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GeoZS

Landslide monitoring at the Cala Rossa sea cliff (Favignana Island, Sicily)

Luca Falconi[1], Roberto Iannucci[2], Salvatore Martino[2], Antonella Paciello[1], Augusto Screpanti[1], Vladimiro Verrubbi[1]

[1] **ENEA**, National Agency for New Technologies, Energy and Sustainable Economic Development Casaccia Research Centre, Via Anguillarese 300, Roma – 00123, Italy

[2] "**Sapienza**" Università di Roma, Dipartimento di Scienze della Terra & Centro di Ricerca per i Rischi Geologici (CERI), Piazzale Aldo Moro 5, Roma 00185, Italy

ABSTRACT

Favignana Island is a historical and environmental attraction site frequented by tourists especially during the long warm season of the year. Over several centuries the sea cliffs have been exploited for the production of building stone. Currently, the quarries used for the rock extraction as well as the natural cliffs are undergoing extensive erosional and gravitational processes. Besides putting at risk the safety of the people attending the area, the widespread rock falls are likely to threaten sites of great historical and anthropological value that, once destroyed, can no longer be reconstructed. The rock mass quality assessment and slope displacement monitoring of cliffs were carried on to identify the most unstable areas providing a support to the local authorities in the implementation of effective and sustainable mitigation measures. If adequate measures will be taken in future, operators and users of the tourist circuit will have the opportunity to enjoy these amazing sites with a reduced risk.

INTRODUCTION

The eastern side of Favignana Island offers some stretches of extremely beautiful coast, where it is possible to appreciate the remains of one of the traditional productive activities of the island: the "pirrere". These are open and underground quarries where a calcareous sandstone was extracted to be used as building stone. The open air quarries are located both in the interior of the island, forming deep pits, or along the cliffs overlooking the sea, while the underground ones form a branched network of caves and tunnels. The high resistance brought the biocalcarenite, improperly called "tuff", to be extracted in several hypogeal and open air quarries and used as building stone since the roman age.

Many buildings were constructed in Tunis with the "tuff" of Favignana, and Messina was rebuilt with it after the 1908 earthquake. After the World War II the "tuff" went out of the market and the mining areas were abandoned to a degradation fate which increased the risk of block collapse.
Although the area is frequented by tourists, currently the quarries as well as the natural rock cliffs are undergoing extensive erosional and landslide processes. Besides putting at risk the safety of the tourists attending the area, the widespread rock falls are likely to threaten sites of great historical and anthropological value that, once destroyed, can no longer be reconstructed.

STUDY AREA

Favignana, the largest of the Egadi Islands, is surrounded by 33 km of indented and mainly rocky coastline, marked by natural and anthropic cavities. The study is focused on the bay named "Cala Rossa", located in the eastern side of the island, where the Pleistocene biocalcarenites form some cliffs with height ranging from few meters up to over 30 meters. In the west side of Cala Rossa, the stiff rock slab lies on the ductile clays belonging to the Pliocene formation. The contact between the two formations can be recognised here above the sea level, while in the east side of the bay the surface is presumably below sea level. Such a juxtaposition leads to a lateral spreading phenomenon that induces the fracturing of the the stiff rock slab and the detachment of single rock blocks by typical rock landslide mechanisms (i.e. planar sliding, wedge sliding, toppling and falling). The resulting landslide process should be defined as a complex-type.
The calcarenite shows relatively high values of porosity related to the low diagenetic process, the low cementation (spathic calcite with meniscus structures) and to the textural characters (equi-dimensional, well sorted, loosely packed, low fine grained matrix). The value of the compressive strength offered in literature, and confirmed through some field measurements with a Schmidt hammer, indicates a weakly cemented carbonate rock.

METHODOLOGY

Geomechanical investigations

The rock mass features and the lithotecnical characteristics of the calcarenites were evaluate in 20 stations (7 in the west side and 13 in the east side), on the basis of 2 classification systems: Beniawsky/Romana (RMR/SMR) and Sicily Region. The latter proposes a simplified approach generating an aggregate of some geomorphological, environmental and historical parameters with the mechanical characteristics typical of the traditional classification.

Traditional monitoring

Discontinuos measurements were carried out between April 2012 and April 2015.

