TOPOGRAPHIC MONITORING OF A WATER TANK IN THE WIDENING WORKS OF EIXO NORTE-SUL HIGHWAY IN LISBON

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Abstract: A monitoring necessity for a water tank in Lisbon originated in the widening work of the Eixo Norte-Sul highway, which involved excavation near the tank. As the excavation could affect the tank's safety and the water supply service, the owner (EPAL – Empresa Portuguesa de Águas Livres) and the employer (EP – Estradas de Portugal) agreed on the installation of a topographic monitoring system. This paper describes the processes in the topographic monitoring of the water tank, and stresses the importance of the installed system. The use of the sub-system for vertical displacement determination as a warning system is also focused. Due to the complexity of the works and an unexpected behaviour of the structure, the integration of the results of the topographic monitoring with the geotechnical instruments was critical in the analysis, understanding and validation of the results.

1. INTRODUCTION

The need to monitor the water tank was motivated by the widening works of North-South highway, one of the largest roads in Lisbon, which involve excavation near the water tank. By project indication, after the excavation two support walls would be constructed, in two different levels. The main function of these walls would be to stabilize the slope in the water tank. Fearing that the excavation could jeopardise the safety of the water tank and affect the normal water supply to the population, it was decided by EPAL – the tank owner and EP - the promoter , to install a topographic monitoring system.

Surveying company GEÓIDE, and Instituto Superior Técnico as a cooperative partner, were responsible for the definition and implementation of such system. Additionally, we also installed geotechnical instrumentation. The topographic monitoring began on April 20, 2005, with daily readings frequency, going on a twice per day stage where shifts had become more significant. After solving the problem, the frequency of campaigns was progressively reduced until the conclusion of works. The system was observed for the last time on January 8, 2007.

2. LOCATION, ENVIRONMENT AND DIMENSIONS

The water tank is located at Alto Lumiar. It is a composed structure of two independent cells, built in different periods, separated by a central corridor allowing the access to both cells, and sharing the terrace. The east cell –, the oldest one –, was built circa 1950; the west cell was built in the 1980's. The constructive process was quite different: the east cell has an exterior buttress system and the west cell has an interior one. The water tank size is 83 meters long, 43 meters wide and 7 meters high, with only one meter above surface level. Figure 1 illustrates the water tank, where the division line between both cells is visible.

Figure 1 – Water tank in Alto Lumiar (Google Earth imagery)

3. SYSTEM DEFINITION AND IMPLEMENTATION

The installed topographic monitoring system is composed by two subsystems: one to evaluate horizontal displacements and a second one to assess vertical displacements. The system was complemented with geotechnical instruments, such as tiltmeters, inclinometers and fissurometers. The least square method was used in observation adjustments to determine the horizontal and vertical displacements. The network has been planned to allow high redundancy, in accordance with Cooper (1987). Among all geotechnical instruments, the main interest was in inclinometers, which provided information on depth and lateral terrain behaviour, and, in the other hand, geotechnical instruments, which operate as an independent system, and help to corroborate the values obtained by the topographic system.

3.1. Horizontal displacement subsystem

The proposed system is composed by seven target points, four station points, three in pillar and one in tripod, and five reference points. Station points were designated respectively by Pillar 1, Pillar 2, Pillar 3 and POD 4. For target points we used Leica GMP104 (Figure 2a) and removable Leica mini-prisms GMP103 (Figure 2b).

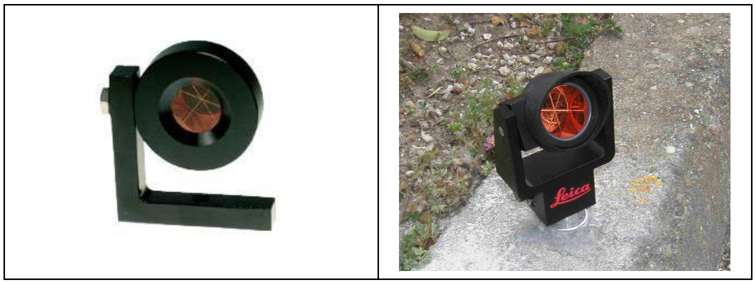

Figure 2 – a) Leica GMP 104 target; b) Leica GMP 103 target.

