Monitoring techniques for analysing subsidence: a basis for implementing an Early Warning System

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Abstract The L’Estació neighbourhood located in Sallent (a town near Barcelona, Spain) is affected by large ground subsidence phenomena that extend within the former exploitation limits of an old underground potash mine. In the 1990s, several damages were reported in different buildings. Since then, different monitoring techniques have been implemented. This paper compares and analyses these techniques that identify, measure and monitor subsid ence phenomena. On the one hand, high precision topographic surveys are used to investigate the subsidence phenomena extent on the terrain and its effects on buildings. On the other hand, in situ extensometers, inclinometers and piezometers are used to investigate the underground conditions and infer the mechanisms that control the subsidence motion in detail. The parameters obtained from the land surface deformation (measured with the automatic total station) and the underground deformation measurements (extensometers network) have been integrated into a real-time monitoring system as a basis for an early warning system developed by the IGC. The use of these techniques, as well as threshold values to activate civil protection alarm and communication procedures, are done on the basis of the experience obtained during the investigation of the phenomena.

Key words mining subsidence; emergency plan; monitoring network; Catalonian potash basin

INTRODUCTION

In the town of Sallent, the L’Estació quarter is located above the exploitation zone of an old underground potash mine, the Enrique Mine. This mine was opened in 1932 and during extraction works a natural great cavity, of about 40 m diameter and 110 m height, was found located under the southeast sector of the present L’Estacio quarter. This cavity had been caused by water circulation and some important groundwater flooding took place during exploitation. The great difficulties of controlling the flooding led to the closure of Enrique Mine in 1973. During the abandonment process the mine was filled up with saturated salty water with the purpose of preventing dissolution processes and the ground subsidence caused by the mining activity. But, in the 1990s damage to several buildings was reported in the L’Estació neighbourhood and so the Catalan ministry for Territorial Planning and Public Works (DPTiOP, its initials in Catalan) started a series of studies through the Geological Institute of Catalonia (IGC) to determine the origin of the damage, monitor the phenomena, and propose solutions to guarantee the population’s safety. For this purpose, several techniques have been applied: topographic measurements, DInSAR techniques (satellite and ground-based), geological mapping, geophysical prospecting, extensometric measurements, drilling, etc. The studies concluded that the largest vertical terrain displacements are located at the corners of Barcelona Tarragona and Arquitecte Gaudí streets (critical area), and are related to the existing natural cavity (Fig. 1).

INSTRUMENTATION

Surface monitoring networks

These networks are based on two different techniques: a high precision topographic levelling and a Geodetic Monitoring System for control building status. The topographic levelling was established in 1997, and originally consisted of 34 points, but has grown gradually to nearly 170 measurements in the L’Estacio quarter and surroundings (Fig. 1). The measurement frequency was initially
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Fig. 1 Location of the maximum subsidence at the L’Estació neighbourhood. Black dots represent the topographic surveying points.

Fig. 2 (a) Simultaneous registered displacements at the SR11 and SR16 extensometers. These extensometers are right above the natural cavity. (b) The deeper the measurement, the larger the descending movement. The plot shows the evolution of vertical movement velocity at the extensometers as function of depth.

monthly, but has varied to weekly during the most active periods (2008 and beginning of 2009). At the critical area, 25 precise prisms are installed on the 8 most vulnerable buildings and monitored by an automatic Leica TCA Total Station in order to control the building response.

Underground monitoring network

This network is located around the critical area, right above the natural cavity, and is composed of extensometers, inclinometers and piezometers. These instruments are installed in 15 boreholes at depths that vary between –140 and –15 m (Fig. 2), and include 25 rod extensometers, four inclinometers (ABS 74, 3 inches, Glötzl Baume β technik) and one piezometer. An automatic measurement system was implemented for collecting data from the extensometers and piezometer.

CHARACTERIZATION OF THE SUBSIDENCE PHENOMENA

Topographic surveying shows that the extension of the subsidence phenomena is controlled by the extension of the underground mine, with a maintained subsidence velocity of about 1 cm/year. But the more intense surface vertical displacement is controlled by the existing underground cavity and
Fig. 3 Diagram showing the orientation and accumulated displacement (during 2009) of points along the extensometers with the largest deformation.

Fig. 4 Main horizontal displacement components from inclinometer registers at different depths. Inclinometer SR14 is further apart and it is less affected by the cavity.
is about 49 cm over the last 13 years, with surface average velocities of about 2.5–4.0 cm/year from the beginning of measurements until July 2008. From this date, the velocity increased to 5.0–8.0 cm/year, and finally in May 2009 there was a significant increase of velocity to between 12–18 cm/year.

Data from the extensometers show that each extensometer progressively registered data which are more or less independent of each other and punctual events (significant jumps on the curves), at the deepest extensometers, are registered (Fig. 2(a)). The evolution of the extensometer measurements have allowed us to establish a velocity gradient as a logarithmic function of depth (Fig. 2(b)) as well as a direct relationship with velocity gradients detected by the topographic surveying (Fig. 3). Also, the direction of the horizontal movements registered by the inclinometers show a convergence to the centre of the cavity, confirming that it induced the most intense subsidence (Fig. 4).

IMPLEMENTATION OF ALERT SYSTEM AND CIVIL PROTECTION PLAN

The maximum subsidence is located immediately above the large natural cavity, and a decrease of land deformation is not expected in the near future and damage to the buildings within the neighbourhood is expected to continue (ICC, 2003; IGC, 2009). An alert (early warning) system and an emergency plan for an organized and efficient response by the civil protection authorities has been elaborated and implemented (Procicat Sallent). The alert triggering levels for the plan are defined on the basis of deformation rates in the critical area. The deformation rates are automatically registered by the monitoring instrument networks: data from the automatic measurements in extensometers and building deformation monitoring systems are sent to the reception centre at the Geological Institute (IGC) that processes the information and evaluates the results. In the case of an alert detection, IGC is in charge of immediately informing the civil defence centre to execute the actions established in an emergency plan.

In December 2008 the control networks showed a significant increase in the speed of subsidence. This situation led to the activation level of alert in the emergency plan and the meeting of different groups in order to assess the activation of the plan. Finally, the preventive evacuation of about 120 residents from 43 homes in the neighbourhood was carried out.

REFERENCES