GEOLOGICAL ASPECTS OF LAND SUBSIDENCES DETECTED BY DIFSAR AT SANT FELIU DEL LLOBREGAT, CATALONIA, SPAIN

Aline Concha; Jordi Ripoll; Jordi Marturià and Jordi Piña

Area d'Enginyeria Geològica i Risc. Institut Geològic de Catalunya. Balmes 209-211. 08006 Barcelona.

KEY WORDS: differential interferometry, subsidence, consolidation, water extraction.

INTRODUCTION

The Differential Interferometry of Satellite Radar (DInSAR) analysis on the entire Catalonian territory from 1993 to 2006, allowed identifies major zones affected by subsidence (ICC, 2007) One of these zones is located along the Llobregat river basin, at Sant Feliu de Llobregat town, 20 km NW from Barcelona City. At the "El Pla" industrial zone (Figure 1), DInSAR maximum deformation rates are up to 0.70 cm/year.

In order to investigate and evaluate the possible triggering factors that control and generates the subsidence, hidrogeological, geological and geotechnical information, as well as the influence of human activity has been compiled.

The objective of this paper is to present the geological conditions and processes to quantify deformation and correlate them with the deformation measured by remote sensing techniques (IGC, 2008). The results serve as guidelines for future and more detailed research.

GEOLOGICAL CONTEXT

The study zone is located on materials of the lower Llobregat river plain to the northwest of the Sant Feliu del Llobregat urban zone (around twenty kilometres NW from Barcelona). Geologically, the materials that form this river plain are quaternary fluvio-deltaic materials that overlaid the basement, composed by paleozoic rocks (mainly composed by siluric shales) and Neogene materials(NP), Figure 1.

The Quaternary sediments are related to five sedimentary cycles delimited by stratigraphic disconformities. Each cycle is characterized in the lower portion by fluvial terrace deposits that laterally can change to alluvial and colluvial deposits. The distribution and thickness of these deposits have depended on the substratum paleorelief and the migration of the river current through time. At the study zone, layers formed by gravels and a upper layer silty-clay that belong to the youngest Llobregat river terrace (Qt1, Figure 1), contain the main aquifer of the LLobregat River. This is a non-confined aquifer within interbedding of gravels, silts and clays, Figure 2.

HYDROGEOLOGICAL CONDITIONS

A high density of water wells and industrial land use was recognized at the zone. This fact lead to the comparison of phreatic levels measurements from the monitoring network of the Catalonian Water Agency (ACA) existing at the zone with DInSAR deformation measurements, Figure 3. Complete information for the same period (from 1993-2006) for the largest deformation zone was possible only for two piezometers, Piez. Estrella 6 and Piez. 9, Figure 1. These comparisons show good correlation between phreatic lower levels and terrain subsidence and recovering periods with lower rates of deformation, Figures 3 and 4.

GEOTECHNICAL EVALUATIONS

The geological and geotechnical investigations allowed to identify and characterized the geological layer that potentially could cause the ground deformation measured by DInSAR. At the area of study the first 15-20 m below de surface consist in a deformable layer of silts and clays deposits. Below this layer there is a sequence of gravels and sands down to 30-40 m that contains the shallow Llobregat aquifer (ICC, 2004). Both silt-clay and gravelly layers belong to what is defined as geological unit Qt1 and Qt2 (Figure 2 and 3). Silts and clays are sediments very susceptible to consolidate by modifications of their natural conditions. Therefore, the principal hypothesis in this study is that the shallower deformable layer is capable to generate the observed deformation by consolidation processes due to changes of water table. In Table 1, appears the laboratory measured deformability parameters used in the analytical evaluations of deformation.
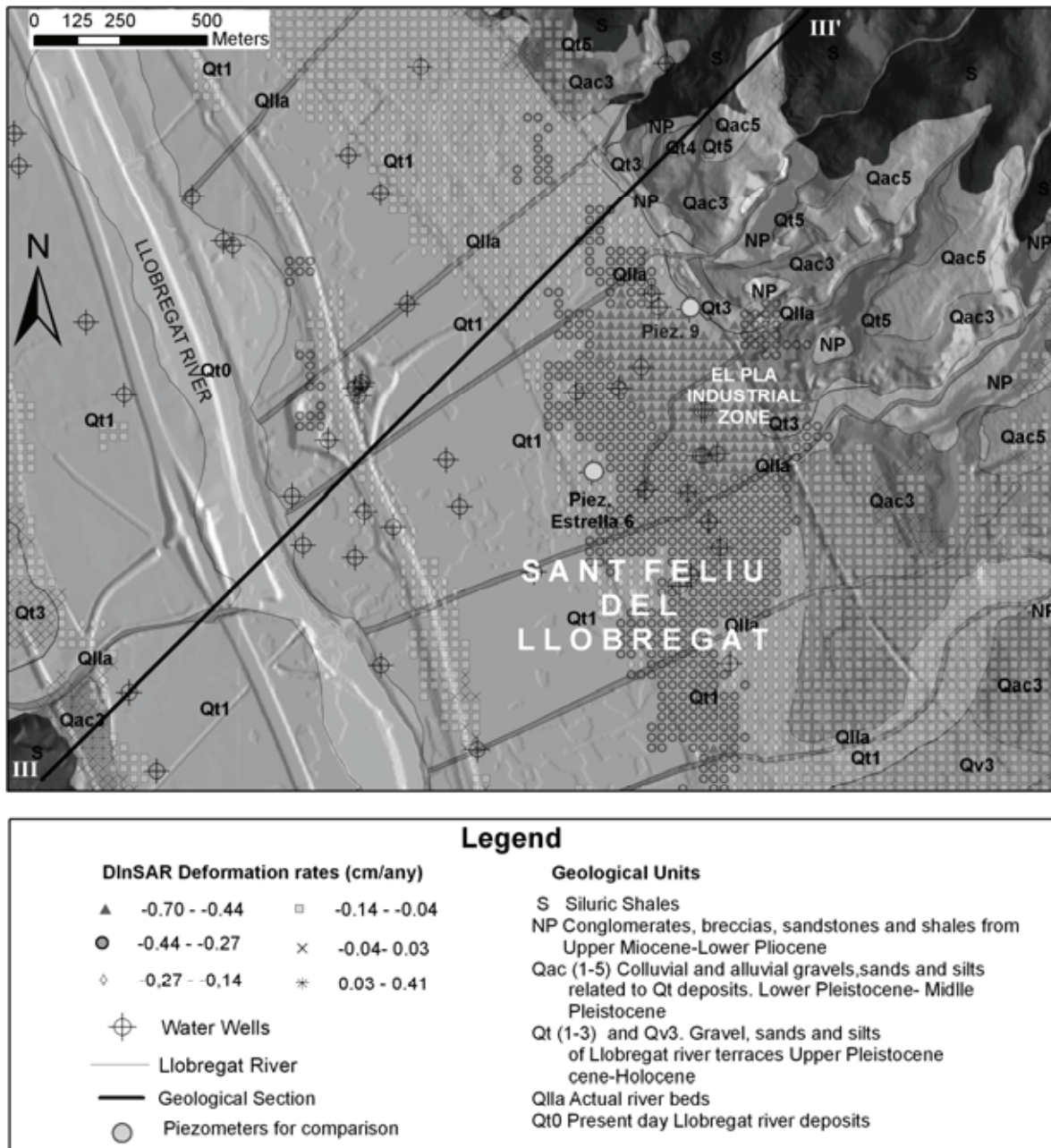
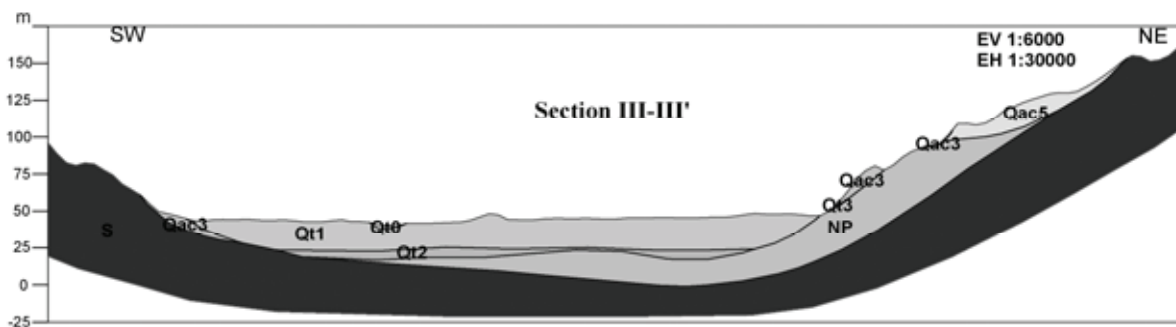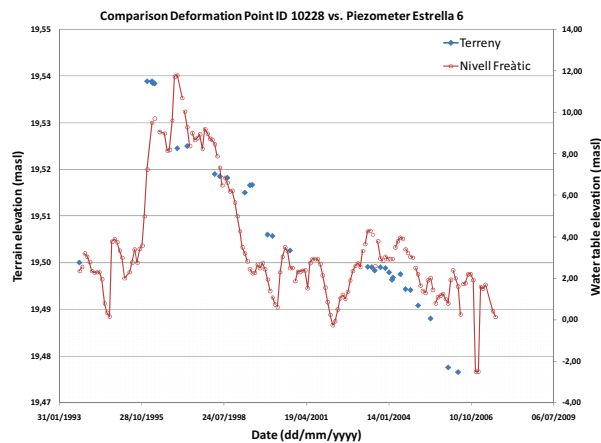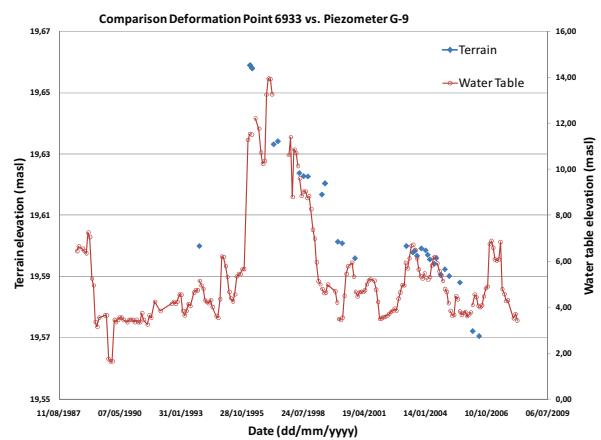*Figure 1 – Detailed geologic map of the zone of study (after ICC, 2006).*

