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SLOPE INSTABILITY AFFECTING THE CANOSSA GEOSITE (NORTHERN APENNINES, ITALY)

ABSTRACT: TOSATTI G., *Slope instability affecting the Canossa geosite (Northern Apennines, Italy)*. (IT ISSN 0391-9838, 2008).

A geomorphological and geomechanical study was carried out on the calcarenite cliff where the ruins of Canossa castle lie (Reggio Emilia Apennines, Italy). This area is of great historical importance since it was the centre of a very powerful fief in the Middle Ages and has been a national monument for two centuries. In more recent times, it has been subject to degradational problems affecting the rock slopes and posing serious problems for the preservation of the castle and the safety of visitors. The methodological approach utilised is based on a specific survey of rock quality and geomorphological hazard in relation to the high tourist vocation of this geomorphosite.

KEY WORDS: Geomorphosite, Engineering rock classification, Geotourism, Northern Apennines.

FOREWORD

Since the early 1990s, many Earth Sciences research groups have focused their investigations on problems concerning the conservation and appraisal of geomorphosites which are important because they combine significant geological/geomorphological features and historical/artistic assets (Poli, 1999; Stanley, 2002; Panizza, 2003; Reynard, 2004; Piacente & Coratza, 2005). Within the framework of this new approach in identifying and defining cultural assets linked to their physical environment, the ancient site of Canossa (Northern Apennines, Italy) has been the object of study, owing to its relevance from both the cultural and geomorphological viewpoint. In particular, this is the first detailed study of the Canossa site within a geosite research programme. The aim of investigations was to identify the slope instability processes at present affecting this site in order to establish adequate remedial measures and ensure its future conservation and safe fruition for tourists.

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HISTORICAL FRAMEWORK

Canossa was first mentioned in 940 AD when count Azzo Adalbertus built the first *Canusia* castle, so called after the whitish – *canus* (in Latin) – colour of the rock, on top of a calcarenite hill. In the following years this stronghold was enlarged and reinforced until 1052, when Countess Matilda, daughter of Boniface III, became its ruler. She was the principal Italian supporter of Pope Gregory VII during the investiture controversy and is one of the few medieval women to be remembered for her military accomplishments on the European political scene of the 11th century. Matilda was also first cousin to Henry IV, king of Germany and Italy and Emperor of the Holy Roman Empire. In 1075, a papal decree forbade any interference of the emperor and civil authorities in the investiture of bishops. This resolution, though, was not accepted by Henry IV who, at the Council of Worms in 1076, removed the pope himself from office. The pontiff, in turn, excommunicated the emperor. This event was worse than dethronement for Henry, since all the German princes stood up against him. At this point, Henry IV decided to beg the pope for forgiveness through the intercession of Countess Matilda. Eventually, reconciliation between pope and emperor took place at the castle of Canossa on 28th January 1077 (fig. 1). Nevertheless, not long after this important event, hostilities between the Empire and the Papacy were resumed.

At the death of Matilda, in 1115, the Canossa stronghold entered a long phase of decline and progressively lost its power. In 1255, it was nearly completely destroyed by soldieries from Reggio Emilia. After various vicissitudes, the Canossa cliff was eventually acquired by the Estense family in the early 15th century, which held it until 1796. Following the unification of Italy, the ancient fief of Canossa passed to the State which declared the castle a national monument in 1878.

Today, some remains of the castle's powerful walls and the apse of a Romanesque church are left in Canossa, and



FIG. 1 - The historic meeting between Pope Gregory VII and Emperor Henry IV in the presence of Matilda in Canossa in 1077 (Vat. Lat. Code no. 4922, year 1115).

a small modern building houses an archaeological museum, where several finds collected during restoration works are displayed (Manenti Valli, 2001).

GEOGRAPHIC AND GEOLOGICAL SETTING

The hill of Canossa is located in the mid-Apennines of Reggio Emilia province within the vast Po catchment. The

coordinates of the topographic benchmark placed on top of the hill are: 44°34'42 N lat. and 10°27'24 E long. from Greenwich. This small ridge rises some 50 m over the surrounding hills and its highest point is 578 m a.s.l., whereas the approximate volume of the entire arenaceous cliff is 500,000 m³ (fig. 2).

