Workshop "Failure Prediction in Geotechnics"

EXTENDED ABSTRACTS

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Key Aspects in 2D and 3D Modeling for the Stability Assessment of a High Rock Slope

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This presentation is intended to describe the rock mechanics and rock engineering studies carried out for the stability assessment of a 120 m high rock slope in a limestone quarry in the Piedmont Region (Italy). The rock slope is characterised by the presence of a 340,000 m^3 estimated rock volume (Figure 1), standing in limit equilibrium conditions, which impairs quarrying activities below the berm elevation reached. Following an outline of the case study, the in situ investigations carried out, including detailed geological mapping, 3D imaging with a laser scanning equipment and infrared thermo-graphic methods will be described. Then, the results of real-time monitoring of the rock face by using a Ground-Based Synthetic Aperture Radar (GBInSAR) will be presented. Three dimensional continuum and discontinuum modeling involving a back analysis of a plane sliding instability at the toe of the slope and detailed slope stability studies of the rock volume, aimed at the definition of the likely instability scenarios, will be described. Finally, the actions envisaged in order to continue with the quarrying activities at the site will be discussed.

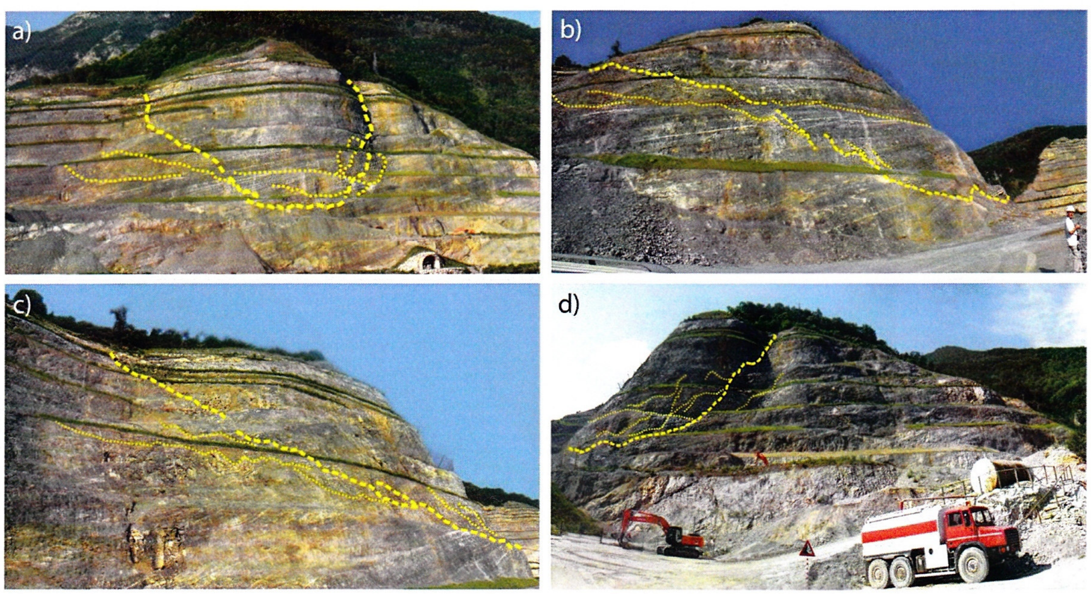
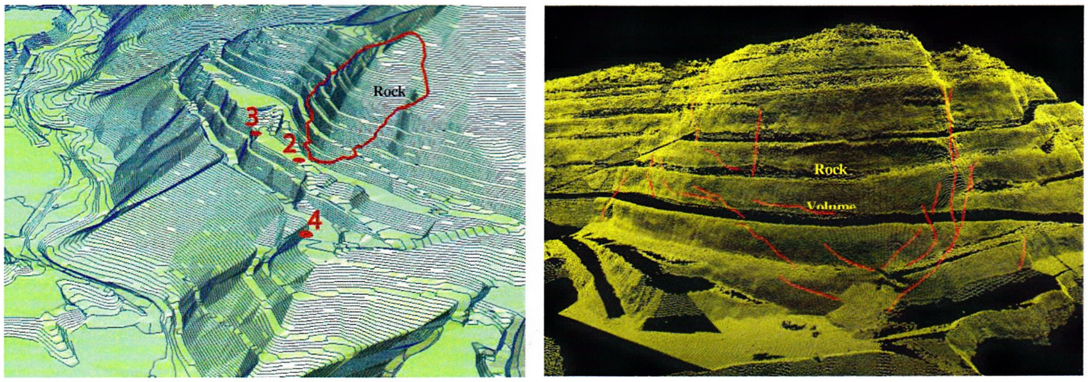


Figure 1: A view of the rock slope with the rock volume in limit equilibrium conditions as observed in the front a) and laterally b), c), d).

