
4. Discusión general

Como se ha mencionado, el objetivo del presente estudio es evaluar diferentes métodos geomecánicos para proponer mejoras en el método Q-slope, contribuyendo así a su aplicación en la estabilidad de taludes rocosos, protección de seres humanos y estructuras durante la ejecución de procesos constructivos.

La tesis doctoral ha explorado diversas aplicaciones de la técnica Q-slope y posibles falencias para abordar problemas geomecánicos en diferentes ambientes y contextos. Estas exploraciones ayudan a comprender las limitaciones existentes y proponer mejoras al método presentado por Barton en 2015, así como líneas de investigación para futuros proyectos de investigación.

En este contexto se describe la integración de publicaciones y la aportación de cada una de ellas al objetivo planteado.

Artículo 1: Los resultados parciales obtenidos en la primera etapa de investigación, relacionados con el objetivo de investigación y el proceso metodológico, demostraron y confirmaron que el número de publicaciones asociadas a la zona andina de Ecuador y al método Q-slope era escaso o inexistente. Este bajo número de publicaciones dejaba un vacío en cuanto a estudios científicos de alto impacto relacionados con la aplicación del método empírico Q-slope en ambientes contrastantes de la región andina y específicamente de Ecuador. Este resultado parcial enfatizó la relevancia y la necesidad de validar este método en Ecuador, así como darle mayor visibilidad en los ámbitos científico e ingenieril, contribuyendo con la publicación a la geomecánica de la región andina.

Artículo 2 y 3: Estos están enmarcados dentro de la segunda etapa del proceso metodológico. El trabajo ejecutado y los resultados bibliométricos obtenidos en la primera publicación pusieron de manifiesto la necesidad de profundizar en temas claves que surgieron aplicar la metodología Q-slope en ambientes contrastantes. Se identificó la necesidad de establecer la relación existente entre la geometría intrínseca de las discontinuidades en estructuras complejas e investigar ambientes poco o nada analizados hasta ese momento, como los taludes afectados por cuñas de hielo.

Artículo 4: Una vez identificadas las limitaciones del método, se continuó la investigación enfocándose solo en una de las limitaciones identificadas, la cual tiene relación a la aplicabilidad de las tablas propuestas para Q-slope en campo. Al focalizar el estudio en esta limitante particular del método, se propone mejoras significativas tomando como ejemplo las investigaciones realizadas por diferentes autores (Marinos & Hoek, 2018; Tomás, Cuenca, et al., 2012), quienes buscaron desarrollar modelos que permitieran la aplicación rápida y efectiva de diferentes métodos empíricos en obra. En el EUROCK 2021, se presenta el primer trabajo sobre mejoras al método Q-slope con la introducción de la primera tabla gráfica para los parámetros Jr/Ja. Posteriormente en EUROCK 2024 presentar la propuesta metodológica conocida como GQ-slope, la cual introduce las restantes tablas gráficas del método Q-slope, tablas gráficas que permiten un aumento considerable en la transferencia, versatilidad y aplicabilidad del método propuesto por Barton en 2015, ofreciendo una solución flexible, amigable y adaptable a entornos reales.

4.1. Conclusiones

Los resultados obtenidos en el estudio bibliométrico sobre rendimiento de producción científica y análisis de mapas bibliométricos basados en coocurrencia de palabras clave permiten concluir que, para la presente investigación, el método de análisis geomecánico con mejores perspectivas para estudio por su novedad científica, consideración de parámetros ambientales, cantidad de publicaciones en un corto período de existencia y número de citas en sus artículos científicos, además de su rápida divulgación a nivel mundial desde su presentación, es el método propuesto por Barton en 2015, conocido en el mundo de la investigación y la construcción como Q-slope. Al mismo tiempo, se analizaron las ventajas y limitaciones de los métodos SMR, CoSMR, CSMR y GSI, los cuales abrieron las puertas para nuevas líneas de investigación y propuesta de solución para parte de las limitaciones actuales del método.

La aplicación del método empírico seleccionado en el estudio bibliométrico en diferentes ambientes climáticos y en un país como Ecuador, donde hasta la presente fecha no se habían realizado investigaciones detalladas sobre la aplicación del método Q-slope, permitió concluir que el método de análisis geomecánico Q-slope puede aplicarse en países de la región andina y en diferentes pisos climáticos con resultados óptimos al momento de clasificar un talud según su grado de estabilidad.

El resultado de la presente investigación permitió corroborar la aplicación práctica de dos enfoques importantes en el análisis de estabilidad de taludes rocosos: i) el primero relacionado a la aplicación metodológica de proyección estereográfica para análisis de pendientes multi-faced (MFS) y ii) el efecto del hielo sobre taludes rocosos en regiones de alta montaña. Estos estudios proporcionaron valiosas contribuciones al estado del arte y la comprensión de la estabilidad de taludes rocosos en diferentes contextos geográficos y geológicos, ofreciendo respuestas surgidas durante la investigación y que se traducen en recomendaciones y procedimientos útiles para la evaluación de taludes rocosos complejos y la gestión de riesgos en zonas vulnerables a deslizamientos.

Los resultados de investigación publicados en revistas de alto impacto permitieron concluir que en la actualidad el método Q-slope es prometedor debido a su reconocimiento internacional, su innovación y su aceptación como tema de investigación en el ámbito de las geociencias. Se puede concluir que el método, si bien tiene muchos puntos a favor, también presenta algunas limitaciones que fueron corroboradas durante la aplicación en diferentes ambientes y continentes. Los hallazgos presentados en esta investigación permitieron proponer mejoras al método Q-slope para agilizar la recolección de datos en campo y optimizar la evaluación de parámetros intrínsecos, mejorando de esta forma su aplicabilidad y divulgación técnico-científica y dejando otros aspectos limitantes como temas para futuros proyectos de investigaciones.

4.2. Futuras líneas de investigación

Las investigaciones futuras relacionadas al método empírico Q-slope deberán abordar algunas de las limitaciones que se pusieron en evidencia durante la presente investigación y que no fueron abordadas debido a la imposibilidad temporal de acometer todas y cada una.

1.- Estudio para integrar la geometría del talud, discontinuidades y modos de rotura en el análisis de estabilidad de taludes rocosos por el método Q-slope. En este aspecto, se puede considerar como ejemplo de partida el método SMR e investigar mediante estudios de casos la forma de presentar una tabulación más ajustada a la realidad de los parámetros relacionados con la orientación de juntas, tales como (O-factor) y (SRFc).

- 2.- Propuesta metodológica para la valoración del factor (J_{wice}). Esta propuesta entregará criterios técnicos comprobables en campo para determinar si una estructura es estable, inestable y cuasi estable. Esta investigación también abordará el estudio y asignación de valores para (J_{wice}) en entornos ambientales no considerados en la propuesta de Barton del 2015.
- 3.- Se conoce que el tiempo es un factor crucial a considerar al momento de evaluar la estabilidad de taludes debido a su influencia sobre varios aspectos detonantes o desencadenantes. Considerando esta premisa se propone realizar una investigación sobre el factor tiempo en la estabilidad de taludes rocosos y su parametrización para la valoración del Q-slope.
- 4.- La gráfica de estabilidad propuesta por Barton en 2015 presenta oportunidades de mejora debido a la ambigüedad al momento de definir la estabilidad de taludes de poca altura y de pendientes bajas o suaves. Se propone realizar un estudio que aborde el ajuste y validación de esta gráfica para estabilidad de taludes rocosos, enfocándose en el área de inestabilidad incierta y sus límites con la zona de taludes inestables (superiores a 50 grados de inclinación) y taludes estables (inferiores a 20 grados de inclinación).
- 5.- Estudio del efecto de los riesgos sísmicos y la presencia de agua superficial y subterránea en la estabilidad de taludes rocosos. El estudio podría integrar los mapas de riesgos sísmicos de cada país con el método propuesto por Barton y estudios geofísicos de detalle para establecer parámetros de valoración relacionados con estos fenómenos.
- 6.- Propuesta de medidas correctivas que incluyan recomendaciones constructivas relacionadas directamente con el valor obtenido del Q-slope y el tipo específico de estabilidad identificado en el gráfico de estabilidad proporcionado por los autores del método.
- 7.- Aplicación del GQ-slope en diferentes condiciones climáticas y geológicas y su validación estadística para establecer mejoras en las tablas graficas propuestas para garantizar su fiabilidad y aplicabilidad generalizada.

Referencias

- Adnan, R. A. A. R., Ismail, M. A. M., Tobe, H., Miyoshi, T., Date, K., & Yokota, Y. (2023). Preliminary Assessment of Joint Roughness Coefficient of Rock Slope Using UAV–SfM Photogrammetry Technique. *Journal of the Geological Society of India*, 99(10), 1465–1473.
- Agisoft. (2020). *Agisoft photscan professional* [Computer software]. <https://www.agisoft.com/>
- Akingboye, A. S., Bery, A. A., Aminu, M. B., Dick, M. D., Bala, G. A., & Ale, T. O. (2024). Surface–subsurface characterization via interfaced geophysical–geotechnical and optimized regression modeling. *Modeling Earth Systems and Environment*, 1–23.
- Albaijan, I., Voronkova, D. K., Flaih, L. R., Alkahtani, M. Q., Mahmoodzadeh, A., Ibrahim, H. H., & Mohammed, A. H. (2024). The gene expression programming method for estimating compressive strength of rocks. *Geomechanics and Engineering*, 36(5), 465–474. Scopus. <https://doi.org/10.12989/gae.2024.36.5.465>
- Al-E'Bayat, M., Guner, D., Sherizadeh, T., & Asadizadeh, M. (2024). Numerical Investigation for the Effect of Joint Persistence on Rock Slope Stability Using a Lattice Spring-Based Synthetic Rock Mass Model. *Sustainability (Switzerland)*, 16(2). Scopus. <https://doi.org/10.3390/su16020894>
- Al-E'Bayat, M., Sherizadeh, T., & Guner, D. (2023). Laboratory-Scale Investigation on Shear Behavior of Non-Persistent Joints and Joint Infill Using Lattice-Spring-Based Synthetic Rock Mass Model. *Geosciences (Switzerland)*, 13(2). Scopus. <https://doi.org/10.3390/geosciences13020023>
- Alejano, L. R., Muralha, J., Ulusay, R., Li, C. C., Pérez-Rey, I., Karakul, H., Chryssanthakis, P., & Aydan, Ö. (2018). ISRM Suggested Method for Determining the Basic Friction Angle of Planar Rock Surfaces by Means of Tilt Tests. *Rock Mechanics and Rock Engineering*, 51(12), 3853–3859. <https://doi.org/10.1007/s00603-018-1627-6>
- Alejano, L. R., Muralha, J., Ulusay, R., Li, C. C., Pérez-Rey, I., Karakul, H., Chryssanthakis, P., Aydan, Ö., Martínez, J., & Zhang, N. (2017). A Benchmark Experiment to Assess Factors Affecting Tilt Test Results for Sawcut Rock Surfaces. *Rock Mechanics and Rock Engineering*, 50(9), 2547–2562. <https://doi.org/10.1007/s00603-017-1271-6>
- Alejano, L. R., Stockhausen, H. W., Alonso, E., Bastante, F. G., & Oyanguren, P. R. (2008). ROFRAQ: A statistics-based empirical method for assessing accident risk from rockfalls in quarries. *International Journal of Rock Mechanics and Mining Sciences*, 45(8), 1252–1272.