From the climatic viewpoint, Canossa is characterised by annual average precipitation of 865.3 mm and annual average temperature of 11.6 °C (Ministero dei Lavori Pubblici, 1950-2005). Therefore, according to the Köppen-Geiger classification (Kottek & alii, 2006), the site belongs to the sub-continental temperate belt.

Geologically the area of Canossa belongs to the Epi-Ligurian Sequence, which is a meso-allochthonous Tertiary sedimentary sequence deposited on top of the Ligurian Units during their tectonic displacement from SW to NE during the Apennine orogenesis (Bettelli & De Nardo, 2001; Various Authors, 2004).

A good portion of this series of rock types, in particular the most recent Oligo-Miocene part, is visible in the badlands surrounding this site. The bottom of these badlands is made up of a light, marly-clayey, Upper Oligocene formation named Antognola Formation, on top of which greyish polymictic argillaceous breccias, known as «Canossa Olistostrome», are found (fig. 4). These sedimentary matrix-supported breccias make up the well-known Canossa badlands and are the result of submarine mud flows and debris flows which interrupted the sedimentation of the Antognola Formation in the Upper Oligocene. The polymictic breccias consist of greyish, sometimes varicoloured, scaly clays, in which calcareous and, more seldom, ophiolite fragments are scattered in proportions and dimensions varying from place to place. This chaotic level attains a maximum thickness of about 150 m and is distributed along a belt some 40 km long stretching between the Modena and Parma Apennines. The Canossa Olistostrome is probably the result of several events, not just a single slide, which have reworked rocks from submarine ridges occupied by Ligurian Units.

The ruins of Canossa Castle rest on top of the cliff which, in turn, overlies the Oligocene sequence. Its mor-



FIG. 2 - General view of the Canossa calcarenite cliff, with the ruins of the castle, overlying gully morphology developed in polymictic breccias.

phology clearly corresponds to an erosion-selected remnant of competent rock types overlying deeply eroded clay shales. The Canossa cliff is made up of calcarenites or whitish, well-stratified calcareous sandstones belonging to the Middle Miocene Bismantova Group and, in particular, to the outer shelf unit known as Pantano Formation (Burdigalian?-Langhian). These rocks have been used through the centuries as building material, in particular during the Romanesque artistic period.

The calcarenites making up the Canossa cliff are stratified in some 6-7 m thick layers, alternating with thin clayey or marly beds. The formation attitude is fairly constant all over the cliff, with a prevalent N 150° strike and a 32°-35° NE dip.

The entire calcarenite slab is affected by various sub-vertical discontinuity systems, with prevailing Apennine and anti-Apennine directions, corresponding to the two main structural lineations of this mountain chain (Gelmini, 1990), which subdivide the slab into several large rock strips. The presence of layers showing different levels of competence leads to the formation of ledges and indentations. Numerous niches, corresponding to eroded epigenetic concretions are also typical of the rock slopes (fig. 3).

The boundary between the Pantano Formation and the underlying polymictic breccias is found at the altitude of 525 m a.s.l., and creates a quite contrasting landscape between the steep cliff slopes, the gently sloping cultivated fields to the east and the rugged badlands to the west (figs. 2 and 4).

GEOMORPHOLOGICAL EVOLUTION AND STABILITY PROBLEMS

Like many other historic sites found all over the Northern Apennines (Conti & Tosatti, 1996; Tosatti, 2004; Nesci & *alii*, 2005; Chelli & *alii*, 2006), the area of Canossa is