The reference points were selected from nearby buildings, sufficiently apart from the area being monitored so that stabilization can be assumed, and implemented by Leica mini-prism GMP 104. We used five points reference, known as RH1,…, RH5.

Angle and distance measurements were made by a total station Leica TCA2003, with average quadratic angular error of approximately 0.5" and 1 mm + 1 ppm in distance measurement. In the planned system, the size of *a priori* error ellipses varies between 1.4 mm and 4.1 mm. The geometric configuration of the network used in the determination of the horizontal displacement is illustrated in Figure 3.

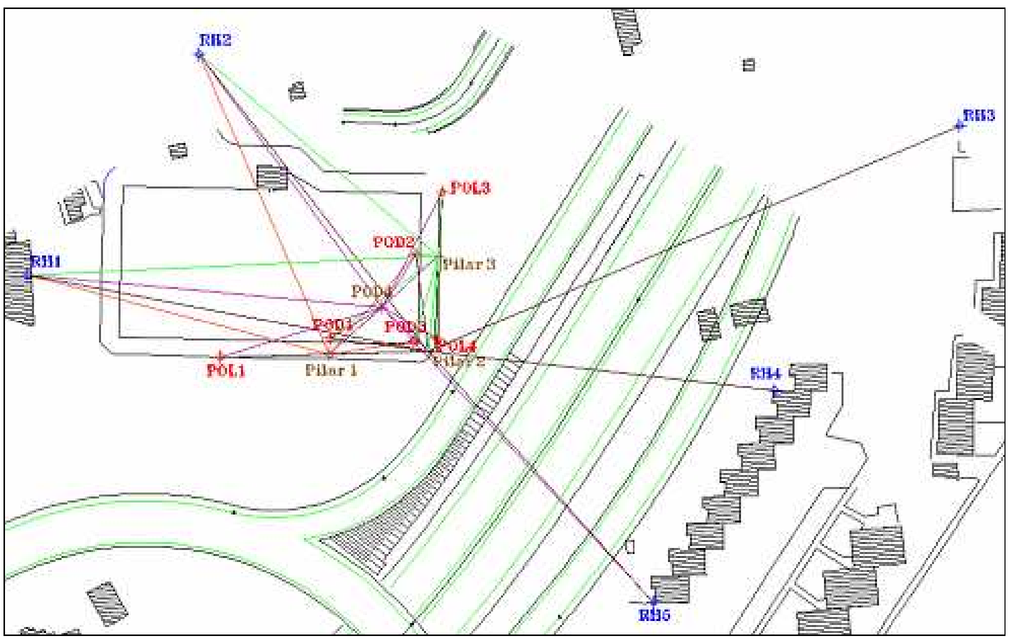

Figure 3 – Network geometric configuration for horizontal displacements.

3.2. Vertical displacement subsystem

The subsystem used to determine the vertical displacement was composed of five reference marks and 13 target marks. In practice, we use levelling (Casaca *et al*., 2005). All marks were welded with a two component epoxy resin in existing structures (curbs, concrete structures, etc). The equipment was a digital level Leica NA2002 and an invar code bar. Mark locations are displayed in Figure 4.