- Alejano, L. R., Veiga, M., Gómez-Márquez, I., & Dellerio, H. (2011). Application of rockfall risk assessment techniques in two aggregate quarries. *ISRM Congress*, ISRM-12CONGRESS-2011-338.
- Alemdag, S., Gurocak, Z., Cevik, A., Cabalar, A. F., & Gokceoglu, C. (2016). Modeling deformation modulus of a stratified sedimentary rock mass using neural network, fuzzy inference and genetic programming. *Engineering Geology*, 203, 70–82. <https://doi.org/10.1016/j.enggeo.2015.12.002>
- Andreev, G. E. (1991). A review of the Brazilian test for rock tensile strength determination. Part I: calculation formula. *Mining Science and Technology*, 13(3), 445–456. [https://doi.org/10.1016/0167-9031\(91\)91006-4](https://doi.org/10.1016/0167-9031(91)91006-4)
- Ansari, T. A., Sharma, K. M., & Singh, T. N. (2019). Empirical Slope Stability Assessment Along the Road Corridor NH-7, in the Lesser Himalayan. *Geotechnical and Geological Engineering*, 37(6), 5391–5407. <https://doi.org/10.1007/s10706-019-00988-w>
- Antonio C. (2015). *Petrografía de Rocas Ígneas y Metamórficas*. Paraninfo.
- Archie, G. E. (1952). Classification of carbonate reservoir rocks and petrophysical considerations. *Aapg Bulletin*, 36(2), 278–298.
- Arozarena Villar, A., & Otero Pastor, I. (2016). *Sistemas de captura de la informacion: Fotogrametria y teledeteccion*. Dextra Editorial. <https://elibro.net/es/lc/uguayaquil/titulos/131471>
- Ayache, N. K., Santos, A. E. M., & Silva, D. de F. S. da. (2023). Assessment of mine slopes stability conditions using a decision tree approach. *REM-International Engineering Journal*, 76(1), 71–78.
- Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative Science Studies*, 1(1), 377–386. Scopus. https://doi.org/10.1162/qss_a_00019
- Bakhtybayev, M., & Akymbek, Y. (2023). Basic governing factors of slope stability in open pit coal mines. *Gornyi Zhurnal*, 2023(12), 41–48. Scopus. <https://doi.org/10.17580/gzh.2023.12.07>
- Bar, N., & Barton, N. (2017). The Q-Slope Method for Rock Slope Engineering. *Rock Mechanics and Rock Engineering*, 50(12), 3307–3322. <https://doi.org/10.1007/s00603-017-1305-0>
- Bar, N., & Barton, N. (2018a). Q-slope: An empirical rock slope engineering approach in Australia. *Australian Geomechanics Journal*, 53(4), 73–86.
- Bar, N., & Barton, N. (2018b). Rock slope design using q-slope and geophysical survey data. *Periodica Polytechnica Civil Engineering*, 62(4), 893–900. <https://doi.org/10.3311/PPci.12287>
- Bar, N., & Barton, N. R. (2016). Empirical slope design for hard and soft rocks using Q-slope. *50th US Rock Mechanics / Geomechanics Symposium 2016*, 2, 1301–1308.

-
- Bar, N., Barton, N. R., & Ryan, C. A. (2016). Application of the Q-slope method to highly weathered and saprolitic rocks in Far North Queensland. *Rock Mechanics and Rock Engineering: From the Past to the Future*, 1, 585–590. <https://doi.org/10.1201/9781315388502-101>
- Bar, N., & McQuillan, A. (2021). Q-slope and SSAM applied to excavated coal mine slopes. *MethodsX*, 8, 101191. <https://doi.org/10.1016/J.MEX.2020.101191>
- Barton, N. (1976). Shear Strength of Joints for Estimating the Stability of Rock Slopes.; [skjaerfasthet av sprekker for bestemmelse av fjellskraningsstabilitet.]. *Nor Geotek Inst Publ*, 112, 41–46.
- Barton, N., & Bandis, S. (1982). *Effects Of Block Size On The Shear Behavior Of Jointed Rock*. ARMA-82-739.
- Barton, N., & Bandis, S. (1990). Review of predictive capabilities of JRC-JCS model in engineering practice. Rock Joints-Proceeding of a regional conference of the International Society for Rock Mechanics. *Leon*.
- Barton, N., & Bar, N. (2015). Introducing the Q-slope method and its intended use within civil and mining engineering projects. *ISRM Regional Symposium, EUROCK 2015*, 157–162.
- Barton, N., & Choubey, V. (1977). The shear strength of rock joints in theory and practice. *Rock Mechanics*, 10, 1–54.
- Barton, N., Lien, R., & Lunde, J. (1974). Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics Felsmechanik Mécanique Des Roches*, 6(4), 189–236. Scopus. <https://doi.org/10.1007/BF01239496>
- Barton, N., Wang, C., & Yong, R. (2023). Advances in joint roughness coefficient (JRC) and its engineering applications. *Journal of Rock Mechanics and Geotechnical Engineering*, 15(12), 3352–3379. <https://doi.org/10.1016/j.jrmge.2023.02.002>
- Basahel, H., & Mitri, H. (2017). Application of rock mass classification systems to rock slope stability assessment: A case study. *Journal of Rock Mechanics and Geotechnical Engineering*, 9(6), 993–1009. <https://doi.org/10.1016/j.jrmge.2017.07.007>
- Baud, P., Wong, T., & Zhu, W. (2014). Effects of porosity and crack density on the compressive strength of rocks. *International Journal of Rock Mechanics and Mining Sciences*, 67, 202–211. <https://doi.org/10.1016/j.ijrmms.2013.08.031>
- Benrabah, A., Senent Domínguez, S., Jorda Bordehore, L., Alvares Alonzo, D., Diez Herrero, A., & de Andrés Herrero, M. (2024). *Preliminary Assessment of Badajo Cave (Segovia, Spain) Stability Using Empirical, Numerical and Remote Techniques*. 1295(1). Scopus. <https://doi.org/10.1088/1755-1315/1295/1/012011>
- Bieniawski, Z. (1979). The Geomechanics Classification In Rock Engineering Applications. *4th ISRM Congress, Montreux, Switzerland*.

- Bieniawski, Z. T. (1974). *geomechanics classification of rock masses and its application in tunneling*. 27–32.
- Bieniawski, Z. T. (1989). Engineering rock mass classifications: A complete manual for engineers and geologists in mining, civil, and petroleum engineering. In *Engineering rock mass classifications: A complete manual for engineers and geologists in mining, civil, and petroleum engineering*.
- Bieniawski, Z. T. (1993). Classification of rock masses for engineering: The RMR system and future trends. In *Comprehensive rock engineering. Vol. 3*. <https://doi.org/10.1016/b978-0-08-042066-0.50028-8>
- Blanco, R. (2015). Estudios y Propuestas de Estabilización del Cerro Las Cabras. *CIPAT-ESPOL: Guayaquil, Ecuador*.
- Borja Bernal, C., Laín, R., Jordá, L., Cano, M., Riquelme, A., & Tomás, R. (2023). Stability Assessment of Rock Slopes Using the Q-Slope Classification System: A Reliability Analysis Employing Case Studies in Ecuador. *Applied Sciences*, 13(13), 7399. <https://doi.org/10.3390/app13137399>
- Borja Bernal, C. P., & Jordá Bordehore, L. (2023). Application of the Kinematic Assessment of Multi-Faced Slopes Using Stereographic Projection: The Case Study of a Planar Failure on the Spondylus Coast, Ecuador. *Applied Sciences (Switzerland)*, 13(14), 1–12. <https://doi.org/10.3390/app13148245>
- Borja, C. P., & Jordá Bordehore, L. (2023). Application of the Q-Slope Empirical Approach for Slope Stability Assessment of Spanish Mountain Roads in Winter—Combining Remote Techniques with Virtual Reality. *Sustainability*, 15(22). <https://doi.org/10.3390/su152215744>
- Borja-Bernal, C. P., & Jordá-Bordehore, L. (2022). Application of the SfM technique for geomechanical analysis according to SMR and Qslope. *ISRM Latin American Rock Mechanics Symposium*, ISRM-LARMS-2022-13.
- Borja-Bernal, C. P., & Jordá-Bordehore, Y. L. (2021). *Determination of frictional resistance pair J_r/J_a using a friendly—Graphical approach in the Q-slope empirical method*. 833(1). Scopus. <https://doi.org/10.1088/1755-1315/833/1/012047>
- Bozdağ, A. (2022). Rockfall hazard assessment in a natural and historical site: The case of ancient Kilistra settlement (Konya), Turkey. *Journal of Mountain Science*, 19(1), 151–166. Scopus. <https://doi.org/10.1007/s11629-021-6961-6>
- Broch, E., & Franklin, J. A. (1972). The point-load strength test. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 9(6), 669–676. [https://doi.org/10.1016/0148-9062\(72\)90030-7](https://doi.org/10.1016/0148-9062(72)90030-7)
- Calderon Carrillo, Z. (2014). *Introducción a la mecánica de rocas y sus aplicaciones en la industria del petróleo*. Ediciones UIS.
- Camones, L. A. M., Vargas, E. D. A., de Figueiredo, R. P., & Velloso, R. Q. (2013). Application of the discrete element method for modeling of rock crack propagation and coalescence in the step-path failure mechanism.

