

Geotechnical issues on the access of the Ojo Guareña karst complex

Problèmes géotechniques dans l'accès au complexe karstique d'Ojo Guareña

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ABSTRACT: Ojo Guareña is one of the biggest karst complex in the world. Located in the Cantabrian Mountains (north of Spain) is formed of over 100km of galleries and it was declared natural monument in 1996.

This big karst complex was built mainly by the erosive action of the Guareña river. Nowadays the Guareña river sinks at the foot of the slope in a blind valley and it runs by the lower galleries. Sometimes with heavy rains the level of water rises and the river enters the higher galleries.

The main access to the karst is located 60 meters higher on the top of the slope where the river Guareña sinks. In this access there are some archaeological findings and hermitages carved into the limestone. This place receives more than 20000 annual visits.

Historically access to the hermitages has suffered subsidence during flood season which has caused damages. In winter 2015 the access settlement reached 20-25cm and some cracks appeared around the access to hermitages and cave, and also in other points on the top of the slope.

A geotechnical campaign has been carried out to find out the complex behaviour of the slope in which they are involved the Guareña river sink, the karst complex and the anthropic filling of the access area.

The geotechnical campaign has consisted in: boreholes with inclinometers and micrometres, Dynamic Probing Super Heavy (dpsH) and geophysical tests. In this paper we present the geotechnical campaign and its results.

RÉSUMÉ: Ojo Guareña est l'un des plus grands complexes karstiques au monde. Situé dans les montagnes cantabriques (nord de l'Espagne), il comprend plus de 100 km de galeries et a été déclaré monument naturel en 1996. L'accès principal au complexe se fait par une esplanade sur laquelle se trouve l'hermitage de San Bernabé (S. XVIII). Dans cet accès, des importants vestiges archéologiques ont été trouvés. Cet endroit reçoit plus de 20 000 visites par an. Historiquement, le esplanade d'accès aux hermitages a souffert un affaissement pendant la saison des inondations, ce qui a provoqué des dégâts. À l'hiver 2015, l'affaissement de l'esplanade a atteint 20-25 cm et des fissures sont apparues autour de l'accès aux hermitages et à la grotte, ainsi qu'à d'autres endroits dans la partie supérieure de la pente.

Une campagne géotechnique a été menée pour connaître le comportement complexe de la pente dans laquelle ils sont impliqués: le perte de la rivière Guareña, le complexe karstique et l'esplanade d'accès aux hermitages.

Keywords: karst; subsidence; sinkhole; landslide; flood

1 INTRODUCTION

Ojo Guareña is one of the biggest karst complex in the world. Located in the Cantabrian

Mountains (north of Spain) is formed of over 100km of galleries and it was declared natural monument in 1996 (Figure1).

