GIS-BASED CALCULATION TO FORESEEING ANGULAR DISTORTION AT URBAN STRUCTURES DUE TO LAND SUBSIDENCE NEARBY MINING CAVITIES IN CATALONIA

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OBJECTIVES

Urban zones above or nearby underground mining excavations, in Catalonia, are already affected by land subsidence and actual urban growth makes necessary evaluations for future damages on edifices due to land deformation.

In order to attend this urban planning need, a new GIS-based methodology is presented here to evaluate critical future deformation in structures on the basis of field monitoring of land deformation by topographic surveys. The objective is to develop a tool to help on subsidence management hazards and urban planning.

INTRODUCTION

Subsidence due to historic and recent mining activities is affecting urban zones at the Potassic Catalonian Basin at the urban zones of Sallent, Cardona, Balsareny and Suria municipalities nearby salt exploitations with underground excavations. Due to rapid growth of population is necessary to evaluate and prevent ground deformations at new developing urban areas within the affected municipalities and evaluate somehow possible structural damages for buildings and infrastructures.

The most basic approximation to quantify structural damage was proposed in 1956 by Skempton and McDonald. They introduced the concept of angular distortion as the difference of settlement between two structural elements and divided by the distance they are separated, Figure 1 and Equation 1.

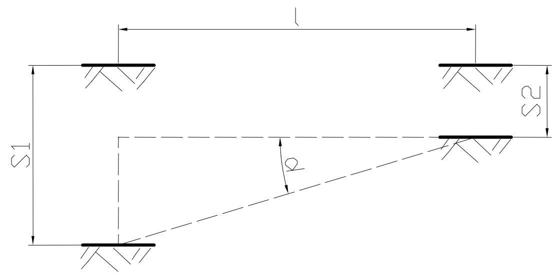

Figure 1 –Angular distortion calculation (Skempton and McDonald, 1956).

$$\beta = \frac{S1 - S2}{l} = \tan d \qquad \text{Equation 1}$$

Where:
β: Angular distortion
$S1$: Settlement of structural element 1
$S2$: Settlement of structural element 2
l: distance in the horizontal plane between structural elements
d: angle of distortion

Based on published data on building settlements, the angular distortion approximation classifies structural damage on the following way:

β	Observed Damages
1/1000	Very slight damage. Hair-width cracks
1/750	Very slight damage. Lower limit where constructing equipment can be sensitive to settlements
1/600	Lower limit for cracking in framed doors
1/500	Lower limit for securiting buildings where cracking is not admitted
1/300	Cracking of brick panels in frame buildings or load bearing brick walls is likely to occur
1/150	Structural damage to columns and beas is like to occurse

Table 1. Estructural damages related to ranges of angular distortion according to Bjerrum (1963) definition.

By characterizing the existing deformation at zones affected by subsidence, the Catalonian Institute of Geology (IGC), has developed an GIS based approach using pre-existing terrain periodic topographic survey data and implementing the angular distortion concept into a GIS tool.

METHODOLOGY

The obtained results are predictive maps that represent the angular distortion of the terrain for different periods of time projected in the future from a date of interest.

The velocity rate calculated from last topographic survey at the date of interest is assumed to be constant in time. With this assumption deformation scenarios are calculated for a time period of interest. Since the main objective of this study is to be an urban planning tool, the suggested period of time for calculations is the useful life of buildings to be constructed e.g. for the Catalonia case were considered 10, 30 and 50 years periods.

Implementation of semi-automatic calculation the Skempton and McDonald concept of angular distorsion consisted in the following steps:

1. Periodic Topographic surveying. As longer the time period better the data to calculate deformation rate tendencies.
2. Calculation of deformation rates on each point of the surveying network. The use of raw data or fitting curves to obtain deformation tendencies will might define abrupt changes or would soft the final angular distortion values.
3. Calculation of deformation for the predicting period. On the basis of "constant" deformation rates, for each point calculate future deformations to deformation values from the moment of calculation to the time of interest.
4. Interpolation and generation of the deformation grid. The size of the cell is defined on the basis of average of the minimum building dimension already existing or to be constructed in the zone of interest. The cell size will define the maximum the value of l on Equation 1.
   Also, absolute values of the deformation depend on the interpolation method though definition of critical zones always has the same general distribution.
5. Application of ARCView Maximum Slope and maximum flow direction (MDF) algorithms. On the resulting deformation grid use these two algorithms to calculate angular distortion (β) and flow direction respectively.
6. By reclassifying the resulting MDF grid, the vector of maximum deformation direction is plotted. Overlying the resulting grid of Maximum slope and classifying it according to the ranges of Table 1 along with and the MDF resulting vectors, a comprehensive figure of isovalues of angular distortion and the direction it has is generated

Steps 3 to 6 were implemented in the in ArcGIS v. 9.2 Model Builder to automatized the calculations, Figure 2.