-
- Engineering Geology*, 153, 80–94. Scopus.
<https://doi.org/10.1016/j.enggeo.2012.11.013>
- Carrión Mero, P., Blanco Torrens, R., Borja Bernal, C., Aguilar Aguilar, M., Morante Carballo, F., & Briones Bitar, J. (2019). Geomechanical characterization and analysis of the effects of rock massif in Zaruma City, Ecuador. *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology, 2019-July*(July), 24–26.
<https://doi.org/10.18687/LACCEI2019.1.1.362>
- Carrión-Mero, P., Briones-Bitar, J., Morante-Carballo, F., Stay-Coello, D., Blanco-Torrens, R., & Berrezueta, E. (2021). Evaluation of slope stability in an urban area as a basis for territorial planning: A case study. *Applied Sciences* (Switzerland), 11(11). Scopus.
<https://doi.org/10.3390/app11115013>
- Carrión-Mero, P., Montalván-Burbano, N., Paz-Salas, N., & Morante-Carballo, F. (2020). Volcanic geomorphology: A review of worldwide research. *Geosciences* (Switzerland), 10(9), 1–17.
<https://doi.org/10.3390/geosciences10090347>
- Cartaya-Pire, M. (2006). Caracterización geomecánica de macizos rocosos en obras subterráneas de la región oriental del país (resumen de tesis). *Minería y Geología*, 22(3), 56.
- Cecil, O. S. (1975). CORRELATIONS OF ROCK BOLT-SHOTCRETE SUPPORT AND ROCK QUALITY PARAMETERS IN SCANDINAVIAN TUNNELS. *Correl of Rock Bolt-Shotcrete Support and Rock Qual Parameters in Scan Tunnels*.
- Chen, Z. (1995). Recent developments in slope stability analysis. *ISRM Congress, ISRM-8CONGRESS-1995*-196.
- Coletti, C., Ciotoli, G., Benà, E., Brattich, E., Cinelli, G., Galgaro, A., Massironi, M., Mazzoli, C., Mostacci, D., & Morozzi, P. (2022). The assessment of local geological factors for the construction of a Geogenic Radon Potential map using regression kriging. A case study from the Euganean Hills volcanic district (Italy). *Science of The Total Environment*, 808, 152064.
- Colman, S. M. (1981). Rock-weathering rates as functions of time. *Quaternary Research*, 15(3), 250–264. [https://doi.org/10.1016/0033-5894\(81\)90029-6](https://doi.org/10.1016/0033-5894(81)90029-6)
- Coon RF, M. A. (1970). Predicting in situ modulus of deformation using rock quality indexes. *ASTM Special Technical Publication*, 154–173.
- Coulson, J. H. (1972). Shear strength of flat surfaces in rock. *Stability of Rock Slopes*, 77–105.
- Culnan, M. J., O'Reilly III, C. A., & Chatman, J. A. (1990). Intellectual structure of research in organizational behavior, 1972–1984: A cocitation analysis. *Journal of the American Society for Information Science*, 41(6), 453–458.

- Da Gama, C. D. (1983). *Interactive graphics in the back-analysis of slope failures*. C53–C60. Scopus. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85059539189&partnerID=40&md5=59dbf5a4de5e3aa53aa9052779730409>
- Daftaribesheli, A., Ataei, M., & Sereshki, F. (2011). Assessment of rock slope stability using the Fuzzy Slope Mass Rating (FSMR) system. *Applied Soft Computing*, 11(8), 4465–4473.
- Davis, G. H., Reynolds, S. J., & Kluth, C. F. (2011). *Structural geology of rocks and regions*. John Wiley & Sons.
- Deaton, B. C. (1987). Quantification of rock color from Munsell chips. *Journal of Sedimentary Research*, 57(4).
- Deere, D. U. (1963). Technical Description of Rock Cores for Engineering Purpose. *Rock Mechanics and Engineering Geology*, 1(1), 16–22.
- Deere, D. U., & Deere, D. W. (1967). *The Rock Quality Designation (ROD) Index*.
- Deere, D. U., & Deere, D. W. (1988). The Rock Quality Designation (RQD) Index in Practice. *ASTM Special Technical Publication, STP 984*, 91–101. <https://doi.org/10.1520/STP48465S>
- Deere, D. U., & Miller, R. P. (1966). *Engineering classification and index properties for intact rock*. National Technical Information Service Springfield, VA, USA.
- Delgado-Reivan, X., Paredes-Miranda, C., Loaiza, S., Echeverria, M. D. P. V., Mulas, M., & Jordá-Bordehore, L. (2023). Stability Analysis of Rocky Slopes on the Cuenca–Girón–Pasaje Road, Combining Limit Equilibrium Methods, Kinematics, Empirical Methods, and Photogrammetry. *Remote Sensing*, 15(3), 862.
- Dewez, T. J., Girardeau-Montaut, D., Allanic, C., & Rohmer, J. (2016). Facets: A cloudcompare plugin to extract geological planes from unstructured 3d point clouds. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 41, 799–804.
- Donthu, N., Kumar, S., & Pandey, N. (2021). A retrospective evaluation of Marketing Intelligence and Planning: 1983–2019. *Marketing Intelligence and Planning*, 39(1), 48–73. <https://doi.org/10.1108/MIP-02-2020-0066>
- Donthu, N., Kumar, S., Pandey, N., & Lim, W. M. (2021). Research Constituents, Intellectual Structure, and Collaboration Patterns in Journal of International Marketing: An Analytical Retrospective. *Journal of International Marketing*, 29(2), 1–25. <https://doi.org/10.1177/1069031X211004234>
- Du, K., Li, X., Tao, M., & Wang, S. (2020). Experimental study on acoustic emission (AE) characteristics and crack classification during rock fracture in several basic lab tests. *International Journal of Rock Mechanics and Mining Sciences*, 133, 104411. <https://doi.org/10.1016/j.ijrmms.2020.104411>
- Echeveste, H. (2018). *Manual de levantamiento geológico*. Editorial de la Universidad Nacional de La Plata (EDULP).

-
- Einstein, H. H., Veneziano, D., Baecher, G. B., & O'Reilly, K. J. (1983). The effect of discontinuity persistence on rock slope stability. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 20(5), 227–236. [https://doi.org/10.1016/0148-9062\(83\)90003-7](https://doi.org/10.1016/0148-9062(83)90003-7)
- Elberg, M. (2011). *Análisis numérico de las discontinuidades del macizo rocoso de la autopista Rafael Caldera en Venezuela*. *Revista Ciencia e Ingeniería*. Vol. 32, No. 2, 2011. 8.
- Elkateb, T. (2009). The point load test in the Persian Gulf carbonate rocks. *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering (Volumes 1, 2, 3 and 4)*, 372–375.
- Fang, K., Dong, A., Tang, H., An, P., Wang, Q., Jia, S., & Zhang, B. (2024). Development of an easy-assembly and low-cost multismartphone photogrammetric monitoring system for rock slope hazards. *International Journal of Rock Mechanics and Mining Sciences*, 174. Scopus. <https://doi.org/10.1016/j.ijrmms.2024.105655>
- Ferrer, M., & Gonzalez Vallejo, L. I. (2007). *Manual de campo para la descripción y caracterización de macizos rocosos en afloramientos*. Instituto Geológico y Minero de España.
- Foucault, A. (1985). *Découverte d'une nouvelle unité tectonique sous le massif subbétique de la Sierra Sagra*. 250.
- Fredlund, D. G., & Rahardjo, H. (1993). *Soil mechanics for unsaturated soils*. John Wiley & Sons.
- Frost, B. R., & Frost, C. D. (2019). *Essentials of igneous and metamorphic petrology*. Cambridge University Press.
- Fujimura, H., Nishimura, T., & Kiyama, H. (1990). Study on Element Constants of Distinct Element Method. *Journal of the Society of Materials Science, Japan*, 39(447), 1711–1717. <https://doi.org/10.2472/jsms.39.1711>
- Galvan Ceballos, M. (2015). *Mecánica de rocas: Correlación entre la resistencia a carga puntual y la resistencia a compresión simple*. Programa Editorial Universidad del Valle. <https://elibro.net/es/lc/uguayaquil/titulos/70339>
- Galvan Ceballos, M. A., & Seron Ganez, J. B. (2020). *Manual de prácticas de laboratorio: Mecánica de rocas*. Programa Editorial Universidad del Valle.
- Galván, M. (2015). *Mecánica de rocas: Correlación entre la resistencia a carga puntual y la resistencia a compresión simple*. (Programa E). Universidad del Valle.
- Galvan, M., Preciado, J., & Serón, J. (2014). Correlation between the point load index, I_p (50), and the resistance to unconfined compression in limestone from the comunidad Valenciana, Spain. *Acta Geotechnica Slovenica*, 11(2), 35–45.
- Gálvez Caballero, J. O. (2019). *Estimación geoestadística del RQD, RCU, JRC y densidad aplicada a entender el comportamiento geomecánico del cerro La Falda, La Encañada–Cajamarca, 2019*.

- García-Luna, R., Senent, S., & Jimenez, R. (2021a). Characterization of joint roughness using close-range UAV-SfM photogrammetry. *IOP Conference Series: Earth and Environmental Science*, 833(1), 012064.
- García-Luna, R., Senent, S., & Jimenez, R. (2021b). Using telephoto lens to characterize rock surface roughness in SfM models. *Rock Mechanics and Rock Engineering*, 54(5), 2369–2382.
- García-Vela, M. T., Borja-Bernal, C. P., Jordá-Bordehore, L., Medinaceli-Torrez, R., Loaiza, S., & Falquez, D. A. (2021). *Teaching rock mechanics using Virtual Reality: Laboratory practices and field trips during the confinement of the Coronavirus COVID-19 in Ecuador, Bolivia, and Spain*. 833(1). Scopus. <https://doi.org/10.1088/1755-1315/833/1/012172>
- Gavilanez, J., & Andrade, B. (2004). Introducción a la ingeniería de Túneles, caracterización, clasificación y análisis geomecánico de macizos rocosos. In 2004 (Issue March).
- Gimenez, E., Salinas, M., & Manzano-Agugliaro, F. (2018). Worldwide research on plant defense against biotic stresses as improvement for sustainable agriculture. *Sustainability (Switzerland)*, 10(2). <https://doi.org/10.3390/su10020391>
- Girardeau-Montaut, D. (2016). CloudCompare. *France: EDF R&D Telecom ParisTech*, 11(5).
- González de Vallejo, Li & Ferre, M. (1999). *Manual de campo para la descripción y caracterización de macizos rocosos en afloramientos*. Instituto Geológico y Minero de España.
- Goudie, A. S., Bull, P. A., & Magee, A. W. (1989). Lithological control of rillenkarrén development in the Napier Range, Western Australia. *Zeitschrift Fur Geomorphologie, Supplementband*, 75, 95–114.
- Griffiths, L., Heap, M. J., Baud, P., & Schmittbuhl, J. (2017). Quantification of microcrack characteristics and implications for stiffness and strength of granite. *International Journal of Rock Mechanics and Mining Sciences*, 100, 138–150. <https://doi.org/10.1016/j.ijrmms.2017.10.013>
- Haimson, B., & Chang, C. (2000). A new true triaxial cell for testing mechanical properties of rock, and its use to determine rock strength and deformability of Westerly granite. *International Journal of Rock Mechanics and Mining Sciences*, 37(1), 285–296. [https://doi.org/10.1016/S1365-1609\(99\)00106-9](https://doi.org/10.1016/S1365-1609(99)00106-9)
- Han, S., Li, H., Li, M., & Luo, X. (2019). Measuring rock surface strength based on spectrograms with deep convolutional networks. *Computers & Geosciences*, 133, 104312. <https://doi.org/10.1016/j.cageo.2019.104312>
- Hashin, Z. (1988). The differential scheme and its application to cracked materials. *Journal of the Mechanics and Physics of Solids*, 36(6), 719–734. [https://doi.org/10.1016/0022-5096\(88\)90005-1](https://doi.org/10.1016/0022-5096(88)90005-1)