1. SITE DESCRIPTION

As shown in Figure 2, the rock slope of interest is part of a limestone quarry face being developed in a bench sequence from the top, at elevation 1000 m a.s.l. approximately, down to elevation 880 m a.s.l. approximately, to a total height of 120 m. During the benching down activities a fault zone, characterized by the same dip direction of the quarry face and 30° inclination approximately, was progressively identified and shown to isolate a rock buttress having an estimated volume of 340,000 m^3 (also see Figure 1) and posing a significant risk for the planned activities below it. This prompted a thorough study to be undertaken in order to analyse its stability conditions, prior to continue excavation down to the toe of the slope at elevation 740 m a.s.l..



(a) (b)

Figure 2: The quarry face with the rock volume in limit equilibrium conditions: (a) 3D visualization, (b) Laser scanning 3D imaging with indication of the fault plane traces.

2. ROCK MASS CONDITIONS, IN SITU OBSERVATIONS AND MONITORING

A SW-NE cross section taken nearly orthogonal to the slope face is shown in Figure 3. The limestone rock mass is of fair quality with the Geological Strength Index (GSI) estimated to be in the range 50-60. The intact rock uniaxial compressive strength is equal to 50-60 MPa for limestone and 15-20 MPa for brecciated limestone which is present along the main fault F4, which nearly isolates the rock volume of interest. The bedding (BG) and three joint sets (K1, K2, K3) characterise the limestone rock mass.

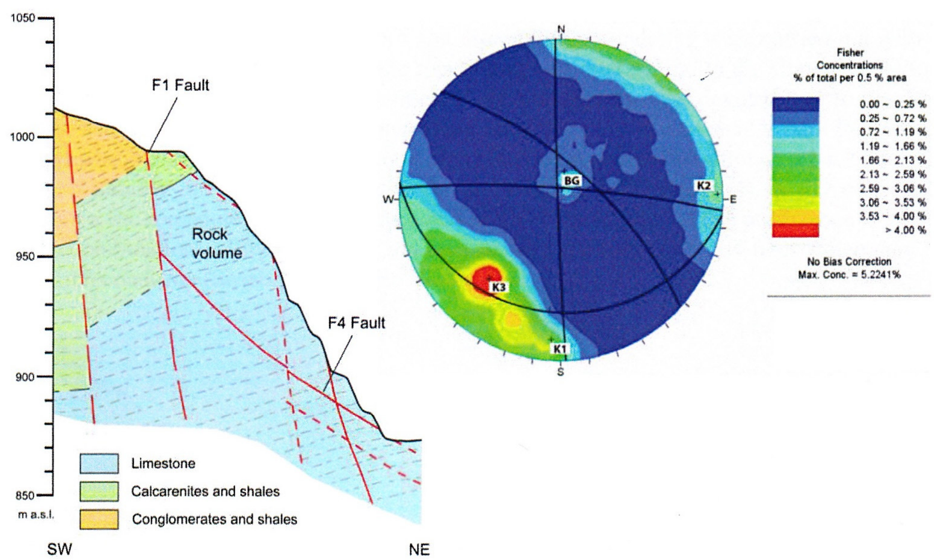


Figure 3: Schematic SW-NE cross section of the slope with a stereographic plot showing the bedding (BG) and joint sets (K1, K2, K3) in limestone.

Detailed studies by using 3D imaging with a laser scanning equipment and infrared thermo-graphic methods have been carried out in order to define the main geometrical features of the slope including an improved description of the major discontinuities (Faults and Shear zones) by determining orientation, roughness, undulation and persistence.

In addition, slope monitoring has been undertaken for a 3.5 month time interval, by using a Ground-Based Synthetic Aperture Radar. The acquisition interval of the radar images was set at first equal to 30 minutes with possible increase of the acquisition frequency up to 6 minutes in case of unexpected slope behavior. Figure 4 illustrates a typical displacement map showing zones A, B, C, D, E of the quarry face undergoing small movement (B, C, D, E) or being in stable conditions (A). In particular the B zone at the toe of the rock volume has been affected by a local sliding instability.

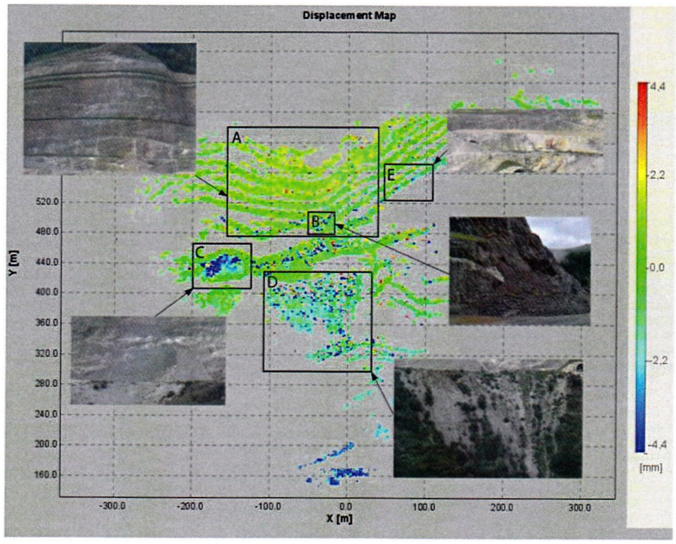
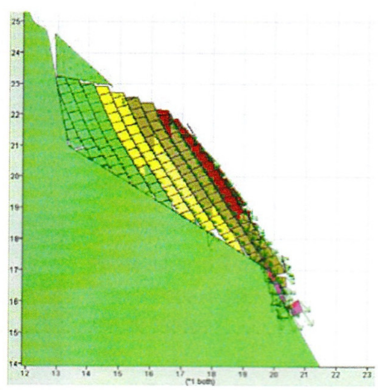


Figure 4: Ground-Based Synthetic Aperture Radar displacement map of the quarry face.

3. 2D AND 3D CONTINUUM AND DISCONTINUUM MODELING

With the above in mind, 2D and 3D continuum and discontinuum modeling were carried out with the dual purpose to assess the stability conditions of the rock volume of interest and to develop possible instability scenarios in view of the future quarrying activities. A special attention was devoted first to the assessment of the strength and deformability characteristics along the sliding surface (typically fault F4), including its continuity and possible existence of rock bridges along it. This was possible through a back analysis of the plane sliding instability occurred at the toe of the slope (Zone B in Figure 4). A 2D discrete element simulation with a friction angle along the joints equal to 35.7° associated to 80% persistence is illustrated in Figure 5. The combinations of friction angle and persistence values along the F4 fault which may lead to a limit equilibrium condition (instability) are also shown.

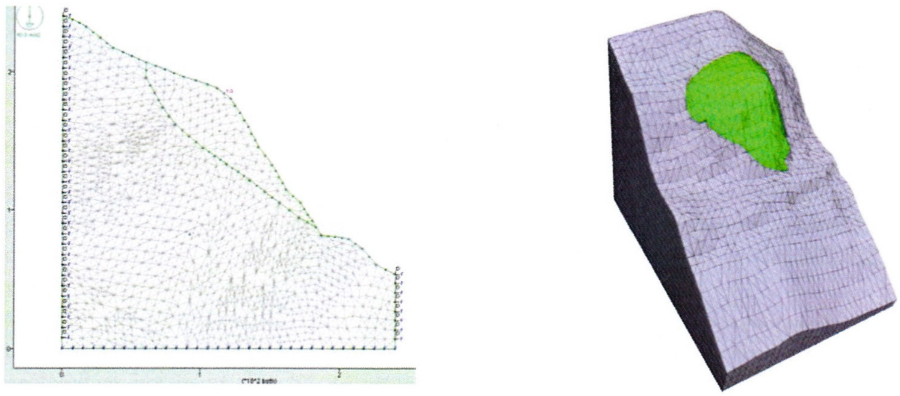


F4 fault without water pressure $F_s = 1$	
Persistence [%]	φ_r [°]
100	45.8
80	36.7
70	34.1
0	30.8

F4 fault with water pressure $F_s = 1$	
Persistence [%]	φ_r [°]
100	53.2
80	43.8
70	41.6
0	40.4

Figure 5: 2D discontinuum modelling of the toe instability (Zone B in Figure 4) and combination of friction angle and persistence values along the fault leading to a limit equilibrium condition.

2D and 3D simulations finalised to assess the stability conditions of the entire slope were then carried out with the 2D and 3D models shown in Figure 6. Also performed were simulations with the combined finite element-discrete element method in order to anticipate possible run-out trajectories along the slope, should instability occurs. In brief, it was found that for an assumed persistence along the sliding surface (i.e. the F4 fault) equal to 80% (i.e. rock bridges are present) and for friction angles in the range 37-44°, the rock buttress between elevation 1000 m and 880 m approximately would reach limit equilibrium conditions (i.e. safety factor equal to 1), in particular if a water pressure distribution was assumed to be present along the sliding surface.



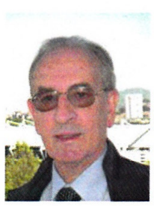
(a) (b)

Figure 6: Continuum and Discontinuum modeling of the quarry face. (a) 2D model, (b) 3 D model.

4. CONCLUDING REMARKS

Based on the results reached, different scenarios were considered regarding the future activities at the quarry as follows: (a) continue excavation and re-profiling below elevation 880 m as initially planned, under closely controlled real-time monitoring; (b) abandon the quarry face with the rock volume in limit equilibrium conditions and continue the mining activities along the neighbouring faces; (c) remove the rock volume of interest, "entirely or partially", by means of slope re-profiling, in conjunction with stabilization measures. At present, option (c) is envisaged.

Authors



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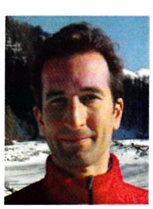

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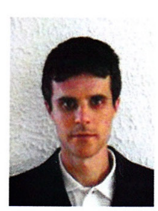

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