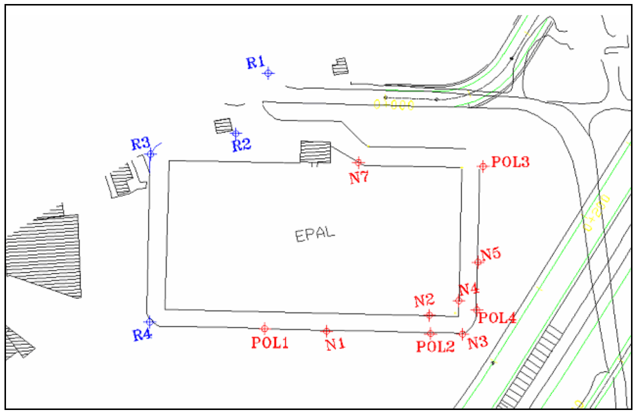

Figure 4 – Network marks for vertical displacements.

The observation system has been designed to enable cross readings between marks, increasing the redundancy and improving the specifications. The final accuracy associated with the determination of the vertical displacement is 0.3 mm.

About geotechnical instrumentation were installed 4 inclinometers, 2 tiltmeters, 10 uniaxial fissurometers and 14 biaxial fissurometers. Examples are shown in Figure 5.

Figure 5 – Geotechnical instrumentation: inclinometers, tiltmeters, uniaxial and biaxial fissurometers.

3.2.1. Inclinometers

The vertical inclinometers were installed at the top of the slope under control, up to 24 m deep (2 m below the wall foundation level), in order to monitor movements of the support wall, during and after the construction.

3.2.2. Tiltmeters

Two tiltmeters here installed on both sides of the external tank, where we were expecting an higher probability of displacement. The bases were placed in perpendicular faces, at the same distance from the corner and at the same height.

3.2.3. Fissurometers

Installed fissurometers were chosen by type of cracking and kind of control desired. Uniaxial fissurometers were installed in the exterior tank walls and biaxial fissurometers in the terrace and inside the water tank. Geotechnical instrumentation location is displayed in Figure 6.

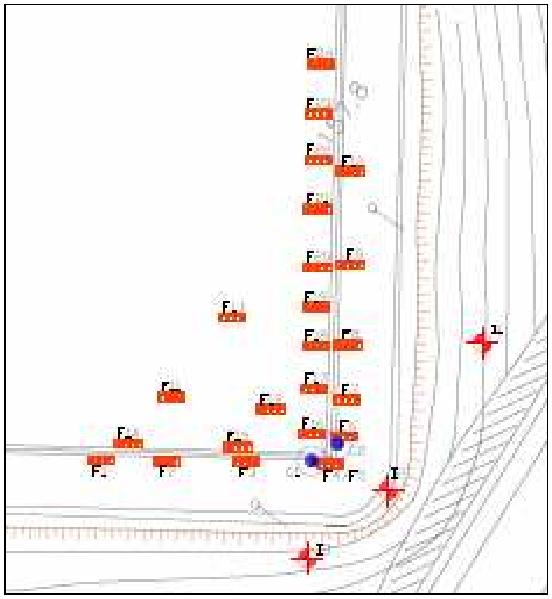

Figure 6 – Geotechnical instrumentation location
(F-fissurometers, O-tiltmeters, I-inclinometers)

4. RESULTS ANALYSIS

All analysis, for the different kinds of instrumentation, were done in an integrated way. Noteworthy were the positive values of vertical displacements obtained by levelling for the N3 mark in L3 epoch (corresponding to April 22, 2005), as shown in Figure 7.

EP REF	L1- A	L2 - A	L3 - A	L4 - M	L5 - A	L6 - M	L7- A	L8 - M	L9- A
20-Apr	21-Apr	22-Apr	22-Apr	23-Apr	23-Apr	26-Apr	26-Apr	27-Apr	27-Apr
0.0	0.4	0.4	2.0	1.8	2.3	2.1	2.4	2.1	2.6