-
- Hencher, S. R. (1976). A simple sliding apparatus for the measurement of rock friction. Discussion. *Géotechnique*, 26(4), 641–644.
- Hencher, S. R. (1977). *The effect of vibration on the friction between planar rock surfaces*. University of London.
- Hencher, S. R. (2012). Discussion of Alejano, Gonzalez and Muralha (2012). *Rock Mechanics and Rock Engineering*, 45(6), 1137–1139. <https://doi.org/10.1007/s00603-012-0288-0>
- Herrera-Franco, G., Montalván-Burbano, N., Carrión-Mero, P., Apolo-Masache, B., & Jaya-Montalvo, M. (2020). Research Trends in Geotourism: A Bibliometric Analysis Using the Scopus Database. *Geosciences*, 10(10). <https://doi.org/10.3390/geosciences10100379>
- Herrera-Franco, G., Montalván-Burbano, N., Carrión-Mero, P., Jaya-Montalvo, M., & Gurumendi-Noriega, M. (2021). Worldwide research on geoparks through bibliometric analysis. *Sustainability (Switzerland)*, 13(3), 1–32. <https://doi.org/10.3390/su13031175>
- Herrera-Franco, G., Narváez C., R. A., Constante, J., Mora-Frank, C., Aguilar-Aguilar, M., Morante-Carballo, F., & Carrión-Mero, P. (2023). Bibliometric Analysis and Review of Low and Medium Enthalpy Geothermal Energy: Environmental, Economic, and Strategic Insights. *International Journal of Energy Production and Management*, 8(3), 187–199. <https://doi.org/10.18280/ijepm.080307>
- Hoek, E. (2007). Practical rock engineering. 2007. *Online. Ed. Rocscience*.
- Hoek, E., & Bray, J. D. (1981). *Rock slope engineering*. CRC press.
- Hoek, E., Bray, J. W. (1974). Rock Slope Engineering. In *Institution of Mining and Metallurgy*.
- Hoek, E., Bray, J. W., & Boyd, J. M. (1973). The stability of a rock slope containing a wedge resting on two intersecting discontinuities. *Quarterly Journal of Engineering Geology*, 6(1), 1–55. <https://doi.org/10.1144/GSL.QJEG.1973.006.01.01>
- Hoek, E., Kaiser, P. K., & Bawden, W. F. (2000). Support of underground excavations in hard rock. In *Support of Underground Excavations in Hard Rock*.
- Hoek, E., Kaiser, P.K., Bawden, W. F. (1997). *Support of Underground excavation in hard rock*.
- Hoek E, Kaiser PK, & Bawden WF. (1995). *Support of Underground Excavations in Hard Rock. Dimensionnement*.
- Hoek, E., Marinos, P., & Benissi, M. (1998). Applicability of the geological strength index (GSI) classification for very weak and sheared rock masses. The case of the Athens Schist Formation. *Bulletin of Engineering Geology and the Environment*, 57(2), 151–160. Scopus. <https://doi.org/10.1007/s100640050031>

- Hoek, E., Read, J., Karzulovic, A., & Chen, Z. Y. (2018). Rock slopes in civil and mining engineering. *ISRM International Symposium 2000, IS 2000*.
- Howarth, D., & Rowlands, J. (1986). Development of an Index to Quantify Rock Texture for Qualitative Assessment of Intact Rock Properties. *Geotechnical Testing Journal*, 9(4), 169–179. <https://doi.org/10.1520/GTJ10627J>
- Hu, J., Wang, M., Rong, X., Wang, X., Xiong, Z., & Shi, S. (2023). Influences of Joint Persistence on the Compressive-Shear and Tensile-Shear Failure Behavior of Jointed Rock Mass: An Experimental and Numerical Study. *Rock Mechanics and Rock Engineering*, 56(11), 8151–8165. Scopus. <https://doi.org/10.1007/s00603-023-03489-8>
- Indraratna, B., Oliveira, D. A. F., Brown, E. T., & de Assis, A. P. (2010). Effect of soil-infilled joints on the stability of rock wedges formed in a tunnel roof. *International Journal of Rock Mechanics and Mining Sciences*, 47(5), 739–751. <https://doi.org/10.1016/j.ijrmms.2010.05.006>
- ISRM. (1977). The Description of Rock Masses for Engineering Purposes. *The Description of Rock Masses for Engineering Purposes*, 10(Engineering Group Working Party Report), 355–388.
- Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M.-H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: A review. *Natural Hazards*, 61(1), 5–28. Scopus. <https://doi.org/10.1007/s11069-010-9634-2>
- James, M. R., & Robson, S. (2014). Mitigating systematic error in topographic models derived from UAV and ground-based image networks. *Earth Surface Processes and Landforms*, 39(10), 1413–1420.
- Jiang, Q., Liu, X., Wei, W., & Zhou, C. (2013). A new method for analyzing the stability of rock wedges. *International Journal of Rock Mechanics and Mining Sciences*, 60, 413–422. <https://doi.org/10.1016/j.ijrmms.2013.01.008>
- Jordá Bordehore, L., & Borja Bernal, C. P. (2024). Geomechanical classification graphical Q-slope (GQ-slope). *New Challenges in Rock Mechanics and Rock Engineering*, 1, 1584. <https://doi.org/10.1201/9781003429234>
- Jordá Bordehore, R. (2016). *Inventario y propuesta de puesta en valor del patrimonio geológico-minero de las minas del Macizo Central de los Picos de Europa (Cantabria)* [Doctoral thesis, Universidad Complutense de Madrid]. <https://hdl.handle.net/20.500.14352/21110>
- Jorda et al. (2016). *Manual de estaciones geomecánicas* (E. técnica S. de I. de M. De, Ed.; p. 208).
- Jorda, L. (2008). *La minería de los metales en la provincia de Madrid: Patrimonio minero y puesta en valor del espacio subterráneo*. Universidad Politécnica de Madrid.
- Jordá, Luis. (2015). *Manual basico de clasificaciones geomecanicas* (M. Impresores, Ed.).

-
- Jordá Luís, Jover Roberto, Rodríguez Manuel, & Fernández Antonio. (2015). *Manual de estaciones geomecánicas y descripción de macizos rocosos en afloramientos* (Ed. E. Minas. U. P. de Madrid. G. de P. de Ingeniería. Madrid, Ed.; Issue January).
- Jordá-Bordehore, L. (2017). Application of Q slope to Assess the Stability of Rock Slopes in Madrid Province, Spain. *Rock Mechanics and Rock Engineering*, 50(7), 1947–1957. <https://doi.org/10.1007/s00603-017-1211-5>
- Jordá-Bordehore, L., Albán, L. G., Valenzuela, R. C., Bravo, G., Menoscal-Menoscal, M., Larreta, E., Garces, D., & Mulas, M. (2023). An Analysis of Slope Stability in the Penipe–Baños Road by Applying Empirical Methods, Kinematic Analysis and Remote Photogrammetry Techniques. *Geosciences (Switzerland)*, 13(12). Scopus. <https://doi.org/10.3390/geosciences13120366>
- Jordá-Bordehore, L., Alejano, L., Tomás, R., Loaiza, S. C., García, M. T., Galindo, R. Á., Pérez-Rey, I., Riquelme-Guill, A., Cano, M., Borja-Bernal, C. P., & Medinaceli Torrez, R. (2021). *Determination of the basic friction angle f_b of joints using the field tilt test: Results of various 'fast' tests on outcrops*. 833(1). Scopus. <https://doi.org/10.1088/1755-1315/833/1/012048>
- Jordá-Bordehore, L., Tomás, R., Cano, M., & Riquelme, A. (2016). Evaluación de la calidad geomecánica de taludes inestables en la zona andina mediante la aplicación de la clasificación Slope Mass Rating. *10º Simposio Nacional de Ingeniería Geotécnica, A Coruña, España*, 1(1), 313–320.
- Jover, R. T., González, M. C., Cañaveras, J. C., Payá, A. C., Marchal, J. D., Rubio, A. E., & Gosálbez, J. A. P. (2006). Nuevas funciones continuas para el cálculo del Slope Mass Rating (SMR): Aplicación mediante un sistema de información geográfica a los taludes rocosos de una cantera. *Revista de La Sociedad Geológica de España*, 19(1), 87–97.
- Kääb, A., & Vollmer, M. (2000). Surface geometry, thickness changes and flow fields on creeping mountain permafrost: Automatic extraction by digital image analysis. *Permafrost and Periglacial Processes*, 11(4), 315–326. Scopus. [https://doi.org/10.1002/1099-1530\(200012\)11:4<315::AID-PPP365>3.0.CO;2-J](https://doi.org/10.1002/1099-1530(200012)11:4<315::AID-PPP365>3.0.CO;2-J)
- Kahraman, S. (2001). Evaluation of simple methods for assessing the uniaxial compressive strength of rock. *International Journal of Rock Mechanics and Mining Sciences*, 38(7), 981–994. [https://doi.org/10.1016/S1365-1609\(01\)00039-9](https://doi.org/10.1016/S1365-1609(01)00039-9)
- Kane, W. F., & Drumm, E. C. (1986). GEOTECHNICAL FACTORS AFFECTING ROCK SLOPE STABILITY IN EASTERN TENNESSEE. *Proceedings - Symposium on Rock Mechanics*, 107–111.
- Khandelwal, M., Armaghani, D. J., Faradonbeh, R. S., Yellishetty, M., Majid, M. Z. A., & Monjezi, M. (2017). Classification and regression tree technique in estimating peak particle velocity caused by blasting. *Engineering with Computers*, 33(1), 45–53. <https://doi.org/10.1007/s00366-016-0455-0>