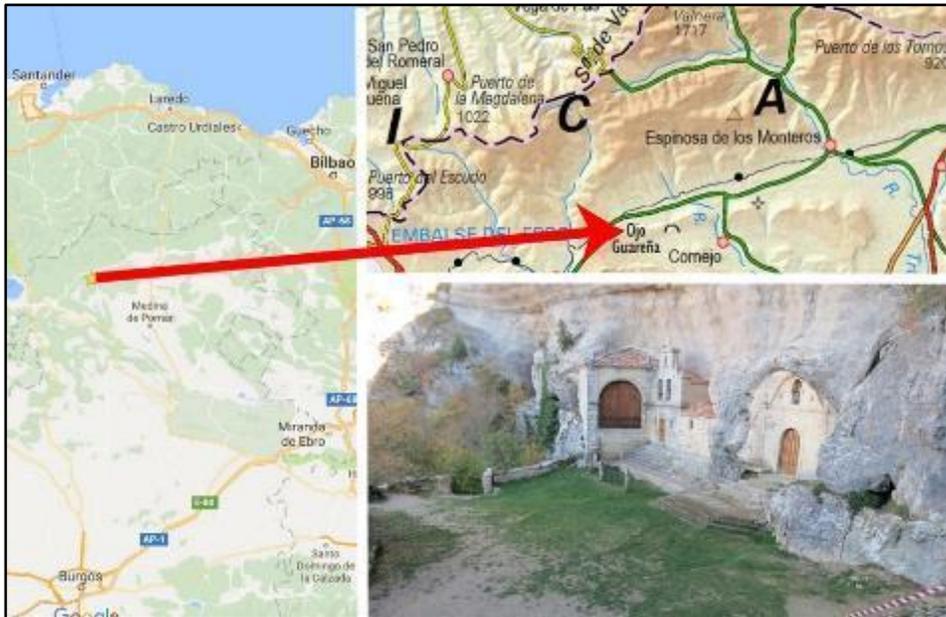


Figure 1 Location of "Ojo Guareña" Karst Complex

The hermitage of San Tirso and San Bernabé sits on the main entrance to the cave where remains of human activity since the Paleolithic have been found. Scientific exploration has also discovered the presence of over 180 species of invertebrates in the complex.

The natural monument of Ojo Guareña receives more than 20000 visits per year and its mains points of interest are the hermitage and the caves.

The main acces to the monument is a esplanade wich was built with an anthropic fill in the early XX century. This esplanade is located above a colluvial deposit in the top of a blind valley.

In the foot of this slope, 60 meters below, the sink of Guareña river is located, known as Ojo Guareña.

In the last 50 years the esplanade has suffered some settelments episodes, but it has been in the 2015 winter when this ground movements have

been more significant. Therefore concern about global establiity of the slope and esplanade is increasing.

2 GEOLOGICAL SETTING

One of the biggest interests of Ojo Guareña monument are the geological and geomorphological aspects.

Ojo Guareña monument is an outstanding example of a karst modeling made by three rivers. It was formed by the erosive action of the Guareña and Trema rivers, in addition to the Villamartín stream.

It is located in the south of Sotoscueva valley and formed on deposits from the late Cretaceous of marine limestone.

The structure of the area consists in a E-W monocline with 10°-12° dip which is crossed by the three rivers.

The figure 2 shows the geological setting and the location of the Ojo Guareña's main entrance.

