RISK OF SUBSIDENCE IN AN URBAN AREA: FROM HAZARD ASSESSMENT TO EMERGENCY MANAGEMENT. SALLENT CASE-STUDY

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KEY WORDS: subsidence, salt mine, urban area, risk management.

ANTECEDENTS

The Conca Potàssica Catalana (Potassic Salt Catalan Basin) is located in the so called Central Catalan Depression, within the Ebre river Depression. This basin is made of a great saline unit, composed by an alternation of potash salts (sylvinita and carnalita mainly) layers.The potash salts have been traditionally exploited since ancient times, being still the most important mining activity in Catalonia. Balsareny, Cardona, Sallent and Súria are the main towns in the Bages region with mining activities (Figure 1).

The town of Sallent, according to the 2004 population census has 6,417 inhabitants. Two areas of the town, L'Estació and La Rampinya neighbourhoods, are on top the exploitation zone of an old underground potash mine, called Enrique Mine (Figure 2).

Enrique mine was opened in 1932 and it is known that some important ground water flooding took place during exploitation. In 1934, during draining works a great vertical cavity of about 40 meters of diameter and 110 meters of height was found.

This cavity was partially filled with materials detached from roof and walls. In the seventies, when the mine was closed, all mine cavities were flooded, including the natural largest one, with water saturated with salt (ClNa) with the purpose of stopping dissolution processes and the ground subsidence present during mining activity. However, twenty years later, in the 1990's the measures taken to avoid ground subsidence were demonstrated to be insufficient for the new present day conditions with the expansion of the urban zone above the old mine exploitation area.

In the early 1990's several buildings damages were reported in L'Estació neighborhood and so the Catalan ministry for Territorial Planning and Public Works (DPTiOP, by its initials in Catalan) started a series of studies through the Geology Unit of the Cartographic Institute (ICC), at present the Geological Institute of Catalonia (IGC), to investigate the causes for the damages in the area of study and to propose possible solutions.

OBJECTIVES AND METHODOLOGY

The objective of the investigation program was to identify, quantify and model the subsidence phenomena in this area (ICC, 2003) in order to propose solutions to this problem. For this reason many studies and monitoring actions have been implemented since 1997 in order to:

- Determine the causes of the ground subsidence at the Estació and Rampinya neighbourhoods.
- Detailed measuring and monitoring of deformation to evaluate the areal extension and its evolution in time.
- Determine the adequate preventive and corrective measures to reduce the risk due to ground deformation.
- Implement and improve security plans and soil use regulations in the area of study.

From the beginning of the study in the 1990's to the present day, the implemented monitoring techniques and surveys have consisted of:

a) Implementation of a high precision surveying network

b) Ground deformation measuring through remote sensing techniques: Radar Satellite Differential Interferometry, DInSAR, since 1992 to present day; and Ground Based Radar, GBSAR, during 2006.

c) Monitoring deformation with a network of extensometers and inclinometers at different depths

d) Geophysical prospecting campaigns for suboil recognition

e) Core drilling to identify geological stratigraphy

f) Geological, geotechnical and hidrogeological studies

g) Geomechanical numerical modelling for evaluations of ground stability.