- Kim, B. H., Cai, M., Kaiser, P. K., & Yang, H. S. (2007). Estimation of Block Sizes for Rock Masses with Non-persistent Joints. *Rock Mechanics and Rock Engineering*, 40(2), 169–192. <https://doi.org/10.1007/s00603-006-0093-8>
- Kim, J., & McMillan, S. J. (2008). Evaluation of internet advertising research: A bibliometric analysis of citations from key sources. *Journal of Advertising*, 37(1), 99–112. <https://doi.org/10.2753/JOA0091-3367370108>
- Krahn, J., & Morgenstern, N. R. (1979). The ultimate frictional resistance of rock discontinuities. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 16(2), 127–133.
- Kulatilake, P. H., & Wu, T. H. (1986). Relation between discontinuity size and trace length. *ARMA US Rock Mechanics/Geomechanics Symposium*, ARMA-86-0130.
- Kwaśniewski, M. (2012). Mechanical behavior of rocks under true triaxial compression conditions—A review. *True Triaxial Testing of Rocks*, 4, 99.
- Lambert, C., & Coll, C. (2014). Discrete modeling of rock joints with a smooth-joint contact model. *Journal of Rock Mechanics and Geotechnical Engineering*, 6(1), 1–12. <https://doi.org/10.1016/j.jrmge.2013.12.003>
- Laubscher. (1990). Geomechanics classification system for the rating of rock mass in mine design. *Journal of the Southern African Institute of Mining and Metallurgy*, 90, 257–273. [https://doi.org/10.1016/0148-9062\(91\)90830-f](https://doi.org/10.1016/0148-9062(91)90830-f)
- Leucci, G., & De Giorgi, L. (2006). Experimental studies on the effects of fracture on the P and S wave velocity propagation in sedimentary rock ('Calcarene del Salento'). *Engineering Geology*, 84(3–4), 130–142. <https://doi.org/10.1016/j.enggeo.2005.12.004>
- Li, B., Li, X., Xiao, W., Cheng, Q., & Bao, T. (2023). Quantitative characterization method of 3D roughness of rock mass structural surface considering size effect. *Smart Construction and Sustainable Cities*, 1(1), 9.
- Li, L. C., Tang, C. A., Zhu, W. C., & Liang, Z. Z. (2009). Numerical analysis of slope stability based on the gravity increase method. *Computers and Geotechnics*, 36(7), 1246–1258. Scopus. <https://doi.org/10.1016/j.compgeo.2009.06.004>
- Li, Y., Chen, J., Zhou, F., Zhou, X., Li, Z., & Wang, Q. (2024). Stochastic kinematic analysis of rock slope failure angle based on multi algorithm optimization, a case study of the proposed bridge project. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 18(2), 375–390.
- Lin, C. T., Amadei, B., Jung, J., & Dwyer, J. (1996). Extensions of Discontinuous Deformation Analysis for jointed rock masses. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics*, 33(7), 671–694. Scopus. [https://doi.org/10.1016/0148-9062\(96\)00016-2](https://doi.org/10.1016/0148-9062(96)00016-2)

-
- Locat, P., Couture, R., Leroueil, S., Locat, J., & Jaboyedoff, M. (2006). Fragmentation energy in rock avalanches. *Canadian Geotechnical Journal*, 43(8), 830–851. <https://doi.org/10.1139/T06-045>
- Lockner, D. (1993). The role of acoustic emission in the study of rock fracture. *International Journal of Rock Mechanics and Mining Sciences And*, 30(7), 883–899. [https://doi.org/10.1016/0148-9062\(93\)90041-B](https://doi.org/10.1016/0148-9062(93)90041-B)
- Lopez Viejo, J. L., Lorenzana Fernandez, M., & Maza Vazquez, F. (2011). *Aplicacion de la topografia y la fotogrametria a la intervencion en el patrimonio*. Editorial Universidad de Alcala. <https://elibro.net/es/lc/uguayaquil/titulos/91825>
- Lozano, A. (1978). *Martillo Schmidt (Esclerómetro)*. línea] Geoengineering Services & Consulting EIRL [Citado el: 25 de junio de ...]
- Macías, A. M., Vera, D. K., Borja, C. P., & Jordá-Bordehore, L. (2021). *Stability assessment of rock slopes combining Slope Mass Rating and Qslope classification systems: A case study in Cerro San Eduardo (Guayaquil, Ecuador)*. 833(1). Scopus. <https://doi.org/10.1088/1755-1315/833/1/012078>
- Manzella, I., & Labiouse, V. (2013). Empirical and analytical analyses of laboratory granular flows to investigate rock avalanche propagation. *Landslides*, 10(1), 23–36. <https://doi.org/10.1007/s10346-011-0313-5>
- Mao, Y., Chen, L., Nanekaran, Y. A., Azarafza, M., & Derakhshani, R. (2023). Fuzzy-Based Intelligent Model for Rapid Rock Slope Stability Analysis Using Qslope. *Water (Switzerland)*, 15(16). Scopus. <https://doi.org/10.3390/w15162949>
- Marinos, P., & Hoek, E. (2018). GSI: A geologically friendly tool for rock mass strength estimation. *ISRM International Symposium 2000, IS 2000*.
- Marshak, S. (2011). *Earth: Portrait of a planet: Fourth international student edition*. WW Norton & Company.
- McCARROLL, D., & NESJE, A. (1993). The vertical extent of ice sheets in Nordfjord, western Norway: Measuring degree of rock surface weathering. *Boreas*, 22(3), 255–265. <https://doi.org/10.1111/j.1502-3885.1993.tb00185.x>
- Menéndez, B., Zhu, W., & Wong, T.-F. (1996). Micromechanics of brittle faulting and cataclastic flow in Berea sandstone. *Journal of Structural Geology*, 18(1), 1–16. [https://doi.org/10.1016/0191-8141\(95\)00076-P](https://doi.org/10.1016/0191-8141(95)00076-P)
- Mitsushita, J., ISHIZAWA, K., ENDO, T., & TAKEUCHI, T. (1998). Study for Color Measurement of Rocks and its Application to Weathering Classification and Physical Property Evaluation. *Journal of the Japan Society of Engineering Geology*, 38(6), 370–385.
- Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. In *Profesional de la Informacion* (Vol. 29, Issue 1). <https://doi.org/10.3145/epi.2020.ene.03>

- Morante, F., Aguilar, M., Ramírez, G., Blanco, R., Carrión, P., Briones, J., & Berrezueta, E. (2019). Evaluation of Slope Stability Considering the Preservation of the General Patrimonial Cemetery of Guayaquil, Ecuador. *Geosciences*, 9(3). <https://doi.org/10.3390/geosciences9030103>
- Morante-Carballo, F., Montalván-Burbano, N., Aguilar-Aguilar, M., & Carrión-Mero, P. (2022). A Bibliometric Analysis of the Scientific Research on Artisanal and Small-Scale Mining. *International Journal of Environmental Research and Public Health*, 19(13). <https://doi.org/10.3390/ijerph19138156>
- Morante-Carballo, F., Montalván-Burbano, N., Carrión-Mero, P., & Espinoza-Santos, N. (2021). Cation exchange of natural zeolites: Worldwide research. *Sustainability (Switzerland)*, 13(14). <https://doi.org/10.3390/su13147751>
- Muñiz, M. M., & González, J. G. (2009). *Clasificaciones geomecánicas en rocas volcánicas*. Universidad Politécnica de Madrid.
- Napier-Munn, T. J., Whiten, W. J., & Faramarzi, F. (2020). Bias in manual sampling of rock particles. *Minerals Engineering*, 153, 106260. <https://doi.org/10.1016/j.mineng.2020.106260>
- Napoli, M. L., Barbero, M., Ravera, E., & Scavia, C. (2018). A stochastic approach to slope stability analysis in bimrocks. *International Journal of Rock Mechanics and Mining Sciences*, 101, 41–49. <https://doi.org/10.1016/j.ijrmms.2017.11.009>
- NLT-252/91. (1991). *Determinación del índice de resistencia a la carga puntual*. http://www.carreteros.org/normativa/otros/nlt/pdfs/negras/1991/252_91.pdf
- Nunez Andres, M. A., Buill Pozuelo, F., & Rodriguez Jordana, J. (2015). *Fotogrametria arquitectonica*. Universitat Politecnica de Catalunya. <https://elibro.net/es/lc/uguayaquil/titulos/61438>
- Obradovic, R., Grubacevic, B., & Stamatovic, A. (1984). Method of Empirical Assessment of Slope Stability in Solid Rock Masses.; [EMPIRIJSKA OCENA STABILNOSTI KOSINA U CVRSTIM STENSKIM MASAMA.]. *Rudarski Glasnik*, 2, 5–10.
- Packulak, T. R., Bonneau, D. A., Dossett, W. C., Rudderham, G. A., & Day, J. J. (2019). Evaluating characterization methods for joint surface roughness. *ARMA US Rock Mechanics/Geomechanics Symposium*, ARMA-2019-1994.
- Palmstrom, A. (1975). Characterization of degree of jointing and rock mass quality. *Intern. Report Ing. AB. Berdel, AS Oslo*.
- Palmström A. (1995). *RMi—A for rock mass characterization system for rock engineering purposes* [Ph.d. thesis].
- Palmström, A. (2001). Measurement and characterizations of rock mass jointing. *In-Situ Characterization of Rocks*, 1–40.
- Palmstrom, A. (2005). Measurements of and correlations between block size and rock quality designation (RQD). *Tunnelling and Underground Space Technology*, 20(4), 362–377. <https://doi.org/10.1016/j.tust.2005.01.005>

-
- Pan, D., Li, Y., Wang, X., & Xu, Z. (2024). Intelligent image-based identification and 3-D reconstruction of rock fractures: Implementation and application. *Tunnelling and Underground Space Technology*, 145, 105582.
- Pantelidis, L. (2009). Rock slope stability assessment through rock mass classification systems. *International Journal of Rock Mechanics and Mining Sciences*, 46(2), 315–325. <https://doi.org/10.1016/j.ijrmms.2008.06.003>
- Park, H., & West, T. R. (2001). Development of a probabilistic approach for rock wedge failure. *Engineering Geology*, 59(3), 233–251. [https://doi.org/10.1016/S0013-7952\(00\)00076-4](https://doi.org/10.1016/S0013-7952(00)00076-4)
- Patnode, H. W. (1941). Relation of organic matter to color of sedimentary rocks. *AAPG Bulletin*, 25(10), 1921–1933.
- Penning-Rowsell, E. C. (1993). *Environmental hazards: Assessing risk and reducing disaster*. JSTOR.
- Perea-Moreno, M.-A., Samerón-Manzano, E., & Perea-Moreno, A.-J. (2019). Biomass as renewable energy: Worldwide research trends. *Sustainability (Switzerland)*, 11(3). Scopus. <https://doi.org/10.3390/su11030863>
- Pérez-Rey, I., Alejano, L. R., Arzúa, J., & Muralha, J. (2016). The role of tilting rate and wear of surfaces on basic friction angle testing. *ISRM EUROCK*, ISRM-EUROCK-2016-033.
- Pettijohn, F. J. (1975). *Sedimentary rocks* (Vol. 3). Harper & Row New York.
- Philpotts, A. R., & Ague, J. J. (2009). *Principles of igneous and metamorphic petrology*. Cambridge University Press.
- Pico-Saltos, R., Carrión-Mero, P., Montalván-Burbano, N., Garzás, J., & Redchuk, A. (2021). Research trends in career success: A bibliometric review. *Sustainability (Switzerland)*, 13(9), 1–24. <https://doi.org/10.3390/su13094625>
- Pine, R. J., Coggan, J. S., Flynn, Z. N., & Elmo, D. (2006). The development of a new numerical modelling approach for Naturally fractured rock masses. *Rock Mechanics and Rock Engineering*, 39(5), 395–419. <https://doi.org/10.1007/s00603-006-0083-x>
- Price, D. G. (1995). Weathering and weathering processes. *Quarterly Journal of Engineering Geology and Hydrogeology*, 28(3), 243–252.
- Priest, S. D. (1993). *Discontinuity analysis for rock engineering*. Springer Science & Business Media.
- Priest, S. D., & Hudson, J. A. (1976). Discontinuity spacings in rock. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 13(5), 135–148. [https://doi.org/10.1016/0148-9062\(76\)90818-4](https://doi.org/10.1016/0148-9062(76)90818-4)
- Priest, S. D., & Hudson, J. A. (1981). Estimation of discontinuity spacing and trace length using scanline surveys. *International Journal of Rock*

