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Monitoring an earthfill dam using differential SAR interferometry: La Pedrera dam, Alicante, Spain

R. Tomás [a,b,*], M. Cano [a,b], J. García-Barba [a,b], F. Vicente [b,c], G. Herrera [b,d], J.M. Lopez-Sanchez [b,c], J.J. Mallorquí [e]

[a] Departamento de Ingeniería de la Construcción, Obras Públicas e Infraestructuras Urbanas, Escuela Politécnica Superior, Universidad de Alicante, P.O. Box 99, E-03080 Alicante, Spain
[b] Unidad Asociada de Investigación de Movimientos del Terreno Mediante Interferometría Radar (UNIRAD), UA-IGME, Spain
[c] Instituto Universitario de Investigación Informática, Universidad de Alicante, P.O. Box 99, E-03080 Alicante, Spain
[d] Geohazards InSAR laboratory (InSARlab), Grupo de Riesgos Geológicos, Departamento de Investigación y Prospectiva Geo-científica, Instituto Geológico y Minero de España (IGME), Ministerio de Economía y Competitividad, c/Alenza 1, E-28003 Madrid, Spain
[e] Remote Sensing Lab. (RSLab), Departament de Teoria del Senyal i Comunicacions, Universitat Politècnica de Catalunya, c/Jordi Girona, 1-3, Ed. D-3, 08034 Barcelona, Spain

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ABSTRACT

Surface displacement at the dykes of La Pedrera reservoir (SE Spain) has been measured by satellite differential Synthetic Aperture Radar (SAR) interferometry. At the main dyke, a displacement of about 13 cm along the satellite line of sight has been estimated between August 1995 and May 2010, from a dataset composed by ERS-1, ERS-2 and Envisat-ASAR images. Two independent short-term processing tasks were also carried out with ERS-2/Envisat-ASAR (from June 2008 to May 2010) and TerraSAR-X (from August 2008 to June 2010) images which have shown similar spatial and temporal displacement patterns. The joint analysis of historical instrument surveys and DInSAR-derived data has allowed the identification of a long-term deformation process which is reflected at the dam's surface and is also clearly recognizable in the inspection gallery. The plausible causes of the displacements measured by DInSAR are also discussed in the paper. Finally, DInSAR data have been used to compute the long-term settlement of La Pedrera dam, showing a good agreement with external studies. Consequently, this work demonstrates the integration of DInSAR with in-situ techniques which helps provide a complete spatial vision of the displacements in the dam thereby helping to differentiate the causal mechanisms.

1. Introduction

Dams produce significant social and economic benefits such as flood control, irrigation, water and electricity supplies, and aiding navigation along reservoirs. The monitoring of a dam plays an essential role in its management and operation, especially for detecting unsafe conditions and/or problems which require appropriate corrective measures at early stages. Due to the importance of this task, the International Commission of Large Dams (ICOLD) created a Technical Committee on Dam Surveillance in 1982 focused on this topic. Surficial vertical and horizontal displacements are among the most important parameters to be measured during construction, reservoir filling and after the first impoundment, and are one of the main indicators of the deterioration in embankments (ICOLD, 1989).

During the last decades, remote sensing techniques (e.g. laser scanner and differential interferometry) have become a complementary method for measuring infrastructure displacements. Among all these techniques, differential SAR interferometry (DInSAR) has shown the capability to successfully measure small displacement of structures with millimetric precision (Karila et al., 2005; Herrera et al., 2010, 2012; Bru et al., 2013). Some additional studies have focused on displacement of the dam body and/or the reservoir slopes (e.g. Albaa et al., 2008; Droz et al., 2008; Fernandez et al., 2009; Power et al., 2009; Grenerczy and Wegmüller, 2011; Wang et al., 2011; Voege et al., 2012; Liu et al., 2013).

In this paper, the Coherent Pixel Technique (CPT), an advanced DInSAR technique that belongs to the Persistent Scatterer Interferometry (PSI) family, is applied to process TerraSAR-X and ERS/ENVISAT-ASAR images for measuring the deformation behaviour of La Pedrera Dam embankments. The CPT technique provides a high density of ground targets (CP) in the dykes where a clear displacement pattern is observed. These DInSAR observations are then compared with recorded damages and the available ground-monitoring measurements. Finally, the plausible origin of the DInSAR observed displacements is discussed.

The paper is structured as follows. Section 2 includes a general description of the dam, the available information, the geological setting and the performed field observations. Section 3 shows the DInSAR

* Corresponding author at: Departamento de Ingeniería de la Construcción, Obras Públicas e Infraestructuras Urbanas, Escuela Politécnica Superior, Universidad de Alicante, P.O. Box 99, E-03080 Alicante, Spain. Tel.: +34 965903400 (3093).
E-mail address: roberto.tomas@ua.es (R. Tomás).

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results that are interpreted in Section 4. The main conclusions are presented in Section 5.

2. La Pedrera earthfill dam

2.1. History of La Pedrera dam

La Pedrera dam, located in SE Spain, is a regulation reservoir whose inflow comes almost completely from the Tagus–Segura transfer. Authorities started planning the construction of the dam during the first "Economic and Social Development Plan" (1964–67), but it was during the second "Development Plan" (1968–71) when technical works started. The construction began in 1973, and the dam was finished in January 1978. The first impoundment of the dam was in 1980, and the dam started working in 1986. Originally, the dam had a monitoring system consisting of: a piezometric net with 91 piezometers, a settlement control using 18 settlement cells, topographic surveys and infiltration measurements. Unfortunately, these data were only measured during the first stages of the dam's operation. Maurandi et al. (1993) published some of the available monitoring data of La Pedrera dam. These authors showed, among other data, the evolution of the settlement in the service gallery between June 1975 and October 1980, obtained by means of levelling. They concluded that the post-constructive settlements in the service gallery were appreciable for the studied period, reaching maximum values up to 100 cm.

