International Society for Rock Mechanics and Rock Engineering
Macedonian Association for Geotechnics

ISRM Regional Symposium
Eurock 2026
Risk Management in Rock Engineering
Skopje, 15-19 September

DOI: https://doi.org/10.68732/206c4664a2602890

ISBN: 978-9989-2053-7-8

Stability assessment of quarry slopes through laboratory tests and numerical modelling

L. Turbessi, C. Caselle, G. Umili, A.M. Ferrero
University of Turin, Turin, Italy
laura.turbessi@unito.it

C. Gagliardi
Geologist for Domograniti S.R.L., Trontano (VB), Italy

Abstract

This paper presents a study carried out in a Serizzo di Antigorio quarry in the Upper Formazza Valley (Premia-VB, northwestern Italy), where the sliding of a rock wedge in September 2023 caused injury to a worker. This fact highlighted the need for an in-depth assessment of the quarry stability. The objective of the study was to analyse the stability conditions of both active and inactive quarry faces through the integration of field surveys, laboratory tests, and numerical modelling.

In particular, laboratory tests performed on representative rock samples included triaxial compression, uniaxial compression and indirect tensile strength tests. At the same time, field and remote surveys provided geometric and structural constraints for the digital reconstruction of the rock mass structure. Stability analyses were initially performed using Limit Equilibrium Method (LEM) codes to estimate safety factors and perform sensitivity analyses. 3D Distinct Element Method (DEM) simulations were subsequently run to investigate stress distribution within complex rock mass geometries. The numerical approach allowed for the identification of areas characterized by high stress concentrations and supported the design of a controlled blasting plan aimed at the safe removal of unstable rock volumes.

The case study highlights the role of numerical models as fundamental tools to support traditional stability assessments, whose reliability is grounded in the geomechanical parameters determined through laboratory testing. These models provide detailed insights into the stress–strain behaviour and potential failure mechanisms, which are difficult to identify using conventional methods alone.

The results demonstrate the effectiveness of an integrated approach, combining surveys, experimental testing, and numerical simulations, in managing risk in Alpine quarrying contexts.

Keywords

Stability, Antigorio gneiss, Experimental testing, Numerical models.

1 Introduction

Mining activity aims to provide raw materials for all economic sectors, from industry to agriculture (Wagner2019). Since resource exploitation is tied to the deposits in which they are concentrated, the relationship between rock mechanics and the mining sector is essential (Taboni 2025).Quarry slopes can be subjected to instability phenomena, which can lead to human life and equipment losses, they mainly depend on slope geometry, degree of weathering, lithotypes, discontinuity properties, stress field and seismic loading (Hoek and Bray 1981).To optimize the extraction process, a detailed and accurate characterization of the rock mass is required (Vagnon et al. 2020). Rock mass properties and related design parameters can be obtained through direct measurements, laboratory testing, or estimated using empirical approaches (Barton 1974).This aspect becomes even more crucial considering the widespread use of numerical simulations for the assessment of mining practices (Li et al. 2015). Such simulations require precise and reliable input data to ensure consistent modelling results and accurate predictions, while the inherent variability of geological materials makes it essential for the adopted datasets to be statistically representative and reliable (Umili et al. 2023).

The paper describes a stability analysis study carried out on a dimension stone quarry located in the Central-Western Italian Alps, which in the recent past was affected by an uncontrolled sliding of a rock wedge. The study was developed through laboratory tests aimed at characterizing the physical and mechanical properties of the rock, followed by the implementation of numerical models for the analysis and identification of possible mechanisms induced by the stress state of the rock mass.

2 Case study

The case study is an active dimension stone quarry located in the municipality of Premia (province of Verbano-Cusio-Ossola, Italy). The quarry area is located on the left orographic slope of the Antigorio–Formazza valley on a pronounced morphological step of glacial origin, approximately between 940 and 970 m a.s.l. In the quarry area, the rock mass is characterized by two gneissic lithotypes (known as Antigorio gneiss), attributable to Alpine metamorphism. On the 27thSeptember 2023 the site was affected by an uncontrolled sliding of a rock wedge which resulted in injuries to a worker and damage to equipment. Following this event, a back analysis of the failure and stability assessments for all the quarry faces of the site were requested.