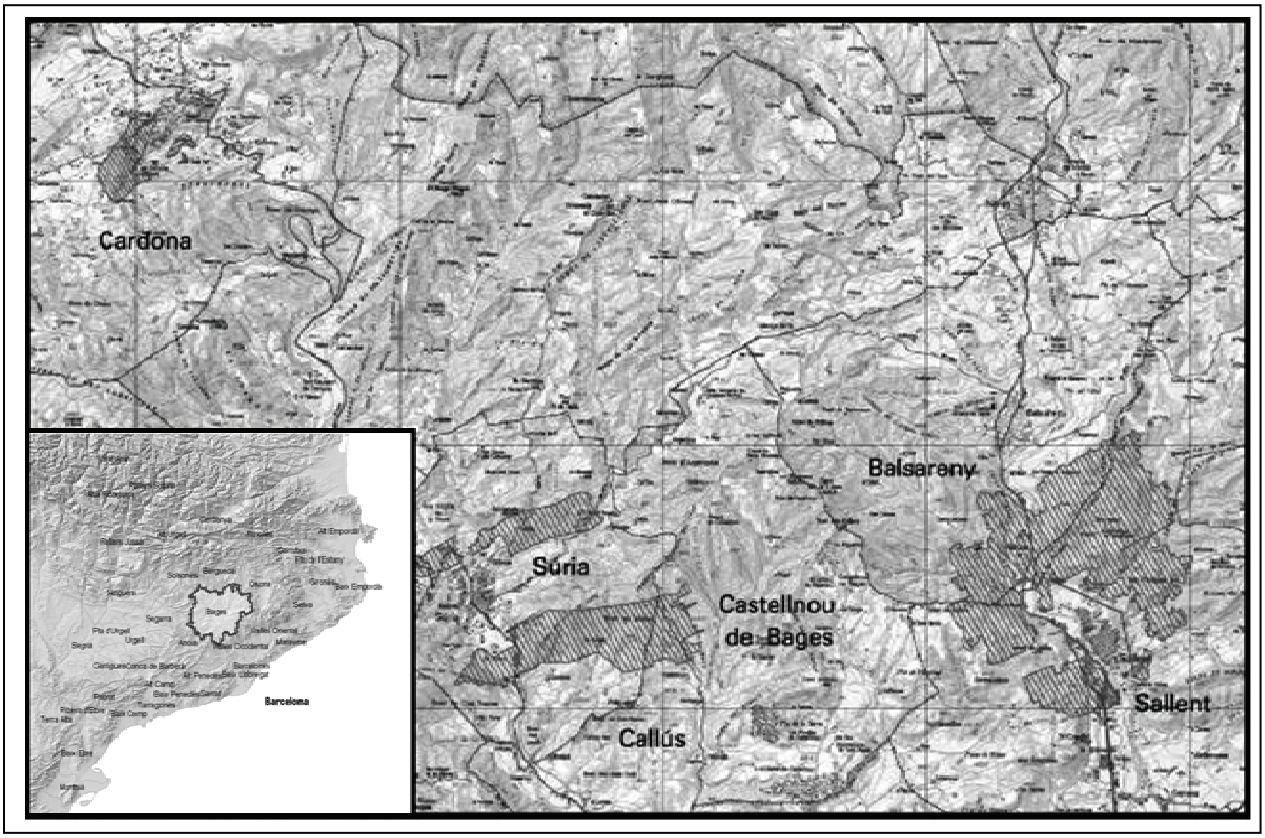

Figure 1 – Figure 1 – This map shows the situation of the main towns with mining activities (grid areas) of the Bages region.

RESULTS FROM THE MEASURING CAMPAIGNS, SURVEYS AND STUDIES

The main results from all the performed studies were integrated analyzed and evaluated (ICC 2003, IGC 2009), allowing the following facts to be stated:

•The structural problems of buildings at the neighborhoods of L'Estació and La Rampinya are the results from large ground subsidence phenomena that extend within the former exploitation limits of the Mina Enrique.

•Data from extensometers and results from geological and geophysical studies showed that ground subsidence is related mainly to the mining cavities. In particular, at L'Estació area the largest vertical ground deformations, up to 5 cm/year, occur over the above mentioned large cavity. Subsidence decreases at increasing distances from this cavity. It should be mentioned that although the values of vertical ground motion are much lower far from the cavity, near the limits of the old mining exploitation the gradient is higher, thus producing differential displacements, deflection and the consequent damages on buildings.

•Decrease of the deformation is not expected in the nearest future and damages in buildings within the neighborhoods are expected to continue.

SUSCEPTIBILITY ZONATION AND CIVIL PROTECTION

It is well known that buildings are especially vulnerable to angular distortion. This parameter can be used to establish levels of building structural damage and thus to assess risk criteria, though the relationship between ground subsidence and building structural damage depends on various factors (e.g. ground subsidence velocity and duration time; size, type and orientation of structural elements). At L'Estació neighborhood, as said before, a belt above the limit of the old mine exploitation, although do not present the largest values of absolute subsidence is the zone with the largest building damage. In this zone, angular distortion induces the largest differential settlements and horizontal deformation induces tensional-compressional loads between buildings.

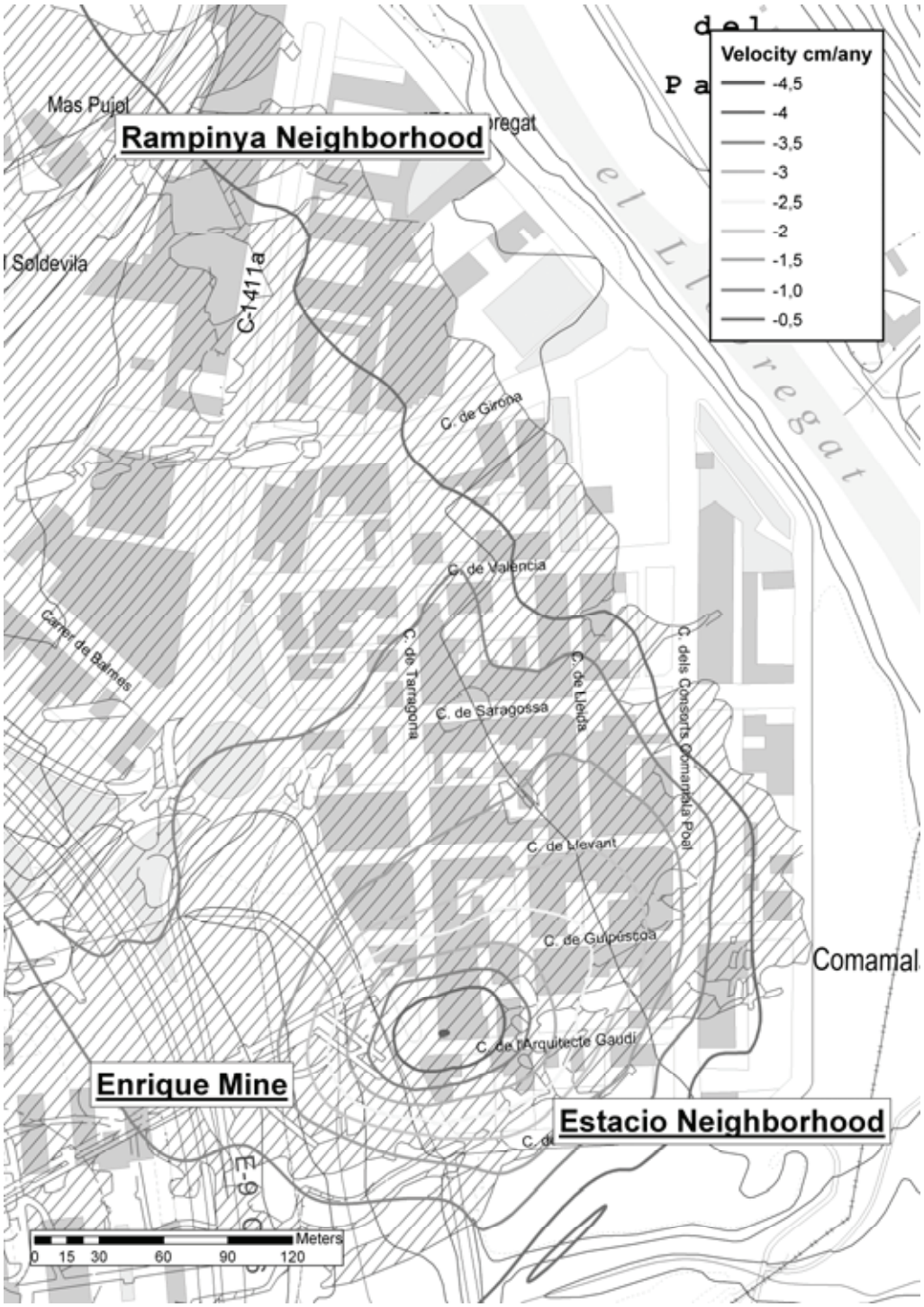

Figure 2 – Estació neighbourhood showing the limits of the Enrique mine and the subsidence velocity contours.

Once the extension and magnitude of ground subsidence and the building susceptibility were assessed, technical solutions were discussed. None of the solutions was technically and economically feasible. The only option was to establish a program for medium term evacuation of inhabitants of the neighborhood and relocation in new urban areas. Since this solution requires some time for the construction of new houses, evacuation is not being performed immediately and temporal preventive measures have been adopted for securing people:

- Demolition of the most damaged buildings (in 2004).
- Implementation of an alert system and an emergency plan for an organized an efficient response of the civil protection authorities. The institutions participating in the plan development

involved different government levels and different scientific institutions (Municipality of Sallent; the Catalan Ministries responsible of territorial planning and public works, civil protection and of environment and housing; the Cartographic and Geologic Institutes; the Institut Català del Sòl; the Polytechnical University of Catalonia, neighbour local associations).

The plan has been elaborated and implemented. Triggering levels for the plan are defined on the basis of deformation rates automatically detected by a surveying network of monitoring points. The monitoring consists of:

1.-) Monthly high precision topographic surveying

2.-) Periodic surveying of buildings behaviour

3.-) Automatic underground monitoring network composed by 16 extensometers, at depths between 50 and 140 m to measure deformation velocities and accelerations.

4.-) Ground automatic surveying (taquymetric) network at the area with the largest subsidence rates (the southwestern section of the Estació neighborhood). Twenty seven monitoring points are located at different buildings. They are monitored with automatic readings in 2 hours time intervals. If the measurements give values above the predetermined rate limits, then an instant message is sent.

Data from the automatic underground (3) and building (4) measuring systems are continuously recorded locally and sent to the reception center at the Geological Institute (IGC) who is in charge of informing immediately the civil defense centre for executing the actions established in the emergency plan, which includes protocols for increasing the frequency of performing topographic (1) and building (2) surveys from monthly to fortnightly or weekly

ALERT ACTIVATION

In December 2008 the control networks showed a significant increase in the speed of subsidence, mainly at the SW area of L'Estació neighbourhood, the zone of maximum subsidence.

This increase in the rate of subsidence led to some points measured beyond the alert thresholds set in the Emergency Plan. 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 neighborhood has been planned.

CONCLUSIONS

The analysis of the data obtained by different techniques, satellite radar interferometry, ground based radar interferometry and high precision topographic surveying, has been crucial for determining magnitude and extension of ground subsidence. Geological, geotechnical and geophysical prospection have aided for identification of the existing materials and the conditions that produce ground movements. The information acquired allow to conclude that ground subsidence will not stop in the nearest future and will continue affecting buildings. The performed studies are the scientific-technical basis for the development of the present protection measures that have been implemented. The automatic monitoring network which is operative in the area is the basic element to activate the emergency plan in the case that acceleration in the subsidence process is detected, and so to provide security to the inhabitants.

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