DInSAR Monitoring of Land Subsidence in Orihuela city, Spain: Comparison with Geotechnical Data

R. Tomás, J.M. Lopez-Sanchez, J. Delgado, F. Vicente
University of Alicante
Alicante, Spain
roberto.tomas@ua.es

A. Cuenca
Conselleria de Infraestructuras y Tte. de la Generalitat Valenciana
Alicante, Spain
art_cuenca@gva.es

J.J. Mallorquí, P. Blanco, S. Duque
Remote Sensing Lab. (RSLab).
Universitat Politècnica de Catalunya
Barcelona, Spain
mallorqui@tsc.upc.edu

***Abstract*—An advanced DInSAR technique called Coherent Pixels Technique (CPT) has been used to measure the subsidence existing in Orihuela city (Spain) during the period 1993-2001 due to ground water level fall. The estimated subsidence, with values lower than 7 cm, is highly influenced by soil geotechnical conditions like the deformable soil thickness. In addition, the wells location is an important subsidence factor because they are directly related to a decrease of the piezometric level.**

Keywords-component; DInSAR, CPT, subsidence, soft soils, geotechnics

I. INTRODUCTION

Differential SAR Interferometry (DInSAR) is a remote sensing technique with a well known capability to monitor ground deformations and particularly ground subsidence. In this work, an advanced technique called Coherent Pixels Technique, CPT [1][2], has been employed to map the settlements that affected the historical city of Orihuela. This city is placed on the border of the valley of the Segura river (Vega Baja of the Segura river, SE Spain). Part of the city is founded on rock (non deformable) and the remaining on soft soils (silty clays and silty sands). During the 90's, a drought period led to intense exploitation of underground aquifers. Water pumping caused an important generalized piezometric level fall of 5-10 meters on the aquifer system, inducing centimetric settlements due to consolidation of the deformable soft soils layer as a result of the increase of effective stresses. The above mentioned subsidence affected an important part of the city, causing several damages on the buildings and an important social alarm.

To study this period of ground subsidence, a set of 38 SLC SAR images acquired by the European Space Agency (ESA) satellites ERS-1 and ERS-2, corresponding to the 1993-2001 period, have been used. The computation of the deformation maps involves several steps: images co-registration, satellite orbits calculation, generation of differential interferograms, application of CPT algorithm, and geo-coding of the results from radar coordinates to Universal Traverse Mercator (UTM). The evaluation of the error associated with this technique depends also on issues external to the algorithm, such as the number of available SAR images, baseline distribution, Doppler centroid differences, control points accuracy, etc.

The obtained deformation maps have been compared with: a) distribution and thickness of soft soils in the zone [3], b) water pumping wells distribution, and c) documented damages location. Some other geotechnical data such as soil pre-consolidation stress, compression index, and lithology [4][5] have been compared with DInSAR derived deformations. In general, the softer (those with lower preconsolidation stresses and higher compression indexes) and thicker the soil layer is, the greater are the measured deformations.

This comparison of measurements is of prime interest for validating DInSAR (i.e. testing its accuracy and demonstrating its potential and limitations), with the objective of increasing the confidence from geologists and civil engineers in this remote sensing technique. The adoption of such a tool in geotechnical studies, for example by studying the correlation among geotechnical features, their spatial distribution, and the monitored deformations, would increase the amount of information necessary to understand these complex processes.

II. AVAILABLE DATA

A. Piezometric data

The available piezometric information consists on long water level evolution series on several points along the valley. The available data start on 1970´s up to present. Three long piezometric series are available near Orihuela (Figures 1 and 2). These piezometers show a common fall up to 8 meters in the studied area from 1993 to 1995, corresponding to a long draught period that affected the whole area and caused important damages also in Murcia city [6][7]. As it can be observed at Figure 2, there exists a relationship between the ground water levels and precipitations, caused by the recharge effect due to infiltration.