- Mechanics and Mining Sciences & Geomechanics Abstracts*, 18(3), 183–197. [https://doi.org/10.1016/0148-9062\(81\)90973-6](https://doi.org/10.1016/0148-9062(81)90973-6)
- Prieto, B., Sanmartín, P., Silva, B., & Martínez-Verdú, F. (2010). Measuring the color of granite rocks: A proposed procedure. *Color Research & Application*, 35(5), 368–375.
- Rajendra, Y. D., Mehrotra, S. C., Kale, K. V., Manza, R. R., Dhumal, R. K., Nagne, A. D., & Vibhute, A. D. (2014). Evaluation of Partially Overlapping 3D Point Cloud's Registration by using ICP variant and CloudCompare. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40, 891–897.
- Ramírez, P., & Alejano, L. (2008). Mecánica de Rocas: Fundamentos e Ingeniería de Taludes. In *Journal of Chemical Information and Modeling*. Gráficas Monterreina S.A.
- RENFE. (2003). *Mantenimiento de infraestructura RENFE, Anejo Geológico, Reconocimiento Geológico*. [https://descargas.adif.es/ade/u18/GCN/NormativaTecnica.nsf/v0/6F95638C29C5FACBC12578B700255C99/\\$FILE/NAP%201202.pdf?OpenElement=](https://descargas.adif.es/ade/u18/GCN/NormativaTecnica.nsf/v0/6F95638C29C5FACBC12578B700255C99/$FILE/NAP%201202.pdf?OpenElement=)
- Riquelme, A. (2015). *Discontinuity Set Extractor (DSE)* [Computer software]. <https://personal.ua.es/es/ariquelme/dse-discontinuity-set-extractor.html>
- Riquelme, A. (2015). *Uso de nubes de puntos 3D para identificación y caracterización de familias de discontinuidades planas en afloramientos rocosos y evaluación de la calidad geomecánica* [Tesis Doctoral, Universidad de Alicante]. <http://rua.ua.es/dspace/handle/10045/51107>
- Riquelme, A., Tomás, R., Cano, M., & Abellán, A. (2016). Using open-source software for extracting geomechanical parameters of a rock mass from 3D point clouds: Discontinuity Set Extractor and SMRTTool. *ISRM EUROCK*, ISRM-EUROCK-2016-176.
- Riquelme, A., Tomás, R., Cano, M., Pastor, J. L., & Jordá-Bordetore, L. (2021). *Extraction of discontinuity sets of rocky slopes using iPhone-12 derived 3DPC and comparison to TLS and SfM datasets*. 833(1). Scopus. <https://doi.org/10.1088/1755-1315/833/1/012056>
- Ritter, W. (1879). *Die statik der tunnelgewölbe*. J. Springer.
- Rocscience. (2019). *2D and 3D Geotechnical Software / Rocscience Inc*. <https://www.rocscience.com/>
- Romana, M. (1985). New Adjustment Ratings for Application of Bieniawski Classification to Slopes. In ISRM (Ed.), *Proceedings of the International Symposium on the Role of Rock Mechanics in Excavations for Mining and Civil Works* (pp. 49-53.).
- Romana, M. (1988). Practice of SMR classification for slope appraisal. *Landslides. Proc. 5th Symposium, Lausanne, 1988. Vol. 2*. [https://doi.org/10.1016/0148-9062\(90\)90152-r](https://doi.org/10.1016/0148-9062(90)90152-r)
- Romana, M. (1991). SMR classification. *7th ISRM Congress*, 955–960.

-
- Romana, M. R. (1993). A geomechanical classification for slopes: Slope mass rating. In *Comprehensive rock engineering*. Vol. 3. <https://doi.org/10.1016/b978-0-08-042066-0.50029-x>
- Romana, M., Serón, J. B., & Montalar, E. (2003). SMR geomechanics classification: Application, experience and validation. *ISRM Congress*, ISRM-10CONGRESS-2003-167.
- Romana, M., Tomás, R., & Serón, J. B. (2015). Slope Mass Rating (SMR) geomechanics classification: Thirty years review. *13th ISRM International Congress of Rock Mechanics, 2015-MAY*, 1–10.
- Romana Ruiz, M., Serón Gáñez, J. B., & Montalar Yago, E. (2001). La clasificación geomecánica SMR: aplicación, experiencias y validación. V *Simposio Nacional Sobre Taludes y Laderas Inestables: Madrid, Spain*.
- Rostami, M., Kahraman, S., Dibavar, B., & Fener, M. (2024). Performance prediction of roadheaders used in coal mines from the needle penetration index and the schmidt hammer value. *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, 10(1). Scopus. <https://doi.org/10.1007/s40948-023-00725-x>
- Ruiz, J., & Li, C. (2014). Measurement of the basic friction angle of rock by three different tilt test methods. *ISRM EUROCK*, ISRM-EUROCK-2014-039.
- Safira, R. A. D., Nurwatik, N., & Hariyanto, T. (2023). Identifying Potential Areas for Oil and Gas Well Location Planning Using Support Vector Machine Algorithm. *IOP Conference Series: Earth and Environmental Science*, 1276(1), 012068.
- Sanmartín, P., Ferrer, P., Cárdenes, V., Martínez-Verdú, F. M., Silva, B., & Prieto, B. (2010). El color de las rocas ornamentales: Comparación de las metodologías de determinación en granitos y pizarras. *IX Congreso Nacional Del Color, Alicante*, 433–436.
- Schön, J. H. (2015). Chapter 7—Geomechanical Properties. In J. H. Schön (Ed.), *Developments in Petroleum Science* (Vol. 65, pp. 269–300). Elsevier. <https://doi.org/10.1016/B978-0-08-100404-3.00007-X>
- Schonberger, J. L., & Frahm, J.-M. (2016). Structure-from-motion revisited. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 4104–4113.
- Schunnesson, H. (1996). RQD predictions based on drill performance parameters. *Tunnelling and Underground Space Technology*, 11(3), 345–351. [https://doi.org/10.1016/0886-7798\(96\)00024-7](https://doi.org/10.1016/0886-7798(96)00024-7)
- Shabarov, A. N., & Tsirel, S. V. (2018). *Geodynamic safety of subsurface management*. 1, 105–120. Scopus. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85061378741&partnerID=40&md5=7b21b0bdc9c33b4d1b211565edb429f2>
- SHAKESBY, R. A., DAWSON, A. G., & MATTHEWS, J. A. (1987). Rock glaciers, protalus ramparts and related phenomena, Rondane, Norway: A

- continuum of large-scale talus-derived landforms. *Boreas*, 16(3), 305–317. <https://doi.org/10.1111/j.1502-3885.1987.tb00099.x>
- Shang, J., West, L. J., Hencher, S. R., & Zhao, Z. (2018). Geological discontinuity persistence: Implications and quantification. *Engineering Geology*, 241, 41–54. <https://doi.org/10.1016/j.enggeo.2018.05.010>
- Sheng, D., Yu, J., Tan, F., Tong, D., Yan, T., & Lv, J. (2023). Rock mass quality classification based on deep learning: A feasibility study for stacked autoencoders. *Journal of Rock Mechanics and Geotechnical Engineering*, 15(7), 1749–1758.
- Siddique, T. (2024). Rock mass classification in slope engineering with special emphasis on Slope mass rating: Current status and future projections. *Geological Journal*. Scopus. <https://doi.org/10.1002/gj.4933>
- Sivakugan, N., Das, B. M., Lovisa, J., & Patra, C. R. (2014). Determination of c and ϕ of rocks from indirect tensile strength and uniaxial compression tests. *International Journal of Geotechnical Engineering*, 8(1), 59–65.
- Sjøgren, B., Øfsthus, A., & Sandberg, J. (1979). SEISMIC Classification of rock mass qualities. *Geophysical Prospecting*, 27(2), 409–442. <https://doi.org/10.1111/j.1365-2478.1979.tb00977.x>
- Sönmez, H., & Ulusay, R. (2002). A discussion on the Hoek-Brown failure criterion and suggested modifications to the criterion verified by slope stability case studies; [Hoek-Brown yenilme ölçütü üzerine bir tartışma ve şev duraylılığı vakaları ile sinanmış ölçüte ilişkin değişiklik öner. *Yerbilimleri*, 26, 77–99.
- Steckley, R. C., Larson, W. C., & D'Andrea, D. V. (1975). Blasting tests in a porphyry copper deposit in preparation for in situ extraction. *US Bur Mines Rep Invest*, 8070.
- Stow, D. A. (2005). *Sedimentary Rocks in the Field: A color guide*. Gulf Professional Publishing.
- Sturzenegger, M., & Stead, D. (2009). Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. *Engineering Geology*, 106(3–4), 163–182. Scopus. <https://doi.org/10.1016/j.enggeo.2009.03.004>
- Synowiec, G. (1999). Rock mass strength assessment for geomorphological purposes and its application to sandstone slopes in the stolowe mountains; [Ocena wytrzymałości mas skalnych dla celów geomorfologicznych i jej zastosowanie dla stoków piaskowcowych gór stołowych]. *Czasopismo Geograficzne*, 70(3–4), XI–361.
- Tarbut, E.J. y Lutgens, F. K. (2005). Ciencias de la Tierra: Una introducción a la Geología física. In *Pearson Prentice Hall* (Vol. 8).
- Terzaghi, R. (1965). *Sources of Error in Joint Surveys* (U. Harvard, Ed.; 76th ed.). Series, Harvard soil mechanics.