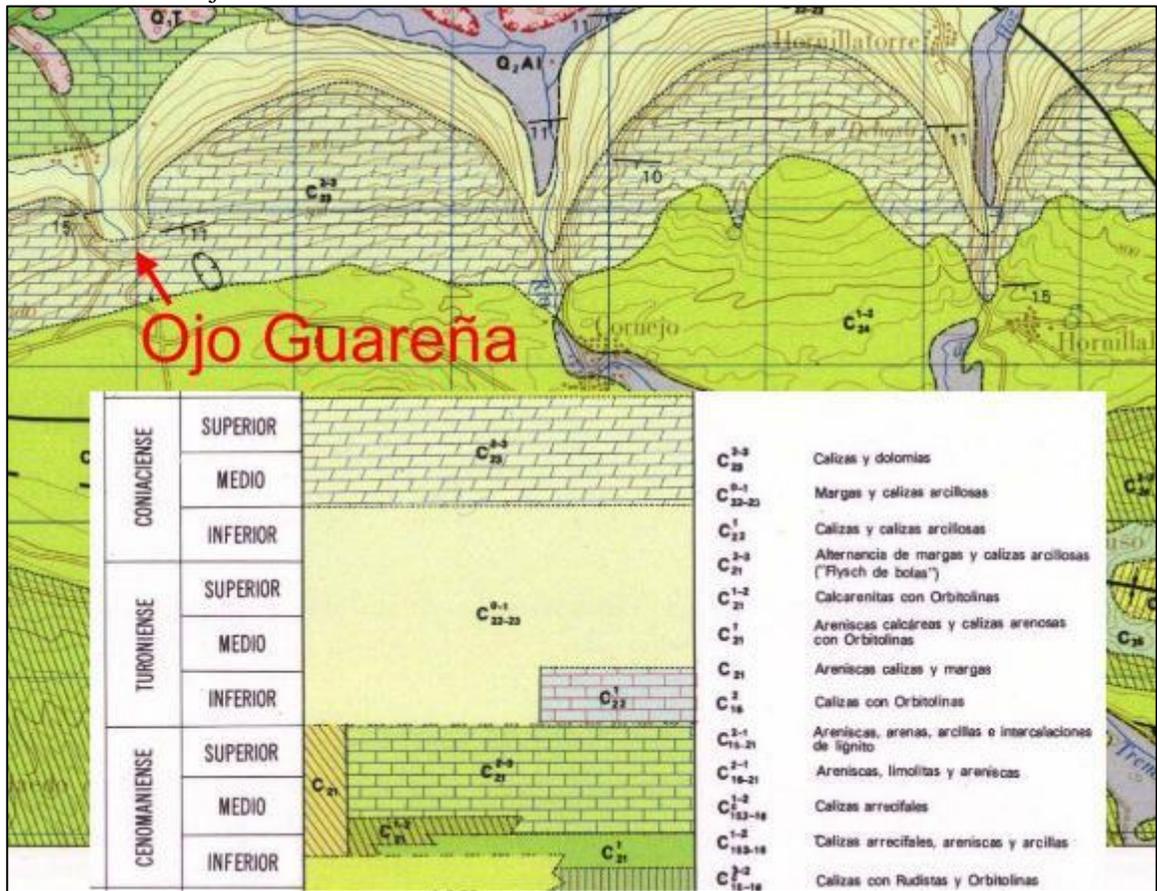


Figure 2 Geological setting (MAGNA 84 IGME)

The limestone formation containing the system is approximately 130 metres thick and sits on a massive water-resistant layer of marl and clayey limestones.

In the north of Sotoscueva valley is the Morteros mountain range which is formed by sandstones and siltstone. From this mountains the three rivers come down and cross the Sotoscueva

valley to break through the limestones of Ojo Guareña monument. Two of them crossed the limestones forming new valleys while Guareña river sank into the mountains forming caves and galleries.

Figure 3 shows a view where it is possible to see the Sotoscueva valley and the three rivers crossing the valley to find the barrier of limestones.



Figure 3 Sotoscueva valley and the three rivers crossing it.

It is remarkable that the Guareña river have been thousand of years drilling in the same place whitout changing its course. As a consequence the Guareña river has built up to six levels of galleries.

The different levels of galleries were formed as the riverbed was downcutting until it reached its current elevation at sink of Guareña river, 60m lower than the hermitage and esplanade.

Figure 4 shows a cross-section in which the esplanade and the hermitage can be seen on top of the slope. Also shows the different levels of galleries, the colluvial deposit and the Guareña sink.

The Guareña river runs through the lower galleries for most of the year, although during flood season it may not have enough drainage capacity and therefore the water rises to enter the higher galleries.

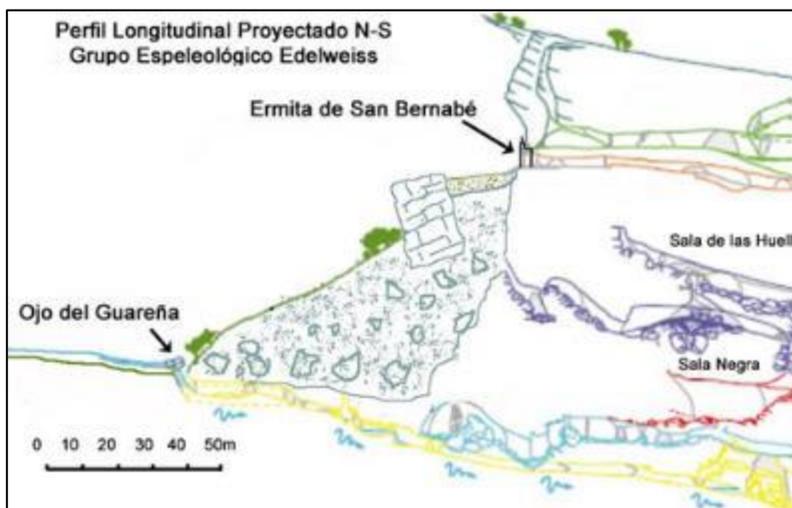


Figure 4. Cross-section: sink of Guareña and hermitage

3 GEOMORPHOLOGICAL EVOLUTION OF THE AREA

In winter 2015 the settlements on the esplanade were unusually pronounced. In some

areas up to 20 cm of settlement have been measured and are well marked in the structural components (stairs, masonry walls, etc).

Figure 5 shows pictures of different areas with important settlements.



Figure 5. Damages and settlements around the esplanade

During the in situ investigation it has been proved that settlements not only appear on the esplanade but also on the slope next to it. Furthermore the magnitude of settlement is very similar on the slope and esplanade.

Figure 6 shows with a red line the upper limit of the settlements on the esplanade and on the slope next to it.

It is remarkable that in the last years the sink overflowed a few times due to heavy rains.

When this happens the water may rise up to 15 meters over the slope forming a lake that can reach the village located upstream. Moreover water goes into the cave by higher galleries.



Figure 6. Upper limit of the settlements on the esplanade

At the same time in the higher galleries important geomorphological modifications have been found, that indicates a change in the karst hydrological behavior. This occurrence has not

been observed in the last 50 years in which the cave has been explored.

Figure 7 shows two pictures with a recent erosion in old deposits and a view of the sink almost clogged.



Figure 7. Recent erosion and the inside of the sink of Guareña River

Speleo Club Edelweiss which has been exploring the cave since the fifties has observed that some important morphological changes has been produced into the sink.

In the years 1980 and 1981 there were episodes with important flooding due to heavy rains and some remarkable settlements were observed on the esplanade. Some structural damages were produced in the entrance to the hermitage, stairs and walls. In 2015 winter flooding episodes have been more frequents than in the previous years.

4 SITE INVESTIGATION

Previously to this work, in 2007 and 2012, two "in situ" investigation campaigns were carried out to find out the geotechnical aspects of the anthropic fill under the esplanade.

However those campaigns were made with the hypothesis that the settlements were due to the lack of strength of the anthropic feel. Therefore those campaigns did not take into account the possible relationship between the overflowing and the hillside behaviour.

At the present time the Geotechnics Laboratory of CEDEX is carrying out a new campaign based on a model of the hillside wich take into account all its characteristics: Antropic fill, Colluvial deposit and the hidrogeological aspects of the karst.

The investigation campaing is being complex due to some factors:

- Works have to be done in a highly protected area.
- Sink only can be visited in dry season.
- The lack of economic resources of the monument natural of ojo guareña
- The rough terrain and vegetation make it difficult to apply some geophysical techniques, GPS, photogrammetry, etc.

To reduce the number of boreholes, in the same drilling, it has been installed an inclinometer with magnetic rings to monitoring

both vertical and horizontal displacements. Moreover, to prevent the cement grout leakage toward the protected area (caves, river, archeological findings, etc) the borehole has been protected with a geotextile sleeve.

Besides, laboratory tests has been made to check the strength of the geotextile with the grout pressure.

The following "in situ" investigation works have been carried out:

- Field reconaissance of the slope, sink and cave. Geological and geotechnical mapping.
- Two geotechnics boreholes with inclinometer and magnet extensometer.
- Topographical survey of the hillside.
- Geophysical campaing: Tomography and LIN (Low induction number).