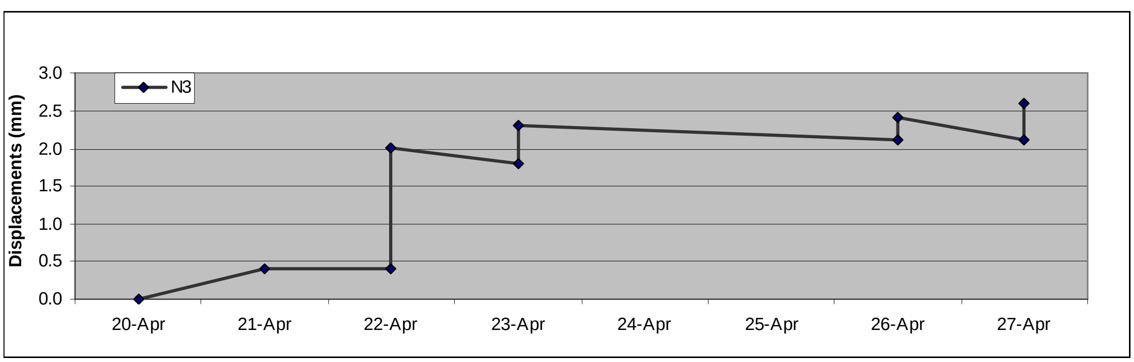

Figure 7 –Vertical displacements of N3 mark

N3 mark is part of the set of marks closest to the excavation site. For the remaining instrumentation significant displacements were not observed in the same epoch. A vertical displacement (uplift) of approximately +2.0 mm was detected. It was considered by supervisors as an alert value, so works were interrupted for several weeks. When the excavation of the slope was resumed, no abnormal results were detected in the first sessions. However, with the increase in excavation depth, re-emerging uplift in marks closest to the slope and subsidence in furthermost marks were noticed, suggesting the rotation of the tank around an axis perpendicular to the plane of the slope.

Only in early August 2005 the horizontal displacement subsystem corroborated the values of vertical displacements, and it was no earlier than the end of that month that the geotechnical instrumentation, in particularly the inclinometers, detected these displacements (Figure 8).

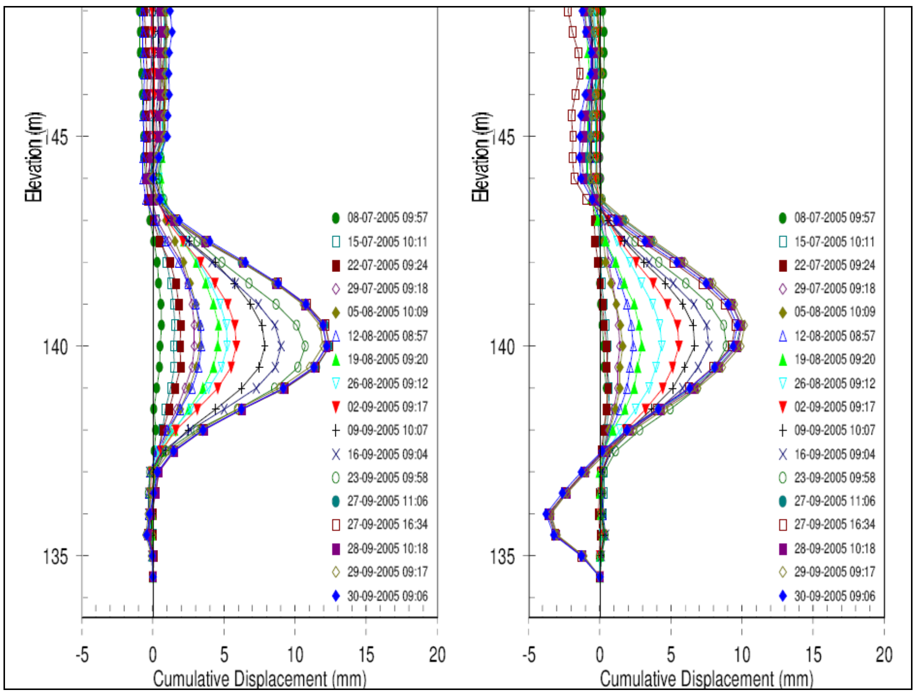

Figure 8 –Inclinometer I3 value.