-
- Tomás et al. (2017). Review of the Current Status of the Geomechanic Classification Slope Mass Rating (SMR). *Boletín de La Sociedad Española de Mecánica de Suelos e Ingeniería Geotécnica*, 190, 25–32.
- Tomás, R., Cuenca, A., Cano, M., & García-Barba, J. (2012). A graphical approach for slope mass rating (SMR). *Engineering Geology*, 124, 67–76. <https://doi.org/10.1016/j.enggeo.2011.10.004>
- Tomás, R., Valdes-Abellan, J., Tenza-Abril, A. J., & Cano, M. (2012). New insight into the slope mass rating geomechanical classification through four-dimensional visualization. *International Journal of Rock Mechanics and Mining Sciences*, 53, 64–69. <https://doi.org/10.1016/J.IJRMMS.2012.04.002>
- Torrijo Echarri, F. J., Garzon Roca, J., & Cobos Campos, G. (2020). *Geotechnical Engineering: Techniques and Methods*. Editorial de la Universidad Politecnica de Valencia. <https://elibro.net/es/lc/uguayaquil/titulos/160378>
- Tung, W. Y., Nagendran, S. K., & Ismail, M. A. M. (2018). 3D rock slope data acquisition by photogrammetry approach and extraction of geological planes using FACET plugin in CloudCompare. *IOP Conference Series: Earth and Environmental Science*, 169(1), 012051.
- Ulmer-Scholle, D. S., Scholle, P. A., Schieber, J., & Raine, R. J. (2014). *A color guide to the petrography of sandstones, siltstones, shales and associated rocks* (Vol. 109). American Association of Petroleum Geologists Tulsa, OK, USA.
- UNE. (1990). *Ensayos para la determinación de la resistencia, parte 1: Resistencia a la compresión uniaxial*.
- UNE 22950-5. (1996). *Ensayos para la determinación de la resistencia. Parte 5: Resistencia a carga puntual*. <https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0002375>
- Valido, J. A., Cáceres, J. M., & Sousa, L. (2024). Mechanical properties of ignimbrites of Tenerife Island employed as building stone and their correlation with some physical properties. *Journal of Building Engineering*, 82. Scopus. <https://doi.org/10.1016/j.jobbe.2023.108222>
- van Eck, N. J., & Waltman, L. (2007). VOS: A New Method for Visualizing Similarities Between Objects. In R. Decker & H.-J. Lenz (Eds.), *Advances in Data Analysis* (pp. 299–306). Springer Berlin Heidelberg.
- Van Eck, N. J., & Waltman, L. (2009). VOSviewer: A computer program for bibliometric mapping. *12th International Conference on Scientometrics and Informetrics, ISSI 2009*, 886–897.
- van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, 111(2), 1053–1070. <https://doi.org/10.1007/s11192-017-2300-7>

- Varnes, DJ; Cruden, DM. (2024, March 7). *Landslide Types and Processes*. <https://onlinepubs.trb.org/Onlinepubs/sr/sr29/29-003.pdf>
- Velastegui-Montoya, A., Montalván-Burbano, N., Peña-Villacreses, G., de Lima, A., & Herrera-Franco, G. (2022). Land Use and Land Cover in Tropical Forest: Global Research. *Forests*, 13(10). Scopus. <https://doi.org/10.3390/f13101709>
- Villamor Lora, R., Ghazanfari, E., & Asanza Izquierdo, E. (2016). Geomechanical Characterization of Marcellus Shale. *Rock Mechanics and Rock Engineering*, 49(9), 3403–3424. Scopus. <https://doi.org/10.1007/s00603-016-0955-7>
- Vyazmensky, A., Stead, D., Elmo, D., & Moss, A. (2010). Numerical analysis of block caving-induced instability in large open pit slopes: A finite element/discrete element approach. *Rock Mechanics and Rock Engineering*, 43(1), 21–39. Scopus. <https://doi.org/10.1007/s00603-009-0035-3>
- Wang, C., Yong, R., Luo, Z., Du, S., Karakus, M., & Huang, C. (2023). A novel method for determining the three-dimensional roughness of rock joints based on profile slices. *Rock Mechanics and Rock Engineering*, 56(6), 4303–4327.
- Wang, M., Wu, Y., Song, B., & Xu, W. (2024). Point Load Strength Test Power Index of Irregular Sandy Dolomite Blocks. *Rock Mechanics and Rock Engineering*, 1–12.
- Wang, Y., Feng, X., Du, J., Liu, Y., Li, D., & Chai, B. (2023). Geomechanical evolution model of bedding rock landslides in construction areas: A case study of the Maidiping landslide in Tiefeng Town, Wanzhou. *Bulletin of Geological Science and Technology*, 42(5), 43–51. Scopus. <https://doi.org/10.19509/j.cnki.dzqk.tb20210774>
- Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, 179, 300–314.
- Wittke, W. (1990). *Rock mechanics*. Springer-Verlag Berlin.
- Yáñez Borja, D. B., & Jordá Bordehore, L. (2021). *Aplicación de la metodología de análisis empírico Q Slope para evaluación de taludes en la provincia Bolívar, caso de estudio vía Guaranda-Echeandía*. ESPOL. FICT.
- Yokoyama, T., & Nakashima, S. (2005). Color development of iron oxides during rhyolite weathering over 52,000 years. *Chemical Geology*, 219(1–4), 309–320.
- Yong, R., Qin, J.-B., Huang, M., Du, S.-G., Liu, J., & Hu, G.-J. (2019). An Innovative Sampling Method for Determining the Scale Effect of Rock Joints. *Rock Mechanics and Rock Engineering*, 52(3), 935–946. <https://doi.org/10.1007/s00603-018-1675-y>

-
- Z. T. Bieniawski. (1973). Engineering Classification of Jointed Rock Masses. *Transaction of the South African Institution of Civil Engineers*, 15, 335–344.
- Zhang, C., GUO, Y., XU, J., LIU, N., XIE, Q., CUI, G., & ZHOU, H. (2023). A new method for evaluating rock joint roughness based on power spectral density. *Rock and Soil Mechanics*, 43(11), 6.
- Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization. *Organizational Research Methods*, 18(3), 429–472. <https://doi.org/10.1177/1094428114562629>

Anexos

1. Otros resultados de la investigación

Determination of frictional resistance pair Jr/Ja using a friendly – graphical approach in the Q-slope empirical method.

C P Borja-Bernal^{1, 3} y L Jordá-Bordehore²

¹ ETSI Minas y Energía. Universidad Politécnica de Madrid. Calle de Ríos Rosas, 21, 28003 Madrid, Spain

² Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid. Campus Ciudad Universitaria, Calle del Prof. Aranguren, 3, 28040 Madrid, Spain

³ Universidad de Guayaquil, Facultad de Ciencias Naturales, Av. Raúl Gómez Lince s/n y Av. Juan Tanca Marengo, Guayaquil, Ecuador

cesar.borjab@ug.edu.ec , l.jorda@upm.es

Abstract. The Q-slope index is a new geomechanical classification for slope [1] that has become popular and is spreading throughout the world. It is currently being applied in various lithologies, in different countries, mining and civil projects. The Q-slope allows engineers to adjust and optimize slope based on field observations of some geomechanical and geometric parameters that are easy to obtain. The selection of the value of each of the different parameters is made based on tables [2] some of whose parameters are the same as in the tunnel Q index, e.g. roughness (Jr), alteration (Ja), RQD etc. However, if the rock engineering has to analyse many slope with different properties, it is not so intuitive to work with very detailed tables and descriptions. We have therefore based ourselves on the concept of the graphic Geological Strength Index [3] that uses short descriptions and designs. In this investigation we have selected the two parameters that form the pair of frictional resistance Jr / Ja (joint roughness number and joint alteration number. This Jr / Ja coefficient is very important since it is the multiplied by a correction factor for favorable or unfavorable orientation called O-factor. This O-factor is one of the novelties of the Q-slope compared to the “classic” Q of tunnels. Throughout the investigation we have simplified the descriptions of Jr and Ja (referring the reader to the previous works to know these parameters in grater detail) and created some graphic images that are easy and friendly to implement on site with a multiple choice table.

1. Introduction

Geomechanical rock mass classifications are widely accepted in the scientific and technical world for their simplicity and adaptability in different studies worldwide. Rock Mass Rating (RMR) and Q-index have been successfully applied worldwide in both civil and mining underground works [4, 5]. Since its appearance, Bieniawski's RMR has been the fundamental basis of multiple adaptations that try to improve the method to make it applicable to specific areas of study and diverse technical situations.

The main and “popular” adaptations of the RMR for slopes are Laubscher's Mining Rock Mass Rating -MRMR (1990) and Romana's Slope Mass Rating -SMR (1985) [6]. The most recent empirical method for stability analysis of road slopes, train lines and open pit mining is known as Q-slope. The main



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd

1

Teaching rock mechanics using Virtual Reality: laboratory practices and field trips during the confinement of the Coronavirus COVID-19 in Ecuador, Bolivia, and Spain

M T García-Vela¹, C P Borja-Bernal^{2,3}, L Jordá-Bordehore⁴, R Medinaceli-Torrez⁵, S Loaiza¹, D A Falquez¹

¹Facultad de Ingeniería en Ciencias de la Tierra FICT Escuela Superior Politécnica del Litoral ESPOL Vía Perimetral 5, Guayaquil, Ecuador

²Universidad de Guayaquil Avenida 10 NO, Guayaquil 090613, Ecuador

³ETSI Minas y Energía. Universidad Politécnica de Madrid. Calle de Ríos Rosas, 21, 28003 Madrid, Spain

⁴Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid. Campus Ciudad Universitaria, Calle del Prof. Aranguren, 3, 28040 Madrid, Spain

⁵Universidad Técnica de Oruro, 6 de Octubre y, Oruro, Bolivia

mistagar@espol.edu.ec

Abstract. Virtual Reality (VR) consists of creating spaces similar to reality where the viewer interacts more or less in a digital world. This digital world can be programmed so that geosciences student takes data as if it were a field trip. The VR can save money, logistical problems and avoid accessing unsafe places. Besides, students can access places that would otherwise require a veritable expedition (hydroelectric projects in the Andes, remote highways, dams, tunnels in the Himalayas, among others.). At the beginning of the project in 2019, we designed some virtual rock mechanics classes to complement the face-to-face classes: In recent years, we have seen it increasingly difficult to organize field trips. We have designed virtual scenarios where students can obtain geomechanical data from tunnels, mines and rock slopes. We have used the CoSpaces commercial platform for this purpose. Within this virtual world, we place photographs, pop-up menus, videos of field and laboratory tests and clues for the student to search the data for himself in a quasi-real scenario. With all this data from the virtual scenario (as if they were in the field trip), students interpret in the cabinet and perform complex calculations (Hoek Brown, Barton-Bandis criteria, RMR, Q index, among others). We have generated two types of virtual classes: laboratory practices and field trips. Since mid-March of this year 2020, there is no face-to-face teaching in many world faculties where rock mechanics, rock slope engineering, tunnels, and underground mining subjects need to be taught. Thanks to these Virtual Reality laboratories, we have been able to carry out our teaching successfully. Combining two means: VR and software, have allowed making classes very practical and realistic, and the students have highly valued this initiative. Besides, rock mechanics plays a very important role in the safety of underground works and excavations. The best way to learn methodologies in risky environments is undoubtedly using simulators. In the same way that pilots and astronauts practice stress situations in simulators, we consider it useful to use Virtual



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

Stability assessment of rock slopes combining Slope Mass Rating and Qslope classification systems: A case study in Cerro San Eduardo (Guayaquil, Ecuador)

A M Macías¹, D K Vera¹, C P Borja^{2,3}, L Jordá-Bordevore⁴

¹Facultad de Ingeniería en Ciencias de la Tierra FICT Escuela Superior Politécnica del Litoral ESPOL Vía Perimetral 5, Guayaquil, Ecuador

²Universidad de Guayaquil Avenida 10 NO, Guayaquil 090613, Ecuador

³ETSI Minas y Energía. Universidad Politécnica de Madrid. Calle de Ríos Rosas, 21, 28003 Madrid, Spain

⁴Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid. Campus Ciudad Universitaria, Calle del Prof. Aranguren, 3, 28040 Madrid, Spain

l.jorda@upm.es

Abstract. In the present study, the stability of the slope located in the Modesto Apolo Ramírez Avenue, is analyzed. The avenue is located prior to the access to the Cerro San Eduardo tunnel, which has had habitual problems of falling blocks to the roadway. For the study, empirical methodology was applied, including the data mapping based on geomechanical classifications such as Rock Mass Rating (RMR), Slope Mass Rating (SMR) and Q-Slope index, which assign a defined score, obtaining the quality of the rocky mass, and with this, the degree of stability of the slope. In addition, through the application of RocFall software, the empirical methodology has been compared with the analysis of rockfall trajectory, making a retrospective study of behavior and simulating the constant falling of blocks on the roadway.

