Book of abstracts
XXIII Conference of PhD Students and Young Scientists
June 13 – 15, 2023, hybrid event

PRELIMINARY ASSESSMENT OF BADAJO CAVE (SEGOVIA, SPAIN) STABILITY USING EMPIRICAL, NUMERICAL AND REMOTE TECHNIQUES

Abdelmadjid Benrabah*[1], Salvador Senent Dominguez[1], Luis Jorda Bordehore[1], David Alvárez Alonso[2], María de Andrés Herrero[2], Andrés Díez Herrero[3]

[1] *UPM (Universidad Politécnica de Madrid, UPM. ETSICCP. Calle del Prof. Aranguren, 3, 28040 Madrid, Spain*)

[2] *UCM (Universidad Complutense de Madrid, UCM. Facultad de Geografía e Historia. Calle del Profesor Aranguren, s/n, Ciudad Universitaria, 28040 Madrid, Spain)*

[3] *IGME-CSIC (Instituto Geológico y Minero de España, IGME-CSIC, Ríos Rosas 23, 28003 Madrid, Spain)*

*Corresponding author: abdelmadjid.benrabah@alumnos.upm.es

Keywords: Cave, stability analysis, Cave Geomechanical Index (CGI), Q index, Rock Mass Classification, numerical modelling, photogrammetry

Badajo cave is a shallow cavity (hemispherical rock shelter) located in the valley of Clamores River, Segovia city, Central Spain. This small canyon carved in Cretaceous dolostones has numerous geosites, as well as a rich archaeological and historical heritage. There are dozens of rock outcrops in the valley's cliffs and slopes, on both banks, where various types of sedimentary rocks can be easily recognized and differentiated, especially carbonates (dolostones and limestones), and mixed carbonate-detrital (dolomitic sandstones, calcareous silts, marls). The cave was formed by karstic and gravitational processes within a mixed dolomitic sandstones and limestones, and it has an important archaeological interest.

This study proposes a preliminary stability analyses of the cave applying: (i) empirical approaches based on geomechanical classifications using Barton's Q Index, Rock mass rating (RMR) and the recently created Cave Geomechanical Index (CGI); (ii) numerical modeling using a 2D model based on the generalized Hoek and Brown failure criterion and also a 3D model for wedge analysis; and, (iii) three-dimensional model performed with the remote photogrammetric technique Structure from Motion (SfM) to allow acquisition of data to complete the parameters established in the geomechanical classifications, and to create the numerical calculation sections of the different critical parts of the cave.

The results of the analysis show that the cave is generally stable, although it presents some places with small problems (falls of slabs and some blocks) that deserve monitoring. Furthermore, the evaluation by the geomechanical classification Q and the corresponding abacus of cave stability indicates that it is located in the "transition" zone, therefore, it requires attention. In addition, SfM photogrammetric technique makes possible to generate a geometric 3D model that allowed the acquisition of data that were difficult to take in situ. The geotechnical parameters obtained from the different methods complement each other, resulting in a more realistic engineering representation of the

subsurface environment. As a conclusion, a graph showing the two empirical methodologies (Barton's Q Index and CGI), and some recommendation for a future analysis are given.

References:

Barton, N.; Bieniawski, Z. RMR and Q-setting records straight. Tunn. Tunn. Int. 2008, 2, 26–29.

Bieniawski, Z.T. Engineering Rock Mass Classification; John Wiley & Sons: Hoboken, NJ, USA, 1989. https://doi.org/10.1016/C2010-0-64994-7.

Jordà-Bordehore, L. Stability Assessment of Natural Caves Using Empirical Approaches and Rock Mass Classifications. Rock Mech. Rock Eng. 2017, 50, 2143–2154. https://doi.org/10.1007/s00603-017-1216-0.

Jordà-Bordehore, L.; García, R.; Alonso-Zarza, A.; Romero, C. Stability assessment of shallow limestone caves through an empirical approach: Application of the stability graph method to the Castañar Cave study site (Spain). Bull. Eng. Geol. Environ. 2016, 75, 1469–1483.

Rodríguez, G.; Mulas, M.; Loaiza, S.; Del Pilar Villalta Echeverria, M.; Yanez Vinueza, A.A.; Larreta, E.; Jordá Bordehore, L. Stability Analysis of the Volcanic Cave El Mirador (Galápagos Islands, Ecuador) Combining Numerical, Empirical and Remote Techniques. Remote Sens. 2023, 15, 732. https://doi.org/10.3390/rs15030732

Brandi, I.V.; Barbosa, M.R.; Barata, A.; de Paula, R.G.; Correa, T.; Mota, H.; Lima, D.; Osborne, R.A.; Vale, S.A.; Lima, N.; et al. Cave Geomechanical Index (CGI). Classification and Contribution to the Conservation of Natural Caves in the Iron Mines. Geoconserv. Res. 2021, 3, 134–161. https://doi.org/10.30486/gcr.2021.1908888.1033.

Jordá Bordehore, L., Adrián Riquelme, Miguel Cano, Roberto Tomás. Comparing manual and remote sensing field discontinuity collection used in kinematic stability assessment of failed rock slopes. International Journal of Rock Mechanics & Mining Sciences 97 (2017) 24–32.

Bastidas, G.; Soria, O.; Mulas, M.; Loaiza, S.; Bordehore, L.J. Stability Analysis of Lava Tunnels on Santa Cruz Island (Galápagos Islands, Ecuador) Using Rock Mass Classifications: Empirical Approach and Numerical Modeling. *Geosciences* **2022**, *12*, 380

Barton, N. Unsupported Underground Openings. In *Rock Mechanics Discussion Meeting*; Befo, Swedish Rock Mechanics Research Foundation, Stifrelsen Bergteknisk Forskning: Stockholm, Sweden, 1976; pp. 61–94

Rodríguez, G.; Mulas, M.; Loaiza, S.; Del Pilar Villalta Echeverria, M.; Yanez Vinueza, A.A.; Larreta, E.; Jordá Bordehore, L. Stability Analysis of the Volcanic Cave El Mirador (Galápagos Islands, Ecuador) Combining Numerical, Empirical and Remote Techniques. *Remote Sens.* **2023**, *15*, 732. https://doi.org/10.3390/rs15030732

Bar, N., Barton, N. The Q-Slope Method for Rock Slope Engineering. Rock Mech Rock Eng 50, 3307–3322 (2017). https://doi.org/10.1007/s00603-017-1305-0