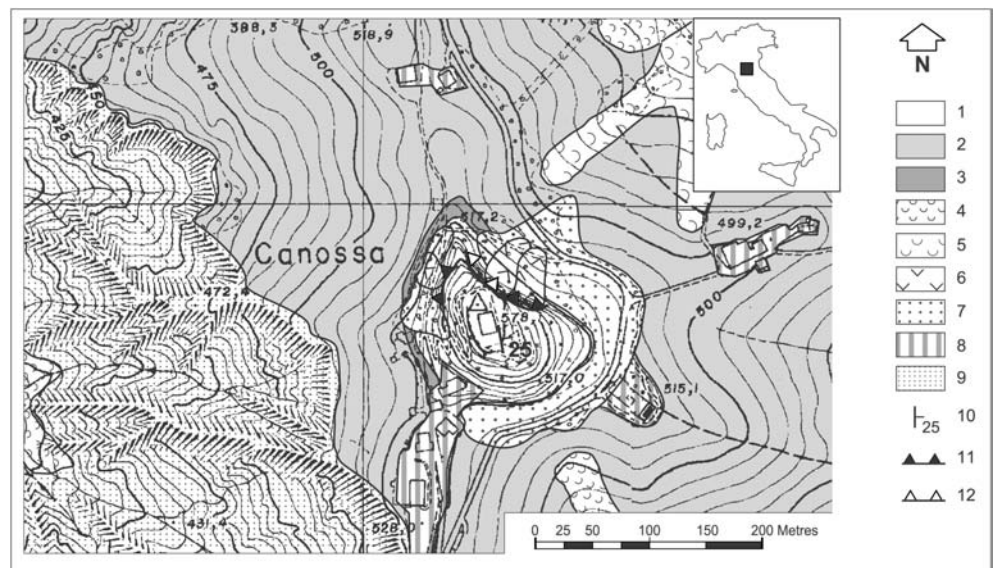


FIG. 3 - Niche due to differential erosion on the NW slope.

particularly prone to mass wasting, with landslides affecting both the calcarenite cliff and the clayey bedrock. In addition, gully erosion is in progress (fig. 4).

The most active processes are found on the NE slope, where dense jointing and dip-downstream layers (dip 25° to 35°) favour the onset of rock falls and block spreads (fig. 5). Other movements are located on the S-SW slope, where tensile stresses have caused the opening of several rock discontinuities. These joints are subject to progressive widening with time, as witnessed by surveys carried out in the past (De Beer, 1979; Soprintendenza Beni Ambientali-Architettonici, 1988), which leads eventually to rock block detachment and fall, with risk not only for the preservation of the geosite itself but also for transport infrastructures and residential buildings.

FIG. 4 - Geomorphological map of the study area. Legend: 1) Pantano Formation - Bismantova Group (Burdigalian?-Langhian); 2) Polymictic argillaceous breccias (Aquitanian); 3) Antognola Formation (Rupelian-Aquitanian); 4) Active earth slide; 5) Dormant earth slide; 6) Rock fall and top-ple; 7) Slope debris; 8) Developed area; 9) Badlands; 10) Bedding attitude; 11) Active landslide crown; 12) Dormant landslide crown.



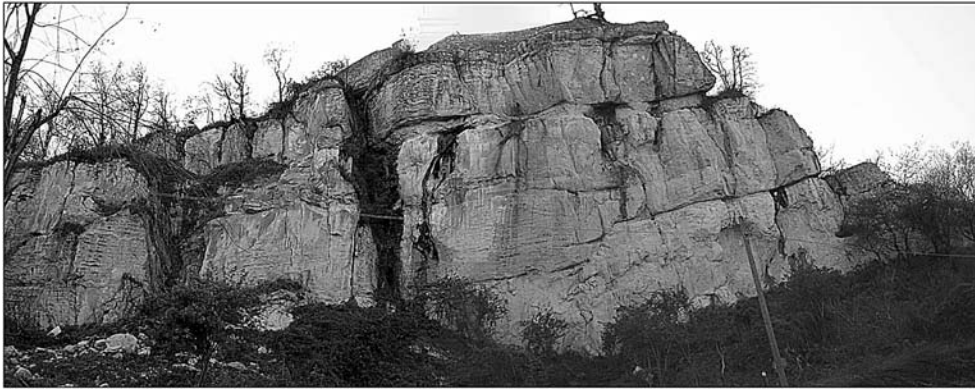


FIG. 5 - Present situation of the NE side of Canossa cliff undergoing block spreading (April 2007).