2.2. Characteristics of the dam

The Pedrera earthfill dam is located in the Alcoriza torrent, Bigastro (Alicante, SE Spain; Figure 1a) and supplies irrigation water to the Campo de Cartagena and several towns and villages of the neighbouring areas. The drainage area that feeds the reservoir is very small (36.34 km^2) because it is a regulation reservoir for the water provided by Tagus-Segura transfer. The main dyke has a straight plant 716 m long and a maximum height of 66.3 m (Figure 2). Three additional dykes (dykes 1, 2 and 3) border the reservoir (Figure 2). The upstream and downstream shoulders have 3.5:1 and 3:1 slopes, respectively, and they are composed of marls covered by limestone rock armour (Figure 3). The dam is also constructed with a complex system of filters used for reducing pore pressures (Figure 3). The materials used for the dam's body were classified as low plasticity clays (CL), according to Casagrande's plasticity chart, and they were compacted until an average maximum normal proctor test density of 16.8 kN/m^3 with an optimum moisture content of 18% (Maurandi et al., 1993). Table 1 summarizes the main characteristics of La Pedrera dam.

2.3. Geological and geotechnical setting

La Pedrera reservoir is located in the easternmost sector of the Betic Cordillera (Figure 1a). It is placed in the southern edge of the Vega Baja of the Segura River basin. This boundary is represented by the Bajo Segura Basin fault (Montenat et al., 1990) (Figure 1b). South

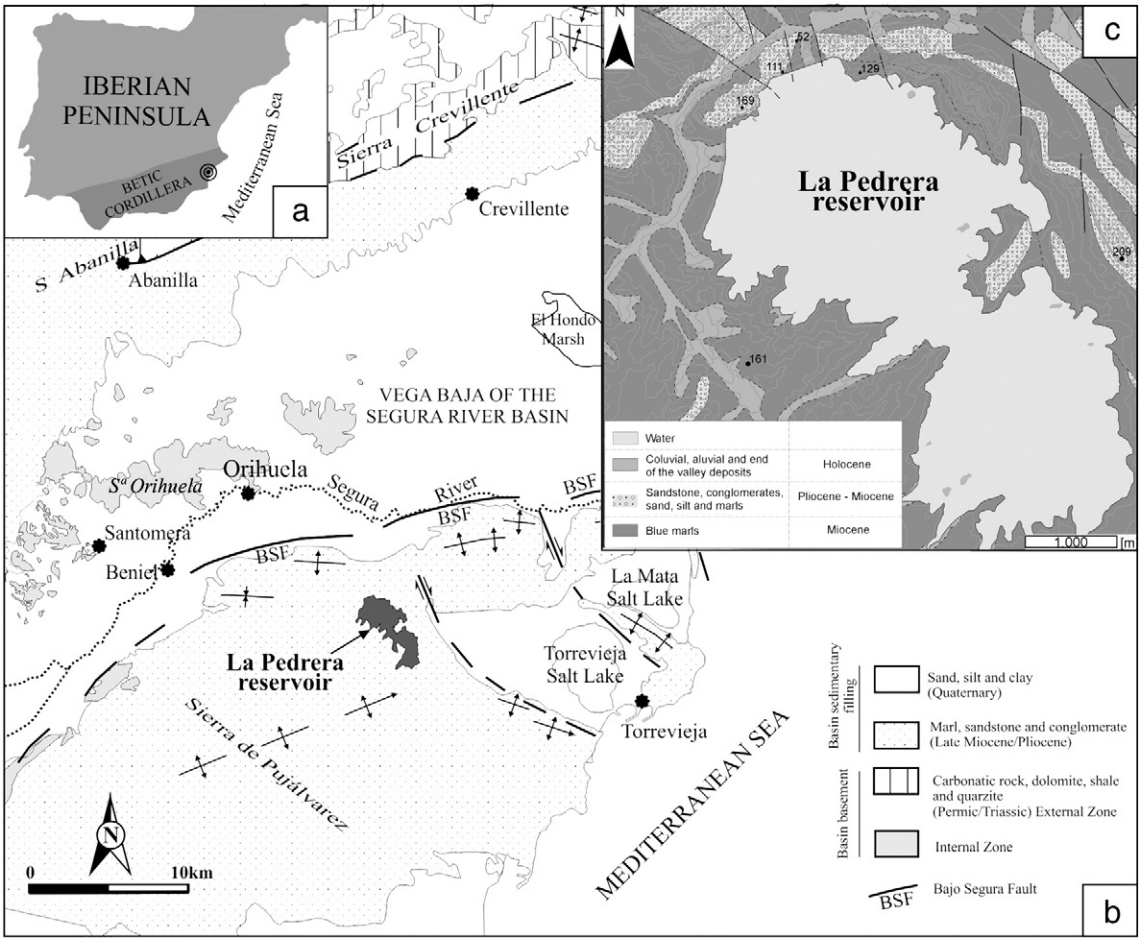

Fig. 1. Location and geological setting of La Pedrera reservoir.