B. Geotechnical data

Several geotechnical boreholes with depths up to 50 m drilled in the Orihuela area are available (Figure 1). The undisturbed samples taken at different depths from these boreholes have been tested at the laboratory in order to characterize them and to determine deformational and shear properties. Delgado et al. [4] studied these properties establishing several sedimentological areas with common geotechnical properties. In Orihuela city we have distinguished two principal areas according to Delgado et al. (2002) sectorization (Table 1): Flood Plain Zone (FPZ) and Sedimentary Rocks (SR). The first one has been subdivided into two news groups: Superficial Flood Plain Zone (SFPZ) and Deep Flood Plain Zone (DFPZ), according to differences in the degree of overconsolidation (OCR). The properties of these sectors are summarized at Table 1. SFPZ is overconsolidated and its compression index (C_c) values are lower (less deformable) than those corresponding to DFPZ. This difference is likely related to changes in water level during the mid 90's draught period, which affected to SFPZ, causing overconsolidation, but not to DFPZ, due to their greater depth.

TABLE I. GEOTECHNICAL PROPERTIES OF SOILS OF THE ORIHUELA CITY

Sector	*Approximated depth (m)*	*OCR*	*Cc*	*q_u (kPa)*	*SPT (Blow count)*	*Lithology*
SF PZ	**0-10**	2.3±1.5 (1.1-5.9)	0.15±0.03 (0.10-0.20)	53±25 (35-82)	4±3	Silt and grey clay
DF PZ	**10-30**	1.4±1.4 (0.5-5.2)	0.17±0.06 (0.09-0.26)	54	9±6	Silt, grey clay and fine sand
S R	**>30**	0.7±0.2 (0.4-0.8)	0.17±0.02 (0.13-0.19)	-	22±12	Gravels and marls

C. Soft soils distribution

The soft soils distribution on the Vega Baja of the Segura River basin was obtained in [3] by using a geophysical method. These data have been completed with new geotechnical and hydrological information (boreholes), gathered for extending the deformable soil thickness information to the west area of Orihuela City, where geophysical data were not available (Figure 1).

D. Damages and wells distribution

From 1993 to 1996, several buildings in Orihuela city suffered damages due, probably, to subsidence caused by soil consolidation after piezometric levels decrease. These buildings required local actions over their structures and foundations to repair them. The distribution of damaged buildings is shown in Figure 1. The subsidence due to water level drop, as a consequence of draught and water withdrawal, caused a great social alarm, as local newspapers reported. Probably, basements and underground parkings placed on the city, that pump important quantities of water (they are constructed under the water level surface) contributed to water level decrease. Moreover, there exist a high number of illegal wells points whose activity still remains unknown.

III. DINSAR DEFORMATION RESULTS

Deformation results in Orihuela city during the 1993-2001 period are shown in Figure 1. Those parts of the city placed on or near the undeformable relief of the Sierra de Orihuela (Mesozoic dolomites) do not show deformation (Point "a" in Figures 1 and 2). On the contrary, other parts placed over the soft, deformable soils (Quaternary filling) show subsidence up to 7 cm (Points "b" and "c" in Figures 1 and 2). The higher deformations are found near the Segura River channel. Several points of the relief (Sierra de Orihuela) show small deformations because they are located over colluvial deposits that creep downslope due to gravity action.

The temporal evolution of the deformations is plotted in Figure 2. It can be seen that during 1993-1996 period the velocity of subsidence was very important with rates of subsidence higher than 3 mm/year.

IV. COMPARISON AND INTERPRETATION

In general, subsidence occurs in the neighborhood of those areas with a higher concentration of wells, but not always because some of them were inactive during this time span. Additionally, ground subsidence usually tends to increase with the thickness of soft soils layer, i.e., from rock outcrops (non deformable) towards the valley centre. However, there is not a clear straight relationship between these two factors and ground subsidence. Neither a cause-effect relationship between location of damages and ground subsidence can be recognized. Probably, this is due to the fact that building structures present different susceptibilities to ground deformation (type of foundation and rigidity of building structures). The OCR of soils in Orihuela city, obtained by oedometer tests, shows values ranging from 1.2 to 6.0 for superficial layers from 0 to 10 meters [5]. These values mean that the soil is highly overconsolidated, likely due to piezometric level decrease and desiccation. This feature agrees with the fact that depth of exploitation of most of wells in the area is lower than 10 meter. This could explain the water level decrease and, consequently, the consolidation of the more superficial layers, causing subsidence. For depths larger than 10 m, soils are normally consolidated [5].