The vertical and horizontal displacements determined through topographic observation system were later confirmed by geotechnical instrumentation, and classified by the team of geotechnical of EP / EPAL as the expected displacements. Notable was the fact that comparing with the geotechnical instruments the topographic methods provided, with some months in advance, the displacement detection: inclinometers I1 and I3 only identified those displacements in August 2005. Figure 9 illustrates slope behaviour.

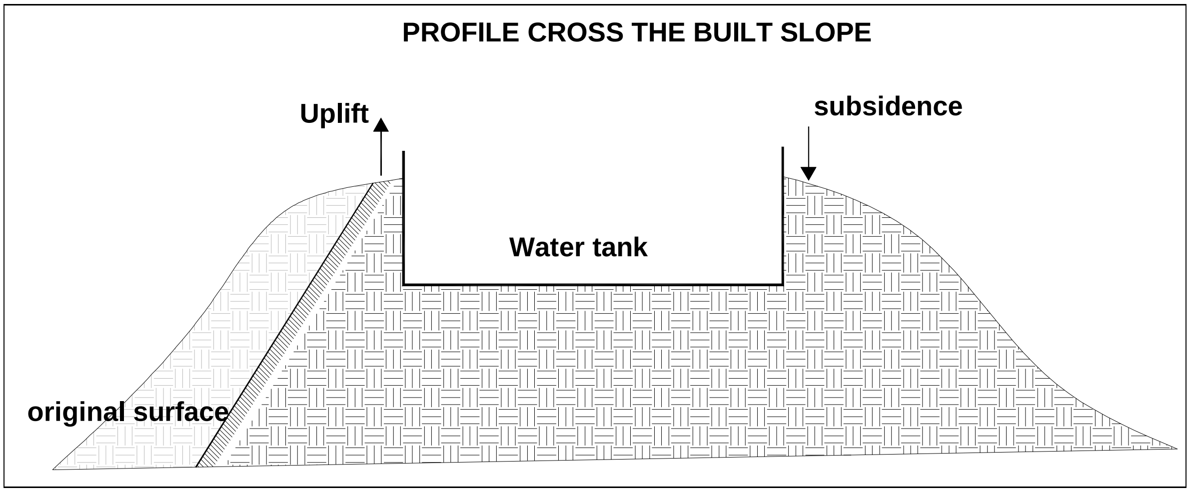

Figure 9 – Displacement description observed by the vertical topographic subsystem.

Figure 10 – Photo of the site during and after final works conclusions.

The analysis of displacement readings observed on the instrumentation system installed, were explained by the team, as the result of the excavation done on the natural slope and due to the presence of a silt sandy layer under saturated conditions, at 16 m depth that created a rotational landslide. When this saturated silty layer was intercepted by the excavation, the water started to flow and it washed very quickly the fine material, increasing the landslide phenomenon. The geological drilling survey done nearby the inclinometer I3, confirmed this interpretation. The solution projected by the geotechnical expert team to stop the landsliding was to shotcrete and install drain pipes on the slope of excavation, in order to stop the fine material wash. Figure 10 shows the slope excavation and the actual situation after construction conclusion. After conclusion works, all observed values stabilized in all types of instruments. As a preventive measure, the topographic monitoring system was still in operation until January 2007, although less frequently.

5. CONCLUSIONS

The slope construction to support the water tank deserved attention of EPAL and EP. Because of the complex works and the unexpected land behaviour, the integration of values from topographic and geotechnical systems was of great importance in the analysis for understanding the slope behaviour. From all the instrumentation used, the values obtained by levelling were the most important by its sensitivity, working as a reference for warning and alert sign. Finally, we conclude that low-cost topographic methods, such as levelling, proved to be important tools in construction monitoring and related decision-making.

References

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