The study focused on different areas (Fig. 1Fig. 1), in this paper a focus was made on the upper east face, namely the highest portion of the quarry and the area where the rock wedge failure occurred (Area A) and the main east face (Area B).



Fig. 1 Representation of the sectors identified as potentially hazardous.

3 Laboratory tests

Since the investigated gneiss presents a pervasive foliation, the specimens were prepared to consider the possible influence of the anisotropy on the mechanical behaviour. Three types of laboratory tests were performed, briefly described hereafter: uniaxial compression tests, triaxial compression tests and indirect tensile tests. Overall results are reported in Table 1.

3.1 Uniaxial compression tests

The uniaxial compression tests were carried out using a Matest press equipped with a high-stability frame (capacity of 3000 kN) and a servo-controlled system, located at the Department of Earth Sciences, University of Turin. The tests were performed on 9 cylindrical specimens with diameter of approximately 54 mm and height of about 135 mm. The height-to-diameter ratio of the specimens is approximately 2.5, in accordance with ISRM (1979), ASTM D3148-02, and UNI EN 1926–2007 recommendations. Of the 9 tested specimens, 3 had foliation oriented vertically, 3 horizontally and 3 at 60° (respectively parallel, perpendicular and at 30° with respect to the applied load). The specimens had an average bulk density of 2660 kg/m³.The uniaxial compression tests were performed under load control at a loading rate of 1.15 kN/s with simultaneous measurement of axial displacement by means of a LVDT.

3.2 Triaxial compression tests

The triaxial compression tests were conducted by an external laboratory. The tests were performed on 9 specimens with foliation oriented horizontally, vertically, and at 60°. The specimens, approximately 54.40 mm in diameter and 100 mm in height were tested in accordance with ISRM (1970), ASTM D7012 and ASTM D2664-95.The results allowed for the reconstruction of Mohr-Coulomb failure envelopes for each orientation of the foliation and, in turn, for the calculation of the cohesion and of the friction angle.

3.3 Indirect tensile tests

Indirect tensile strength tests (Brazilian tests) were also carried out at the Department of Earth Sciences, University of Turin, on 20 cylindrical specimens (10 with horizontal foliation and 10 with vertical foliation – parallel to the applied load) with diameter of approximately 50 mm and height of approximately 25 mm. The tests were performed using a Matest press equipped with a high-stability frame (capacity of 3000 kN), a 300 kN load cell and a servo-controlled system, and the device for Brazilian tests. The tests were conducted in accordance with the procedures suggested by ISRM (1978). The load was applied at a rate of 1.15 kN/s.

Table 1. Summary table of the physic-mechanical properties assigned to the rock matrix based on the results obtained from laboratory tests. c: cohesion, ϕ: friction angle, E: tangent elastic modulus,ρ : bulk density.

Dip of foliation	**c**	**ϕ**	**E**	**ρ**	**uniaxial compression strength**	**indirect tensile strength**
(°)	(MPa)	(°)	(GPa)	(kg/m^3)	(MPa)	(MPa)
0	19.65	53	23.28	2660	117.36	8.26
60	17.2	49	19.05	2660	93.47	/
90	22.50	55	31.85	2660	138.1	9.20

4 Stability assessment

To assess the stability of the quarry's three main faces, laboratory test data were integrated with information from on-site surveys (conducted both in this research and in previous technical works, personal communication from Dr. Geol. Claudio Gagliardi) and with non-contact geomechanical analyses performed on a high-resolution quarry point cloud.

4.1 Upper east face

A back-analysis of the wedge sliding phenomenon that occurred on this slope face was carried out to calibrate the shear strength parameters through stability analyses performed using the LEM.

First, a kinematic analysis was performed to verify the possibility of wedge sliding. For the geometric construction of the Markland test a friction angle of 30° was assumed. The test revealed critical intersections corresponding to the surfaces along which the sliding effectively occurred. Then, the Factor of Safety obtained from the LEM resulted equal to 0.94, below the limit equilibrium condition, thereby confirming that the block could not remain stable in the analyzed geometry that represented a predisposing factor for the initiation of the detachment. After the removal of material at the toe, during excavation activities, the movement was thus triggered.

4.2 Main east face

The eastern face shows a critical situation at its junction with the southern face. It coincides with a major fault dipping steeply to the south (173/87). On the eastern face, at the corner with the southern face, a persistent fracture (350/82) can be observed, isolating a large potentially unstable rock mass (Fig. 2). The fracture continues downward, partially displacing the bench at the base of the face.The volume of the unstable rock mass was calculated through non-contact measurements on the point cloud (Table 2).



Fig. 2 The figure illustrates the location and orientation of the discontinuities on the slope and show the geometry adopted to approximate the unstable rock mass.

Table 2. Table showing the dimensions of the rock geometry measured using CloudCompare.

Sector	L (m)	W(m)	H (m)	Volume	Vol. tot
1	~13	~22.5	~12	~3510	
2	~10	~22.5	~32.8	~3700	~7210

A DEM numerical model of the analyzed rock structure was generated in 3DEC (Itasca) ().The model geometry was initially defined as a rectangular prism (140 × 70 × 70 m), subsequently cut and modified to reproduce the geometry of the structure. The natural discontinuities present on-site were incorporated into the model: the fault (173/87) and the fracture (350/80). The deformable block approach was followed, aimed at highlighting the stress conditions within the structure. The model accounts for the deformability characteristics of both the intact rock (Table 3) and the discontinuities (Table 4), allowing for the calculation of the stress and strain state induced by excavation activities.

Table 3. Table showing the parameters used to characterize the rock matrix.

Density (kg/m³)	Friction angle (°)	Young's mod. (GPa)	Poisson's ratio	Cohesion (MPa)
2.66×10^3	53	23.28	0.25	19.65

Table 4. Table showing the parameters used to characterize the discontinuities.

Normal stiffness (GPa)	Shear strength angle (°)	Shear stiffness (GPa)	Cohesion (MPa)
1	30	1	0

The model reveals a natural tendency for displacement of the yellow-marked block in , defined by the intersection of the fault and the fracture, toward the free surface corresponding to the platform between the eastern and southern faces, with a magnitude of approximately 1.5 cm. The stability of this block appears to be ensured by the interlocking zone at its base, which is highly stressed under a critically flexural condition due to possible induced tensile forces (Fig. 4).

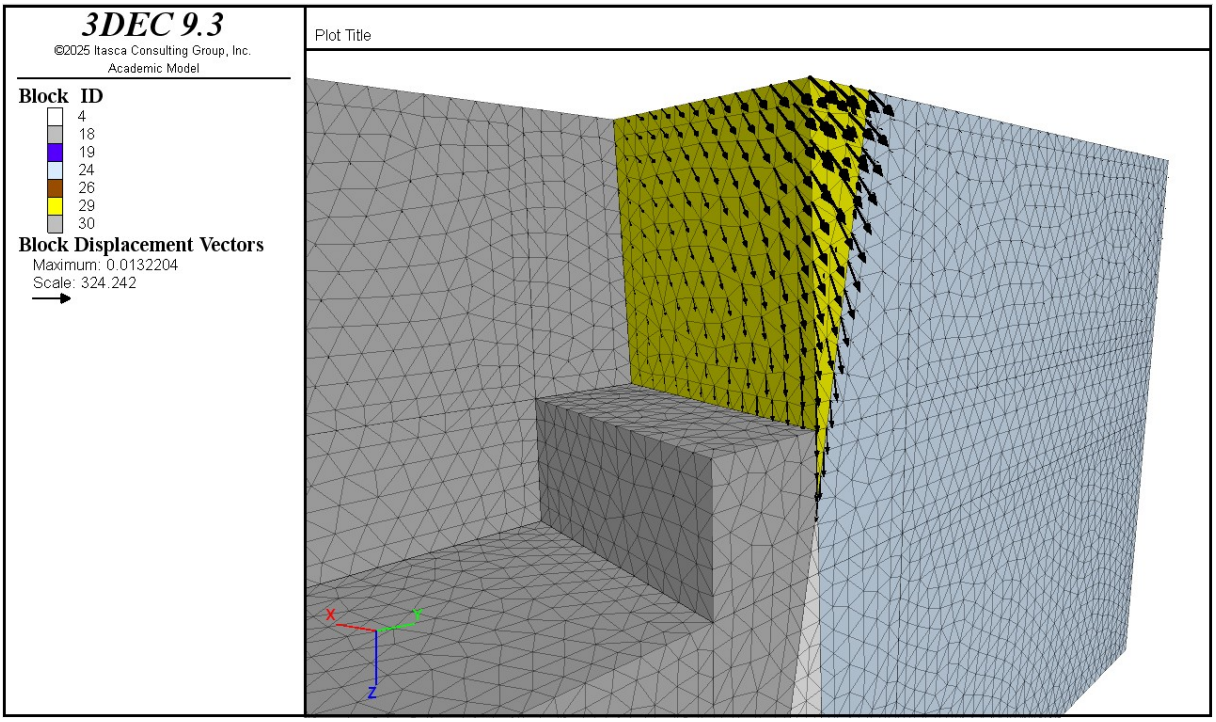


Fig. 3. Sections of the deformable model generated in 3DEC.