Mass wasting of the calcarenite cliff is strictly related to the erosional and displacement processes affecting also the underlying polymictic breccias.

The clayey slopes surrounding the cliff are subject to creep and in some areas small, superficial, rotational slides occasionally take place following intense precipitation. Furthermore, the seasonal plasticisation of these soils has greatly contributed to the disarray conditions affecting the Canossa cliff. This type of mass movement leading to progressive dismembering of the rock strips making up the Canossa cliff may be ascribed to block spreading (Cruden & Varnes, 1996).

Finally, the area west of the rocky cliff is characterised by active badland degradational phenomena extending over some 0.5 km².

The velocity of retrogressive erosion leading to a progressive expansion of badland morphology was calculated as 2-3 cm/year (Carri, 1987). The consistency of this datum has also been confirmed by comparing aerial pho-

tographs taken in 1994 with the present situation, which shows that the badland front is only 50 m away from the outer edge of the calcarenite cliff.

Retrogressive gully erosion is most visible at the foot of the gabion wall supporting the car park adjacent to a snack-bar in Canossa (fig. 6).

Other evidence of active gully erosion is provided by the remnants of the old provincial road, now almost completely obliterated (fig. 7).

SEISMICITY

Mass wasting processes affecting the study area have undergone sudden increases of the displacement rate not only in concomitance with intense precipitation but also with seismic shocks. Although most of the earthquakes which have struck this area are usually of low intensity, occasionally there have been stronger tremors which have



FIG. 6 - The gabion wall affected by gully erosion.

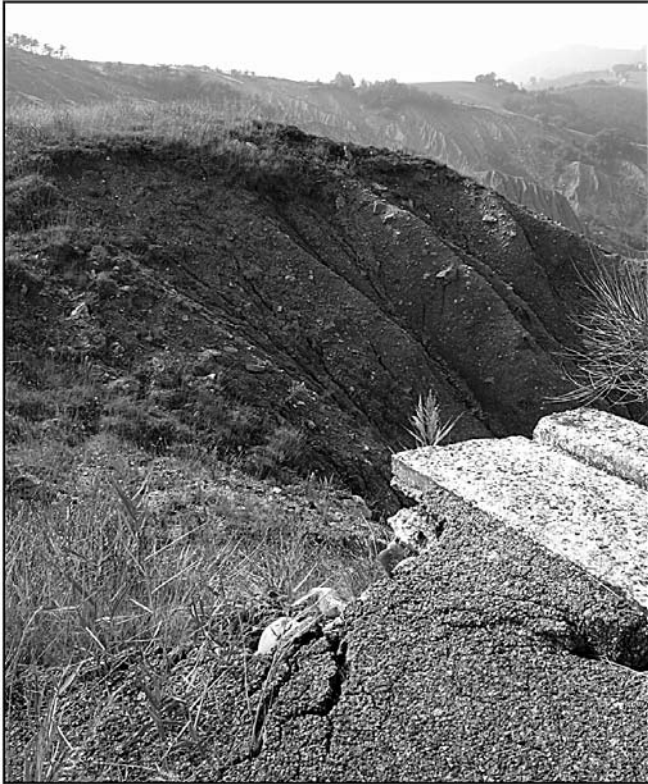


FIG. 7 - Remains of the old provincial road destroyed by gully erosion.

caused rock falls from the slopes of the cliff. Worthy of note is the earthquake of 13th March 1832 (rated VIII-IX degree of the MCS scale) when large pieces of masonry detached from Canossa castle and rolled downhill (Baratta, 1901). Other earthquakes occurred in 1904 and 1909, triggering rock falls. In more recent times, the VII MCS-degree quake of 9th November 1983 (Istituto Nazionale di Geofisica e Vulcanologia, 2004), with an epicentre in the adjacent Parma province, further dismembered the cliff with the fall of several rock blocks that rolled and bounced as far as the provincial road. As an immediate response for safeguarding human lives and the historical assets of this site, the Landscape and Archaeological Assets Office of Emilia-Romagna Region set up a restoration and consolidation project which was carried out in the following years (Soprintendenza Beni Ambientali-Architettonici, 1988). Since then, though, stability conditions have worsened owing to the progression of erosional and landslide processes which have compromised most of the remedial measures carried out in the 1980s.

GEOMECHANICAL CHARACTERISATION

The modified Rock Mass Rating (RMR) system by Bieniawski (1989, 1993) was used to assess the geomechanical characteristics of the calcarenites making up the Canossa

cliff in relation to its proneness to instability processes, and parameters were related to the Q-System by Barton & alii (1974). These classification systems are based on semi-quantitative measurements and observations concerning the strength of the rock and the density and space orientation of its joints, such as roughness coefficient, spacing, alteration, presence of groundwater etc. A numerical coefficient is attributed to each parameter and the corresponding rating is determined.

Over the years, this system has been successively refined as more case records have been examined. The following six parameters are used to classify a rock mass adopting the RMR system (Bieniawski, 1989):

1. Uniaxial compressive strength of rock material (determined by means of Schmidt hammer in the field or Point Load test in laboratory);
2. Rock Quality Designation (*RQD*) (measured as the percentage of intact core pieces longer than 100 mm in the total length of core or in the thickness of the outcropping rock considered);
3. Spacing of discontinuities (direct measurements);
4. Condition of discontinuities (direct measurements and Barton contour device);
5. Groundwater conditions (direct observation and flow rate measurements);
6. Orientation of discontinuities (by means of geological compass).

In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions, as in the case here discussed where ten structural regions were defined (fig. 8).

The final results of the Rock Mass Rating system are presented in tab. 1, giving the average ratings for each of the six parameters listed above measured at each area. These ratings are then summed to give a value of *RMR*.

Analyses and measurements carried out on the rock outcrops were preceded by bulk unit weight (γ) determinations on some calcarenite samples, in order to insert this parameter in calculating the uniaxial compressive strength by means of Schmidt hammer. Geomechanical data were collected from ten different areas (structural regions) corresponding to significant sectors of the cliff walls. The rock mass was thus characterised and the parameter ratings attributed in order to produce a clear and detailed picture of the overall mechanical conditions (tabs. 1 and 2).

The modified RMR total rating resulting is 40, which corresponds to a «poor rock» (poor = 21 to 40).

This classification takes into account the influence of joint orientation which, in most cases, is unfavourable to stability conditions and is expressed by a negative number (average -10 in this case).

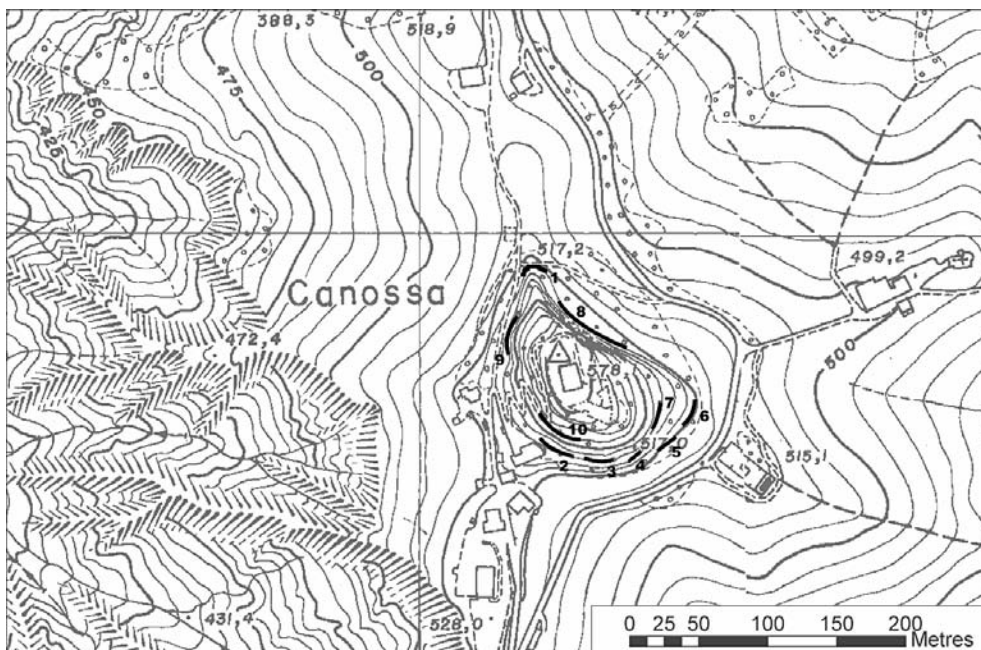


FIG. 8 - The Canossa cliff showing the location of the ten structural regions identified (drawn on CTR 1:5000 topographic maps nos. 218021-024, Regione Emilia-Romagna).

TABLE 1 - Total average ratings of RMR parameters from ten structural regions (according to Bieniawski, 1989)

Index	Parameter	Average values of the RMR system determined from total ratings			Rating	Rating Rang	
		Description	Value	Unit			
1	Uniaxial compressive strength	moderate	32	MPa	4	4	
2	Drill core quality RQD	good	86	%	17	13 to 20	
3	Spacing of discontinuities	moderate	35	cm	10	8 to 10	
4	Condition of discontinuities	Persistence	medium-high	3-20	m	2	0 to 4
		Separation	moderate-wide	1 to >10	mm	1	0 to 1
		Roughness	rough	10	-	3	3 to 5
		Infilling	cohesionless	>5	mm	0	0 to 2
5	Groundwater conditions	Weathering	moderate	-	-	3	1 to 5
		damp	0.0-0.1	l/min	10	10	
6	Joint orientation	unfavourable	-	-	-10	-5 to -12	
TOTAL	RMR value	«poor rock»	IV	-	40	29 to 51	

Measurements of orientation allowed joints to be ranked into five discontinuity families according to their attitude (tab. 2).

The intersection of these five joint families has divided the Canossa cliff into numerous blocks which are af-

ected by gravitational tensile stresses leading eventually to rock falls.

In addition, rock mass cohesion (c_M) and friction angle (ϕ_M) were estimated by direct relationships as proposed by Bieniawski (1989):

$$c_M = 5 \times RMR = 0.20 \text{ MPa}$$

$$\phi_M = 5 + (RMR/2) = 25^\circ$$

with average bulk unit weight (γ) = 21.2 kN/m³.

Similarly, the Q-Index (Barton & alii, 1974) was calculated by applying the following ratio:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

TABLE 2 - Average strike-dip values of the five joint families identified

Family	Strike - Dip
1	N40°/47°
2	N230°/70°
3	N130°/58°
4	N270°/60°
5	N325°/60°

where RQD is the Rock Quality Designation (as previously defined)

J_n is the joint set number (systems of joints in the rock mass: 0.5 to 20)

J_r is the joint roughness number (assessment of joint roughness: 0.5 to 4.0)

J_a is the joint alteration number (degree of weathering: 0.75 to 20)

J_w is the joint water reduction factor (0.05 to 1.0)

SRF is the stress reduction factor (fault zones intersecting rock faces: 1.0 to 1.5)

In particular, the first quotient (RQD/J_n), representing the structure of the rock mass, is a crude but fairly realistic measure of the rock block size, the second quotient (J_r/J_a) represents the roughness and frictional characteristics of the joint walls or filling materials, whereas the third quotient (J_w/SRF), which can be regarded as a total stress parameter, is in this case equal to one (tab. 3).

The resulting Q-Index is about 2.3 which corresponds to a «poor» quality rock (poor = 1 to 4).

Although the two methods lead to the same geomechanical definition («poor rock»), the data obtained by Barton classification should be considered as more reliable since they produce a more cautious result.

In addition, kinematic and stability analyses were carried out all along the Canossa cliff in order to assess whether this geomorphosite required particular stabilisation interventions, considering the frequent rock falls occurring in the past few years.

STABILITY ANALYSES

The assessment of the stability conditions of the Canossa geosite was carried out on both the rocky cliff and the underlying clayey soils in order to have an overall picture of the kinematic and evolutionary trend of the area.

First of all, the proneness to give rise to rock falls was considered by analysing several sections in various portions of the cliff, adopting suitable slope stability programmes («CRSP»¹ and «Lumped Mass»² methods devel-

¹ «CRSP» (*Colorado Rockfall Simulation Program*) model proposes the modelling of fall of blocks having, in the vertical plane of fall, spherical, cylindrical or disc form. CRSP describes the behaviour of the blocks by applying the equations of parabolic trajectory of bodies in free fall and the principle of conservation of total energy. The model treats even combinations of movement in free fall, bounce, roll, and slide that can vary in relation to the size of the blocks and the roughness of the slope. The reliability of this method has been verified by comparison of the numerical results against field trials.

² Also a *Lumped Mass* approach can simulate rock falls: the boulder is considered dimensionless with all the mass concentrated in one point (the centre of mass) and air resistance is immaterial. The size, shape and mass of the boulder are not considered and a kinematic simulation of the rock fall process is performed. The advantage of the Lumped Mass approach lays in its simplicity and computational speed.

TABLE 3 - Total average Q-system parameters according to Barton & alii (1974)

Parameter	Value
RQD	86
J_n	15
J_r	4
J_a	10
J_w	1
SRF	1
Q-Index	2.293

oped by Pfeiffer & Bowen, 1989) which take into account the cases of both plane failure and wedge failure analyses (Norrish & Wyllie, 1996). Subsequently, slope stability analysis (Bishop, 1955) was carried out also on the clayey bedrock for assessing the possible formation of deep-seated rotational-translational surfaces of rupture.

A comprehensive analysis of the factor of safety (F) of the rock walls confirmed that the most unstable slopes are the NE and S ones. In particular, on the NE slope the lowest plane failure F values were found ($F = 0.973$). This type of movement caused the fall of a 40 m³ large rock block in February 2004. On the other hand, the lowest wedge failure F values were calculated on the S facing slope ($F = 0.981$). This portion of the cliff is under constant monitoring by means of optical prisms and is protected by rock catch fences, since it overlooks the hamlet of Canossa. As for the W portion, which was affected by rock falls early in 2005, active instability processes have not been detected at present.

Following the calculation of F values lower or equal to 1, an analysis of rock fall dynamics was also carried out in order to reconstruct the motion of falling boulders and assess the impact that they would have on the infrastructures located at the foot of the cliff (Canossa hamlet, roads and footpaths). On the NE facing slope possible rock falls would not affect the houses below since the detached blocks would exhaust their motion on the clayey soils, without rolling for long distances. On the contrary on the S slope rock blocks would undergo several bounces before stopping. Bouncing would be generated by the impact on other rocks or the asphalted surface of the car park below and could hit some houses in the village. Indeed, the highest risk level has been identified in this area. Some measures, mainly consisting of rock catch fences and micropiles driven into the rock, were implemented a number of years ago, but at present they no longer offer adequate protection.

On the contrary, the stability analyses carried out on the clayey bedrock have revealed no deep surfaces of rupture ($F > 1$). Only limited, superficial earth flows could take place near the boundary with the overlying marls and calcarenites, but the main problem affecting these rock types is the high rate of gully erosion.

FINAL REMARKS

Although the historic site of Canossa is well-known in Europe and has been properly appraised by local administrations and cultural institutions, its fruition still poses problems of safety due to persisting instability conditions, resulting in occasional rock falls and concentrated erosion processes. This has determined the closing of the main tourist path across the area. In addition, some of the widening rock joints have caused cracks also in the outer portions of the castle's ruins and St. Apollonius' basilica. Geomechanical analyses and measurements carried out all along the Canossa cliff have shown that the most unstable portions are the NE and S faces, where the rock parameters are poorest and degradational processes are particularly intense. Therefore, more low-impact remedial measures, compatible with the high landscape value of the area, are required in order to preserve this geomorphosite in its entirety for future generations. In particular, the most precarious blocks should be fixed with rock anchors, open joints filled with cementing mixtures and percolation water adequately collected and discharged.

Only after thorough upgrading of the cliff will it be possible to safeguard adequately the important historical, artistic and environmental assets which make up the Canossa cliff and extend its complete and safe fruition to all visitors.

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