CALIBRATION

As example of the of the implemented algorithm for angular distortion calculations, the case of Sallent City is used in this paper. At that place some neighbourhoods were developed in the 1950's above mining underground excavations. In 1996 building damage began to be reported. Since then, monthly topographic surveying is taking place at the most affected site.

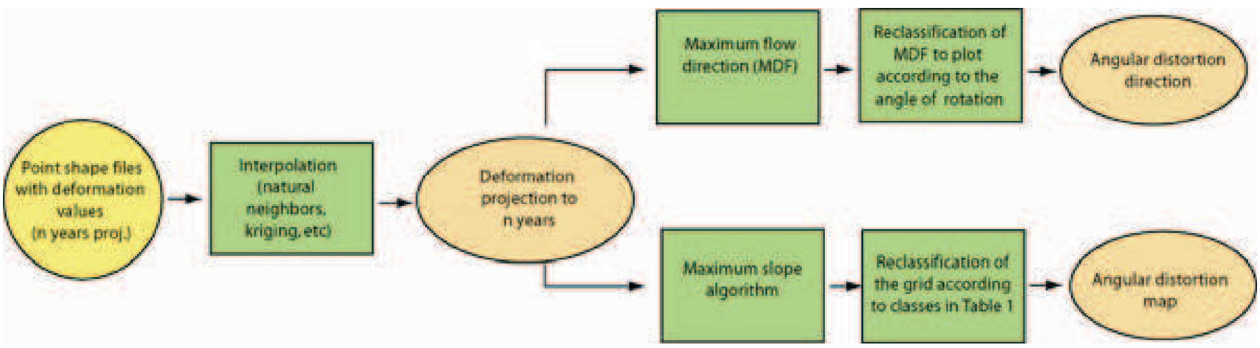

Figure 2 – Calculation of angular distorsion implemented within Model Builder Arc View 9.2

The first assumption to perform the analysis was that the measured points have constant deformation rates. Considering those velocities, calculations of future deformation were performed for 10, 30 and 50 years. Deformation grids were generated with a cell size of 5 m on the base of the shortest edifice dimension at the site (minimum value of *l* value on Equation 1).

Figure 3 and 4 show the angular distortion sceneries and direction for 10 and 30 years from present day respectively. Figure 5 shows the buildings with the largest structural damage from the beginning of controlling topography in 1997 to the present day. There is clearly a deformation a zone at the Estación neighbourhood and the NW-SE band with the most intense angular distorsion that correlates with the edifices with the that posses the largest damage, even though, that present approximation doesn't considers the structural characteristics of the buildings and only the terrain deformation.