As a consequence of the exploration, it was evident that the geomechanical classifications -in this particular case- are not completely effective to determine the degree of stability of the massif. This is due to the fact that, even though the slopes are globally stable, these classifications do not seem to adequately determine a level of risk against rockfalls, as can be seen from visu. Therefore, it can be seen that the slope does not have a risk of collapse, but instead presents a high danger of landslides that could cause considerable economic and human lives losses. The study recommends geometric solutions for impact mitigation to prevent future damage.

Keywords- RMR, SMR, Q-Slope, stability, massif, impact.

1. Introduction

Given the population growth of the city of Guayaquil, there is a need for roads that communicate certain populated areas, which is the case of the Modesto Apolo Ramírez Avenue. The avenue has a slope located on the right side, prior the entrance of the tunnel San Eduardo in the north-south direction, where the hill of the same name is located. This hill has an exposed slope of considerable height, with a limestone - diastolic lithology and presence of fragments of clay and silty rocks, which leads to constant slides of exposed blocks. This generates a situation of risk for the users of the road and urges the present stability analysis.



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

Application of the SfM technique for geomechanical analysis according to SMR and Qslope

C. P. Borja-Bernal

ETSI Minas y Energía. Universidad Politécnica de Madrid. Calle de Ríos Rosas, 21, 28003 Madrid, Spain

Universidad de Guayaquil, Facultad de Ciencias Naturales, Av. Raúl Gómez Lince s/n y Av. Juan Tanca Marengo, Guayaquil, Ecuador.

L. Jordá-Bordehore

Departamento de Ingeniería del Terreno. Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid. Campus Ciudad Universitaria, Calle del Prof. Aranguren, 3, 28040 Madrid, Spain

ABSTRACT:

The stability of a rock mass is influenced by the multiple interactions between the rock matrix, planes of weakness, the surrounding environment and the human processes that shaped the actual slope. The objective of this paper is to apply the Structure from Motion (SfM) photogrammetric survey technique to obtain reliable data that can be used to determine the relative stability of a slope. Data extracted from the 3D model were processed with kinematic analysis and subsequently applied to the SMR and Qslope geomechanics classification systems. The case study is in an almost stable state according to SMR and unstable for Qslope, clarifying that in the latter classification system the value is located very close to the zone called "uncertain slope stability", results that coincide with the physical evidence of instability found at the time of the field survey. It can be concluded that the SfM technique is applicable for the calculation of slope stability through empirical methods in tropical environments of the Andean countries.

Keywords: Smartphone, 3D model, Structure from motion, Qslope, Slope Mass Rating.

1 INTRODUCTION

When we talk about Rock Mechanics, the mind of the researcher is transported to an idealized world in which the problem to be addressed is simplified to two fundamental actors, rock matrix and discontinuities, which when combined allow the movement of rock masses of different sizes (Ramírez & Alejano, 2008). These rock masses are influenced by environmental and anthropic processes that facilitate or not the displacement of rock bodies in search of a position of equilibrium of forces and moments. Geomechanics classifications for tunnels and subway mining have been around since 1946 when Terzagui presented his version called Rock Load. It was not until 1973 when Bieniawski modified his RMR and applied it to slopes (Hernán & Andrade, 2007), this milestone gave way for Romana to propose his method known as SMR Slope Mass Rating in 1985 (Romana, 1985) and in 2015 Barton presented the most recent method of geomechanics classifications for slopes known as Qslope (Barton & Bar, 2015). The technician or researcher when performing a geomechanical survey, i.e. structural survey of existing weakness planes in logically unstable conditions for data collection and sampling, is subject to constant danger due to the hazardous working environment surrounding the slope as well as the scale of the work and the limited access to the unstable cut faces (Adrián Riquelme et al., 2020).

111. Volcanes virtuales: Aula invertida de geotecnia de materiales volcánicos a través de entornos virtuales y TICs

Jordá Bordehore, Luis¹; Caracuel Mateos, Marta¹; Pastor, José Luis³; Hernández Gutiérrez, Luis E⁴; Galindo Aires, Ruben Angel¹; González Galindo, Jesús¹; García Luna, Ramiro¹; González Tejada, Ignacio¹; Page Antequera, Jesús¹; Tomas Jover, Roberto²; Cano González, Miguel²; Riquelme Guill, Adrian²; Mulas, Mauricio⁴; García Vela, Mishel Tatiana⁴; Borja Bernal, Cesar Patricio⁵; Jordá Bordehore, Rafael⁶

¹ Universidad Politécnica de Madrid,

² Departamento de Ingeniería Civil. Universidad de Alicante

³ Instituto Volcanológico de Canarias (INVOLCAN)

⁴ Escuela Superior Politécnica del Litoral, ESPOL, Facultad de Ingeniería en Ciencias de la Tierra. Ecuador

⁵ Universidad de Guayaquil. Ecuador

⁶ Ilustre Colegio Oficial de Geólogos, España

RESUMEN

El proyecto de innovación educativa que se presenta abarca dos objetivos: explicar aspectos fundamentales de la ingeniería de rocas y suelos volcánicos al público no especializado, así como colegios y bachiller, y elaborar contenidos técnicos a modo de excursiones y laboratorios virtuales para aula invertida de ingeniería – geología a nivel universitario. Para la implementación de estos escenarios virtuales se han escogido aplicaciones ya existentes que el equipo de trabajo ya ha aplicado profusamente y con éxito durante los confinamientos de la pandemia de COVID-19 y las clases remotas. La idea es generar unos contenidos de calidad y accesibles (i.e. gratuitos) en diferentes plataformas a las que el alumno acude para obtener información de diferentes grados de complejidad. Para los estudiantes de primaria, secundaria y público en general se ha optado por repositorios digitales de rocas, estructuras volcánicas y obras de ingeniería (e.g. carreteras, taludes y túneles). En estos repositorios se suben imágenes tridimensionales (elaboradas con fotogrametría SfM) con algún tipo de explicación sobre usos y propiedades de rocas volcánicas y temas de interés sobre las obras; se complementa con ensayos y experimentos de laboratorio “amigables”. En cuanto a los contenidos adaptados al nivel universitario de grado y máster durante el confinamiento se

To go or not to go when the lava flow is coming: understanding of evacuation decision of Goma inhabitants during the 2021 Nyiragongo eruption crisis

Blaise Mafuko Nyandwi^{1,2,3}, Matthieu Kervyn², Muhashy Habiwaremye¹, François Kervyn³, Caroline Michellier³

¹Université De Goma, Goma, Democratic Republic of Congo, ²Geography department, Vrije Universiteit Brussel, Brussels, Belgium, ³Earth Sciences department, Royal Museum of Central Africa, Tervuren, Belgium

The challenging crisis management during the Nyiragongo 22nd May 2021 eruption (D. R. Congo)

Adalbert Muhindo Syavulisemba¹, Julien Barrière³, Nicolas d'Oreye^{3,4}, Caroline Michellier², Adrien Oth³, Benoît Smets^{2,5}, Delphine Smittarello³, François Kervyn²

¹Goma Volcano Observatory, Goma, Democratic Republic of Congo, ²Royal Museum For Central Africa, Tervuren, Belgium, ³European Center for Geodynamics and Seismology, Walferdange, Grand Duchy of Luxembourg, ⁴National Museum of Natural History, Luxembourg, Grand Duchy of Luxembourg, ⁵Vrije Universiteit Brussel, Brussels, Belgium

Virtual volcanoes: Flipped classroom on geotechnics of volcanic materials through Virtual and Augmented Reality

Luis Jorda-Bordehore¹, Rubén Ángel Galindo Aires¹, Salvador Senent Domínguez¹, Jesús González Galindo¹, Ramiro García Luna¹, Ignacio González Tejada¹, Jesús Page Antequera¹, Roberto Tomás Jover², Miguel Cano², José Luis Pastor², Adrián Riquelme Guill², Maurizio Mulas³, Mishel Tatiana García Vela³, César Patricio Borja Bernal⁴, Luis E. Hernández Gutiérrez⁵, Rafael Jordá Bordehore⁶

¹Universidad Politécnica De Madrid, Madrid, Spain, ²Universidad de Alicante, Alicante, Spain, ³Escuela Superior Politécnica del Litoral, Guayaquil, Ecuador, ⁴Universidad de Guayaquil, Guayaquil, Ecuador, ⁵Gobierno de Canarias, Spain, ⁶Ilustre Colegio Oficial de Geólogos, Spain

Lessons learned from the 2021 Cumbre Vieja eruption: effective international scientific cooperation during a volcanic crisis

Luca D'Auria^{1,2}, Nemesio M. Pérez^{1,2}, Pedro A. Hernández^{1,2}, Matthew J. Pankhurst^{1,2}, Cumbre Vieja Eruption International Collaborative Research Team INVOLCAN's¹

¹Instituto Volcanológico de Canarias (INVOLCAN), San Cristóbal de La Laguna, Spain, ²Instituto Tecnológico y de Energías Renovables (ITER), Granadilla de Abona, Spain

Management of the crisis response to the 2020 – 2021 eruption of La Soufrière volcano, St. Vincent

Erouscilla Joseph¹, Michelle Forbes², Stacey Edwards¹, Elizabeth Riley³

¹Seismic Research Centre, The University of the West Indies, St. Augustine, Trinidad and Tobago, ²The National Emergency Management Organisation, Kingstown, St. Vincent and the Grenadines, ³Caribbean Disaster Emergency Management Agency, Lower Estate St. Michael, Barbados

Managing the 2021 concomitant crises of Etna and Vulcano volcanoes (Italy)

Stefano Branca¹, Francesca Bianco², Mauro Coltelli¹, Francesco Italiano³, Augusto Neri⁴, Carlo Doglioni⁴

¹Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy, ²Istituto Nazionale di Geofisica e Vulcanologia, Napoli, Italy, ³Istituto Nazionale di Geofisica e Vulcanologia, Palermo, Italy, ⁴Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy