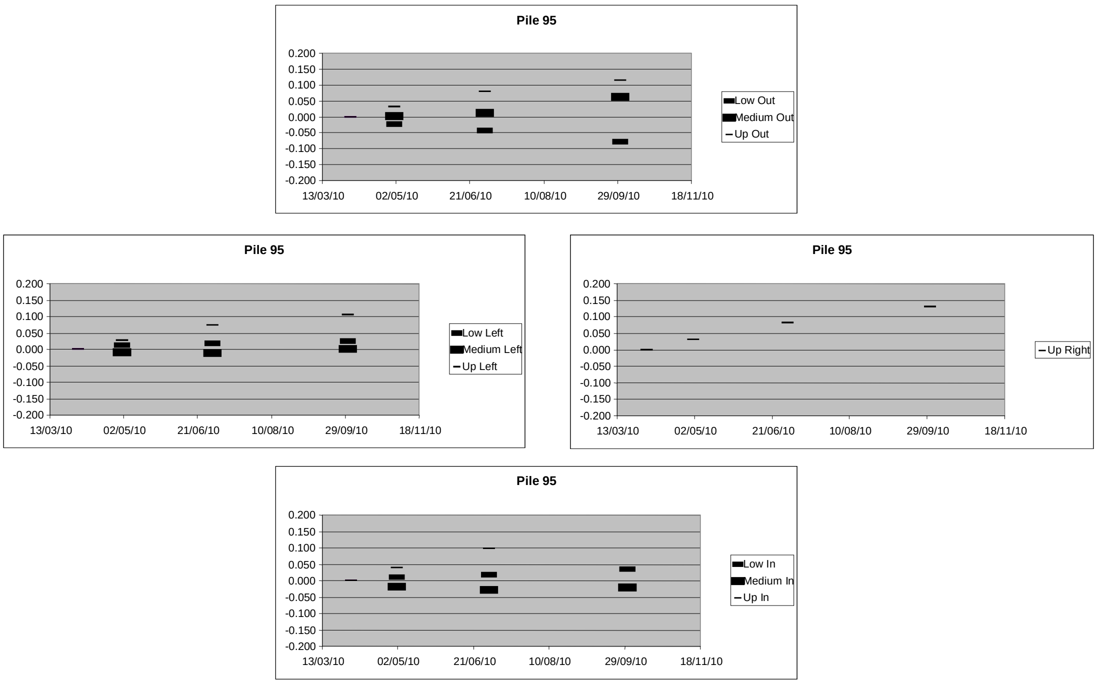
4 CONCLUSIONS AND FURTHER ANALYSIS

The analysis of data shows that the deformation in pile 95 is less than in pile 17. Moreover, measures of average values seems to ensure that the most stressed bars are "in" and "out" (Figure 2) and the both of them are is traction. It is worth noting INGV (Istituto Nazionale di Geofisica e Vulcanologia) and the Italian Department of Civil Protection (Pacor et al., 2007) made a report based on in situ tests (geoelectric, tomography, gravimetric tests, seismic reflection). According to this report, in which a 3-D model of the plain was obtained, it was possible to establish that in the Memorial Park there are 4 unlock of a fault at various depths.

In a parallel project, two triaxial accelerometer sensors will be installed at this site, one on the surface and the other about 30 *m* under the surface, in order to analyze the input at the bedrock and the amplification. This could be the occasion for the installation, in the same hole, a metallic bar to which connect a series of sensors FBG opportunely spaced, to record the deformations near contacts between soil layers that may generate an elevated variation of stiffness (and therefore of speed of the shear waves) with possible inversions. The permanent ground deformations induced by teleseismic (low energy) events could also be measured.

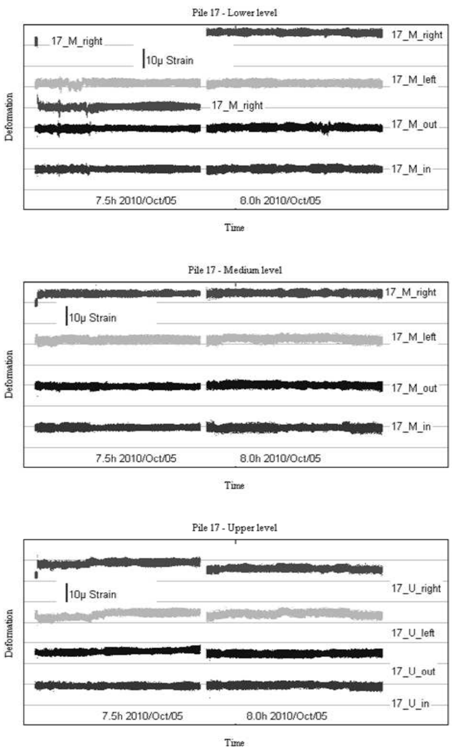


a)

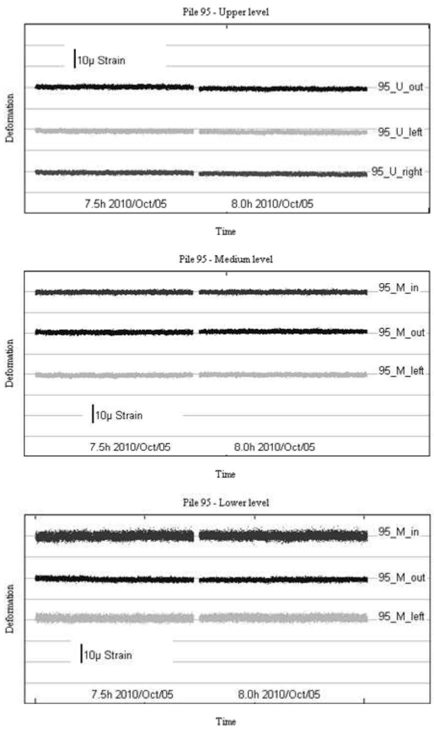


b)

Figure 3. Measurements taken between April and October 2010: a) Pile 17; b) Pile 95.



a)



b)

Figure 4. Measurements carried out on the piles 17(a) and 95 (b) in the period 5 to 6 October 2010

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