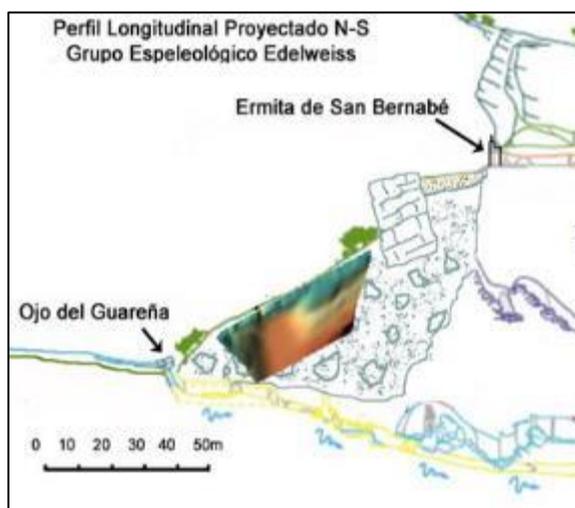


Figure 8. Cross-section with results of electrical tomography on the slope

5 CONCLUSIONS

So far the results obtained could confirm that there is a direct relationship between the settlements in the esplanade and the overflowing sink.

The magnitude of settlements in the esplanade and the contiguous hillside are very homogeneous and hence it indicates a

mouvement of the whole slope and not only of the anthropic fill.

This investigation started in october 2016 and since then there have not been reports of overflowing in the sink. Therefore there have not been new settlements registered with the "in situ" monitoring.

Only in the S102 borehole a small deformation has been detected at 12 m deep wich could be confirmed by next measures (Figure 9).

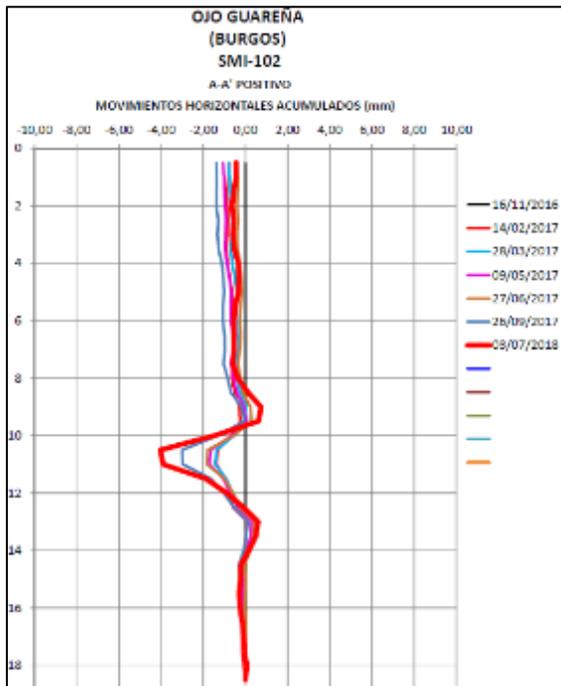


Figure 9. Inclinometer SMI-102

The natural monument protected area has not suffered any damages or modifications due to monitoring and investigation works.

Figure 4 shows the geotechnical cross-section made with the results obtained. The anthropic fill is 8 m deep. Under this fill there is a colluvial deposit down to 50m deep formed by limestone blocks with very different sizes and a matrix made by clay, sand and gravel.

Small caves, with a maximum section of 1,5 m, have been found in the colluvial deposit.

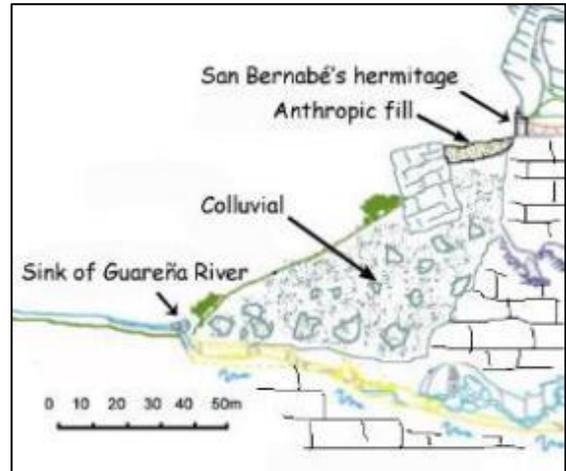


Figure 10. Geotechnical cross-section

At the present moment works go on with the monitoring of displacements, settlements and hydrological behavior, to find out the kinematics of the hillside of ojo guareña and its environment.

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