Figure 2 – Section III-III' with the main geological units (after ICC, 2006).

a)

b)

Figure 3 – Piezometric levels and terrain surface deformation correlations within the DInSAR analysis period (1993-2006) for a) Piezometer 6 and b) Piezometer 9 located at Figure 2.

Table 1 – Geotechnical parameters of the silty-clayey layer used in the analytical quantification of deformation.

Parameter	Value	Units
Dry density, g_d	17.50	KN/m^3
Porosity, n	0.55	--
Initial void ratio, e_o	0.562	--
Compression Index, C_c	0.130	--
Swelling Index, C_s	0.012	--

The analytical evaluation consisted in using the one-dimension consolidation theory from the classic Terzaghi's formulation (Jimenez-Salas and de Justo-Alpañes, 1975) where the vertical deformation (*s*) is calculated from the following equation:

$$s = \frac{H}{1 + e_0} \cdot C_c \cdot \log\left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0}\right)$$

Where:
H: the thickness of the layer of interest
e_0: initial void ratio
C_c: compressibility index from consolidation tests
Ds': effective stress change related to changes of phreatic levels
s'_0: initial effective stress

The analytical approach considered 10 stages of decrements of water table position to calculate differential changes of thickness. This calculated deformation was compared with the observed DinSAR terrain measurements at the piezometer Estrella 6, Figure 4. The resulting theoretical curve has the same tendency as the measured DinSAR deformation and phreatic levels variations. Though the analytical values are not similar, the order of magnitude is the same and shows that consolidation process is a large component of the total deformation observed within the area of interest during the period of study.
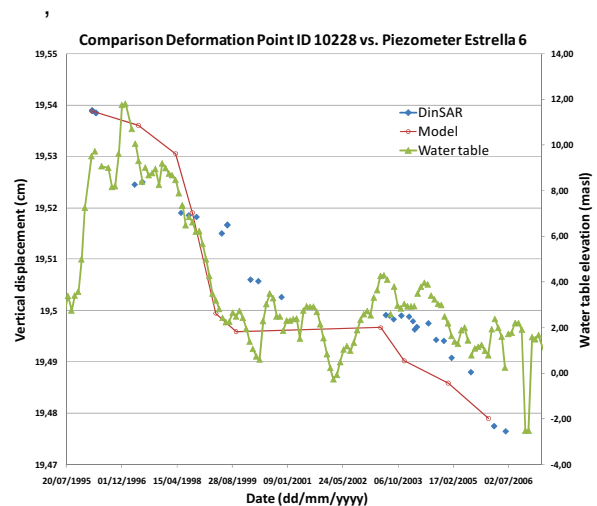

Figure 4 – Comparison of phreatic levels, DInSAR deformation and calculated deformation through time at Estrella 6 piezometer

Comparing only phreatic levels increments versus increments of deformation, the DinSAR measured increments of deformation are scattered and form a highly dispersed cluster (Figure 5) while the 10 calculated values follow the expected incremental lineal relationship. (Figure 6). Scattering of the measured data might be due to the intrinsic DinSAR technique precision or other geological or anthropic aspect that have not yet identified such as: not registered points of water extraction, basement morphology, lithological heterogeneities, inelastic recovering of the materials etc., that result in a complex deformation field curve.
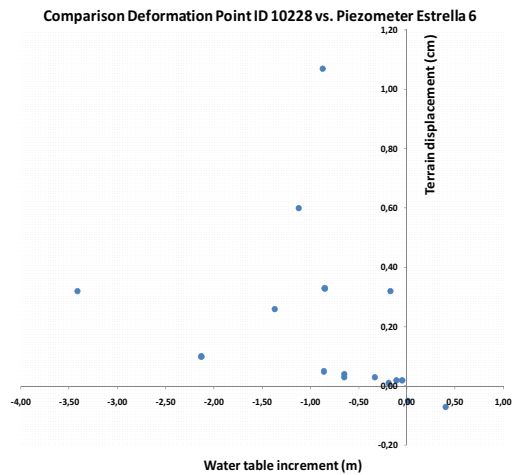
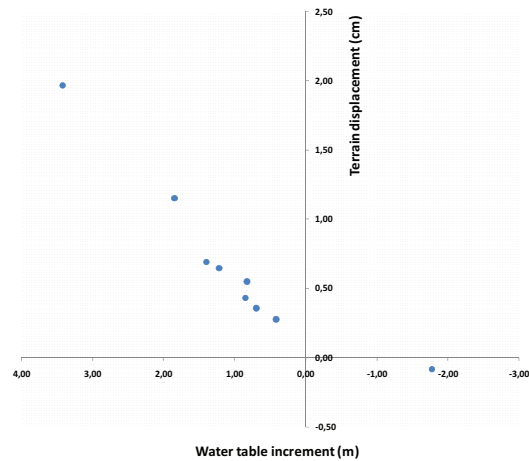*Figure 5 – Comparison between changes of phreatic levels and corresponding DInSAR deformation changes*

Figure 6 – Comparison between changes of phreatic levels and corresponding calculated deformation changes

REFERENCES

INSTITUT CARTOGRAFIC DE CATALUNYA (ICC), 2006. Mapa Hidrogeològic del tram baix del llobregat i el seu Delta 1:30000, 1st. Edition

INSTITUT CARTOGRAFIC DE CATALUNYA (ICC), 2007. Mapa de subsidències. Internal report Num. 001486001

INSTITUT GEOLOGIC DE CATALUNYA (IGC), 2008. Subsidències a Catalunya: Anàlisi preliminar dels aspectes geològics en la interpretació de mapes DInSAR de deformació vertical a Catalunya. Internal Report Num. AP-177/08

JIMENEZ SALAS, J.A. AND DE JUSTO ALPAÑES, J.L.1975. Geotecnia y Cimientos I. Editorial Rueda, Madrid, 466 pp