V. CONCLUSIONS

A set of 38 SLC images from ERS1 and ERS2 satellites has been used to measure subsidence caused by a ground water level drop that at some points reached values of 7 cm, by employing an advanced DInSAR technique called CPT. The subsidence map has been superimposed to several geotechnical and hydrological data in order to know better this phenomenon and its driving mechanisms. From the analyses we can conclude that the superficial layer of the soft soils (that can reach depths higher than 40 meters at some points) are the most affected by the subsidence caused by ground water level decrease. Moreover, it has been noticed a relationship between the higher subsidence and the proximity to river's channel, probably due to the kind of sediments accumulated near the river banks and the existence of old abandoned meanders of poor geotechnical properties. This comparison of measurements is of prime interest for validating DInSAR, with the objective of increasing the confidence from geologists and civil engineers in this remote sensing technique. Further subsidence studies and new geotechnical and hydrogeological information will allow us to corroborate the geotechnical interpretations.

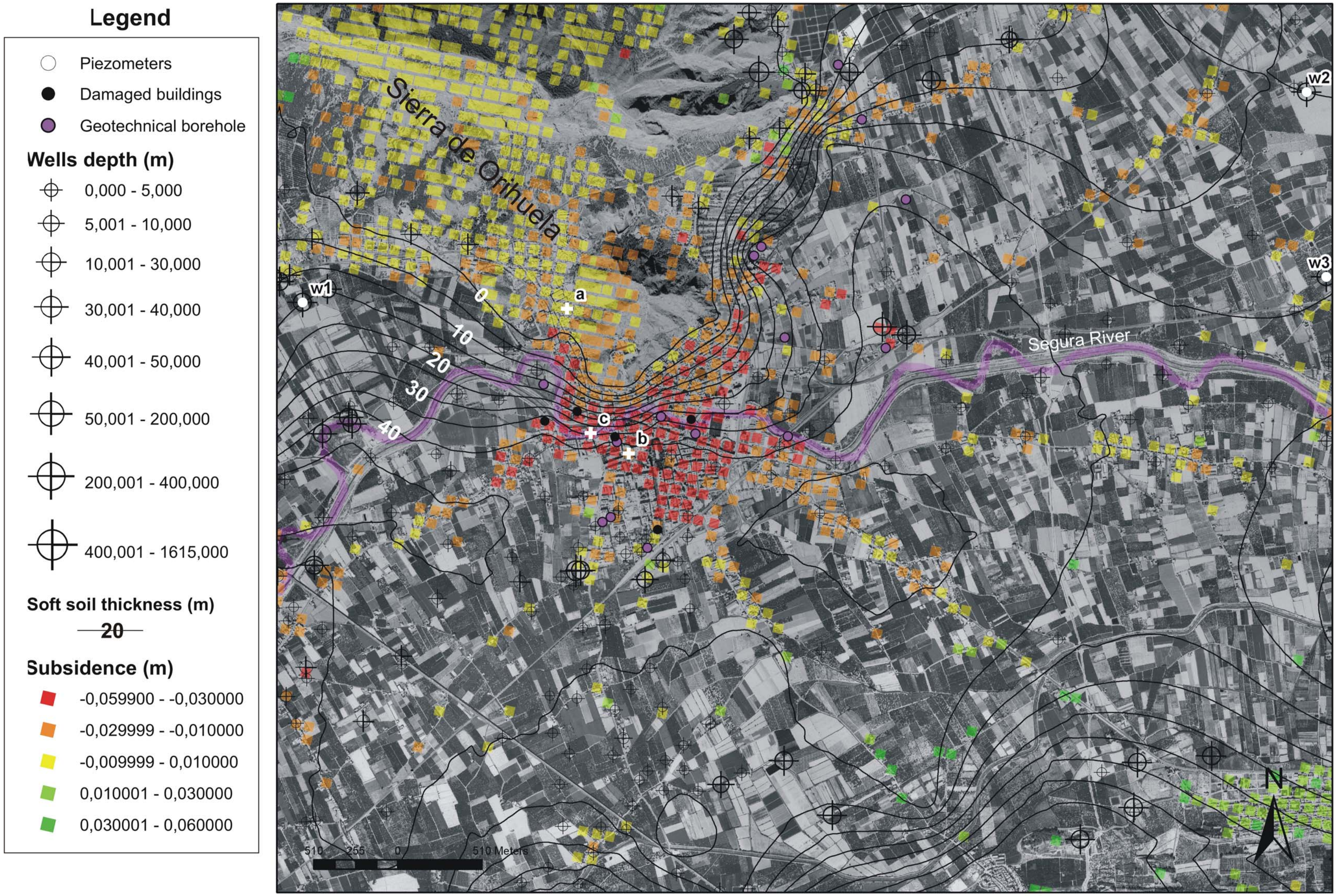

Figure 1. DInSAR deformation map of the Orihuela city. Soft soil thickness, well distribution and damaged buildings have been superimposed.