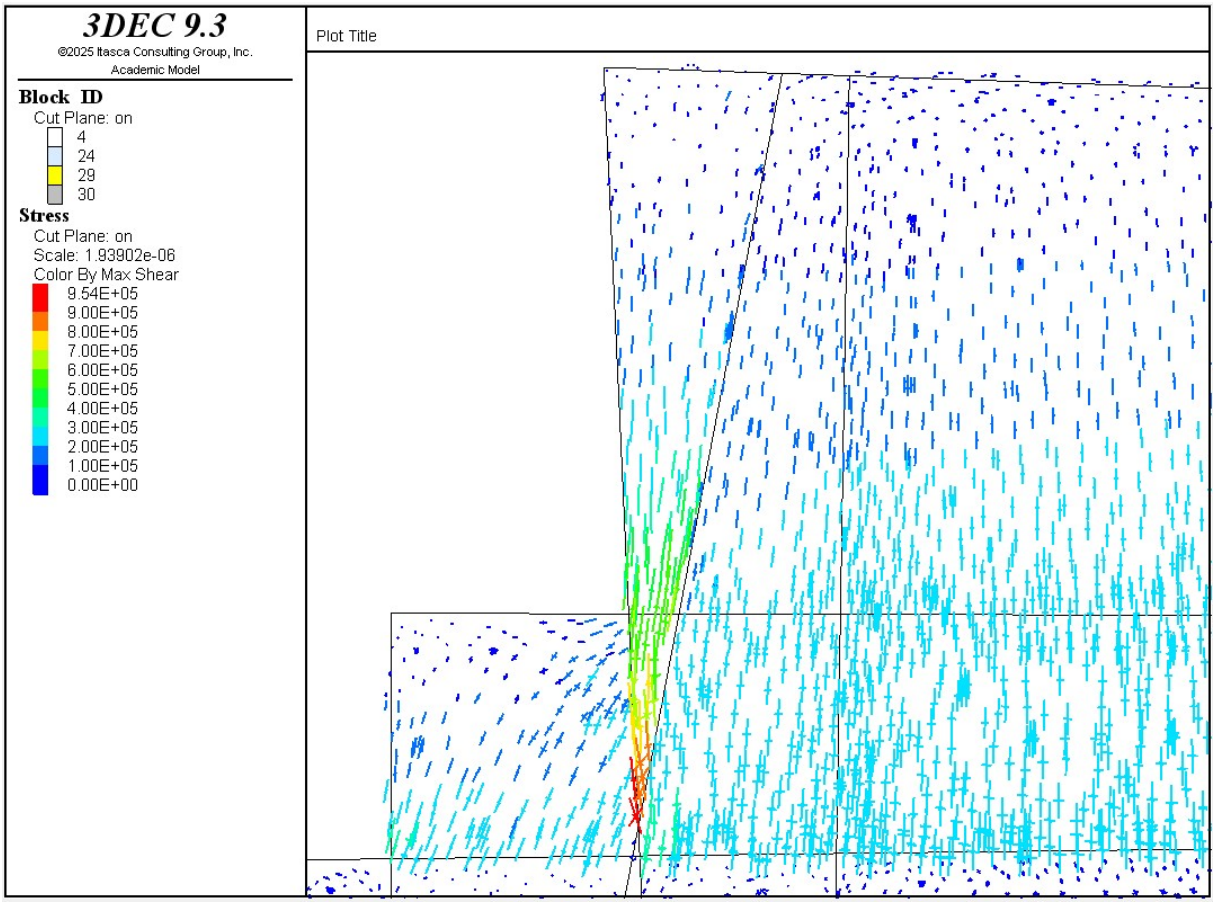


Fig. 4 The image shows the tensile condition affecting the wedge formed by the intersection of the fracture and the fault.

5 Conclusions

The work focused on analyzing the slope stability conditions of the quarry faces following a rock block detachment that occurred in 2023.Representative samples were analyzed through laboratory tests to determine the fundamental mechanical properties of the rock. A total of nine uniaxial compression tests, twenty indirect tensile tests (Brazilian tests) and nine triaxial compression tests were performed, from which key parameters for the subsequent stability analyses were derived. The collected data were processed using specialized software for the mechanical–structural modeling of rock masses to perform kinematic assessments and 3D simulations of failure mechanismssupporting the planning of safe intervention measures.

References

Wagner H (2019) Deep mining: a rock engineering challenge. Rock Mech Rock Eng 52:1417– 1446. https://doi-org.bibliopass.unito.it/10.1007/s00603-019-01799-4

Taboni, B., Ferrero, A.M. & Umili G. (2025). A Novel Application of In Situ Block Size Distribution and Shape Classification in Dimension Stone Quarries. Rock Mech Rock Eng 58, 4509–4526. https://doi-org.bibliopass.unito.it/10.1007/s00603-024-04363-x

Hoek E & Bray JW (1981). Rock slope engineering. London, UK.: E & FN SPON. 3rd Edition, 358 p.

Vagnon F, Dino GA, Umili G, Cardu M, Ferrero AM (2020) New developments for the sustainable exploitation of ornamental stone in Carrara basin. Sustainability 12:9374. https://doi-org.bibliopass.unito.it/10.3390/su12229374

Barton N, Lien R, Lunde J (1974) Engineering classification of rock masses for the design of tunnel support. Rock Mech 6(4):189–236. https://doi-org.bibliopass.unito.it/10.1007/BF01239496.

Umili G, Taboni B, Ferrero AM (2023) The influence on uncertainties: a focus on block volume and shape assessment aimed at rockfall analysis. J Rock Mech Geotech Eng 15(9):2250–2263. https://doi-org.bibliopass.unito.it/10.1016/j.jrmge.2023.03.016

Li W, Bai J, Peng S, Wang X, Xu Y (2015) Numerical modeling for yield pillar design: a case study. Rock Mech Rock Eng 48:305–318. https://doi-org.bibliopass.unito.it/10.1007/s00603-013-0539-8

ISRM (1979) Suggested methods for determining the uniaxial compressive strength and deformability of rock materials, Int J Rock Mech Min Sci. 16 (2), 135-140.

ISRM (1978) Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 15, 319-368.

UNI EN 1926:2007 Testing methods for natural stones – Determination of uniaxial compressive strength.

ASTM D 3148-02 Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression (Withdrawn 2005).

ASTM D 2664 - 95-Triaxial Compressive Strength of Undrained Rock Core Specimens Without Measurement of Pore Pressure, American Society for Testing and Materials.

ASTM D7012-13 (2013) Standard test methods for compressive strength and elastic moduli of intact rock core specimens under varying states of stress and temperatures, American Society for Testing and Materials.