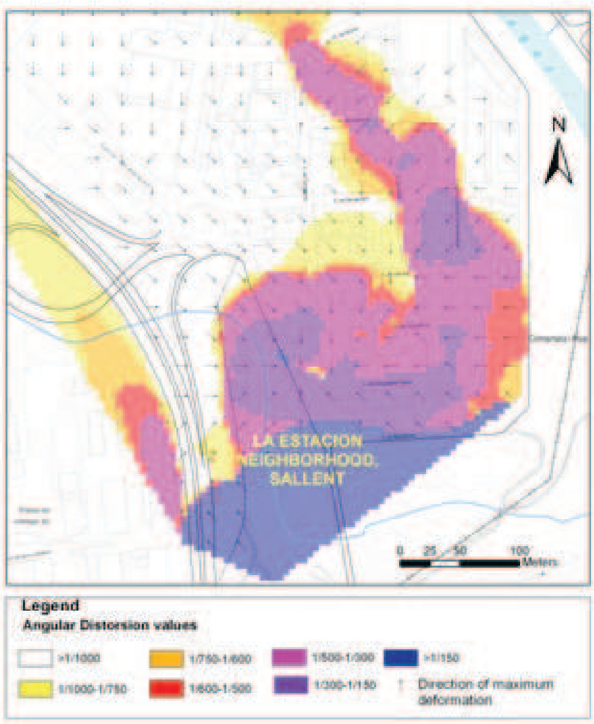

Figure 3 –Angular distortion calculation for 10 year period from present day

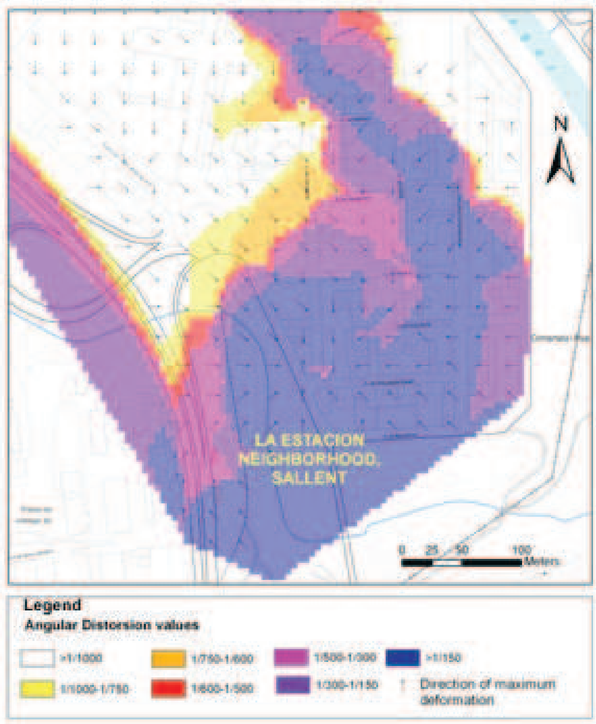

Figure 4 –Angular distortion calculation for 30 year period from present day

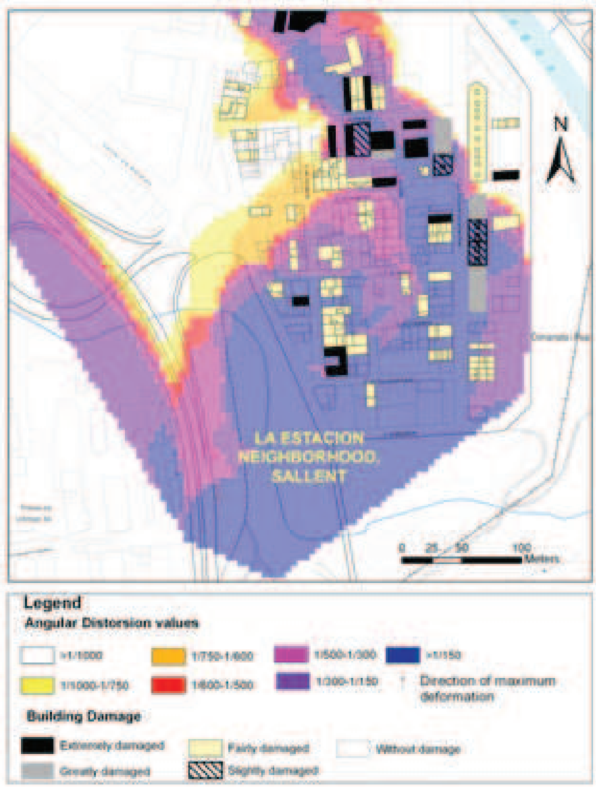

Figure 5 –Angular distortion calculation for 30 years and present day building damage

CONCLUSIONS

Both, maximum vertical distortion and flow vectors make a comprehensive figures to evaluate structural building damages and to foreseeing zones where maximum angular distortion and its orientation occur. Though the assumptions of constant deformation rates, these predictions might help on defining potentials zones to suffer structural damage due to land subsidence and help to define different levels of hazards and improve urban planning. The use of the angular distortion concept has been considered useful in the management of areas affected by subsidence. Evaluations of future sceneries by increment of terrain deformation, for the Catalonian case (Sallent), are coherent with the observed evolution of structural damages and have been useful in the evaluation of future risk and civil protection sceneries.

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