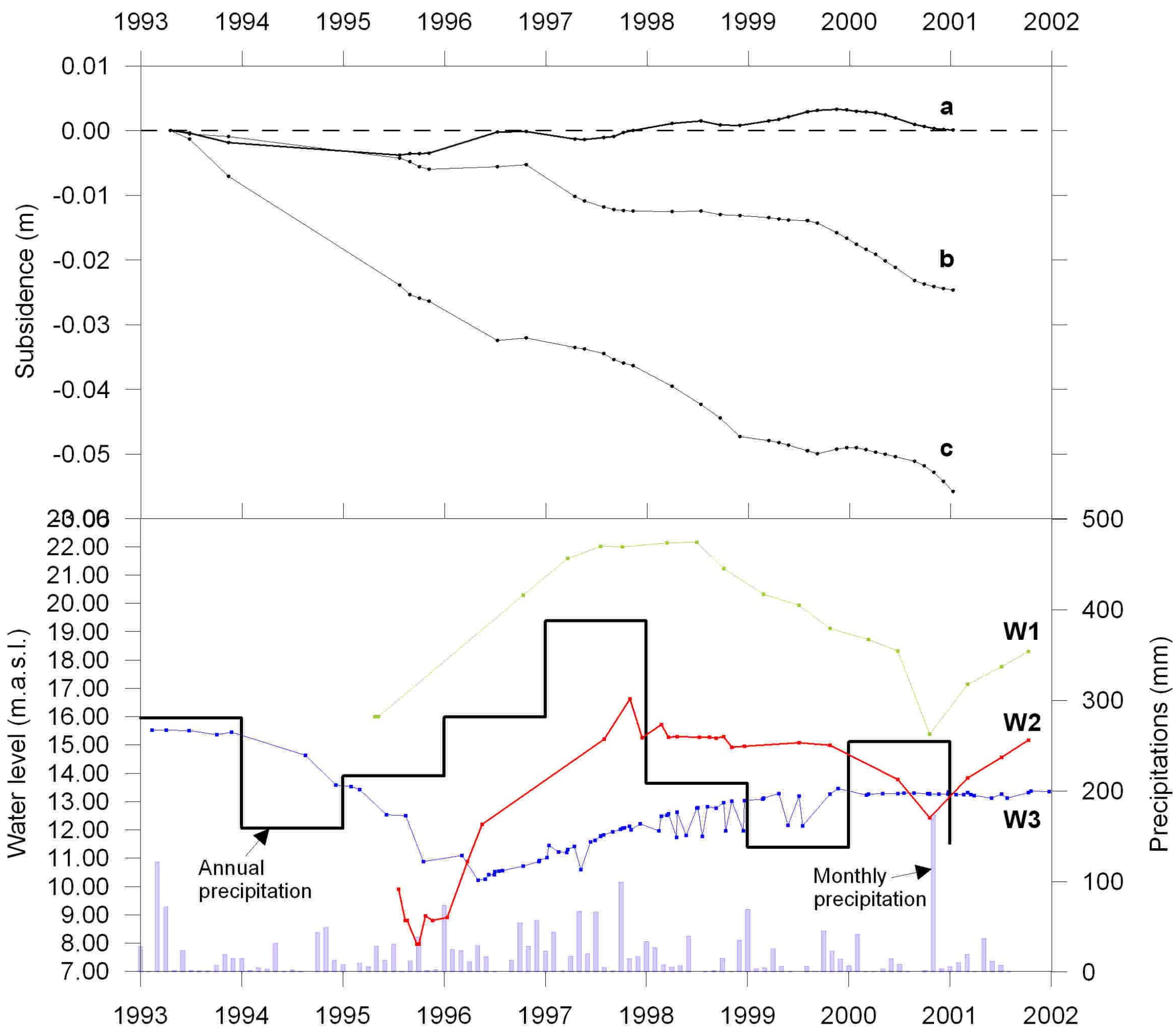

Figure 2. Deformation evolution at three diferent points of the studied area, correlation with three diferent piezometers (see location in Figure 1), and monthly precipitations.

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