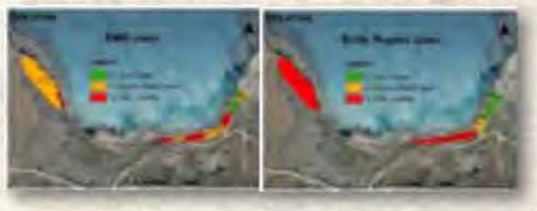
- A direct measurement system was implemented with 40 mechanical joint-meters (tell-tales, removable joint-meters and 3D joint-meters)
- A GPS monitoring network, linked with the Italian Geodetic Network (IGM95), was realized through four stable vertices used as references for four potentially unstable sites in proximity of the edge of the cliffs.

Seismic noise measurements

Seismic noise was recorded in 47 single-station measurement sites over an area of approximately 0.05 km^2, to cover both the unstable zones of the sea cliff and the stable carbonate plateau. Each station was equipped with a 3-component seismometer: 28 measurements were carried out using a LE-3D/5s seismometer by Lennartz Electronic GmbH and a REFTEK 130-01 datalogger set to a 250 Hz sampling frequency; 19 measurements were carried out using a 1.5 Hz SL06 acquisition unit by SARA Electronic Instruments, set to a 200 Hz sampling frequency. The seismic noise records were processed using Geopsy software (www.geopsy.org). The 1-hour time histories were divided into non-overlapping windows of 40 s and the Fast Fourier Transform was computed for each component in the frequency range between 1.0 and 60.0 Hz. By averaging over the windows, the amplitude spectra and the H/V spectral ratio were finally achieved for each single record.

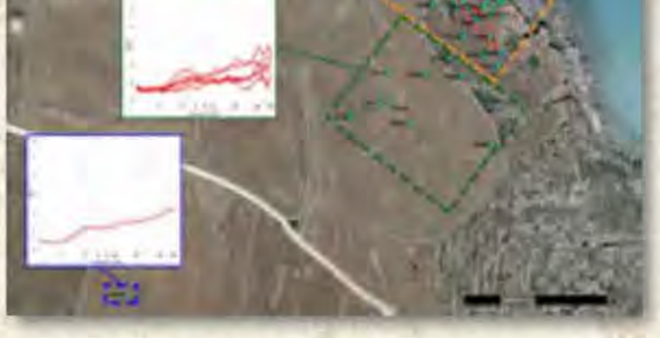
RESULTS

The biocalcarenitic slab shows a high degree of fracturing especially in the front portion of the cliffs. In the west cliff, upon the plateau, 3 major discontinuities have been recognized, longer than 100 meters, 50 cm open and with 40 cm of offset. If they would reach the contact with the underlying clays, a huge block of approximatively 30,000m^3 would find isolated.



GPS data: horizontal and vertical millimeter movements always inside the error ellipse and without an apparently defined trend.

The results of the noise analyses pointed out a marked difference in the seismic response between the unstable areas and the stable plateau zone. The HVSR curves show significant resonance peaks at frequency higher than 3.0 Hz in the measurements carried out within and in proximity of the unstable zones, while these peaks are not present in the measurements carried out on the plateau zone.
The seismic energy in the frequency higher than 3.0 Hz can be related to the vibrational behavior of the dislodged rock blocks and the seismic response at these frequencies can depend on geometrical and mechanical properties of the rock blocks.



DISCUSSION

- The plastic clay deformation induces stress conditions in the overlying rigid body of calcarenite and favors fracturation of the stiff rock slab and gravity-induced instability of single rock blocks..
- Two controlling factor play a significant role: the pre-existing neo-tectonic shear zones and the position of the contact surface between the two formations above or below sea level.
- The lack of significant movement registered by the integrated monitoring system in the periodic acquisition during the 36 months study does not exclude the possibility of future single or massive movements.
- The rock mass rating of the cliffs attributed to the different measuring stations shows good agreement between the traditional (RMR/SMR) and the recent experimental classification of Sicily Region (SR).

CONCLUSIONS

Although the geotechnical monitoring systems did not record significant precursor displacements, several portions of the sea cliff show evidences of rock slides or falls. The complex local seismic response at high frequencies (10-60 Hz) confirmed the presence of dislodged rock blocks. Consequently, a significant hazard level has been recognised in several measurement stations.
On this basis, identifying appropriate actions is absolutely crucial to prevent accidents to the users of these beautiful natural places and to avoid that the most significant quarries are further abandoned to an inexorable degradation process. The enhancement of the safety level of these areas is an essential step for a sustainable and safety tourism exploitation in the island. This is the way to ensure that what was left of the quarries can become an economic resource again, while respecting the historical and the environmental context.

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1963 was effectively a reactivation of a prehistoric large rockslide, as already hypothesised by previous studies dealing with the Vajont slide, but the structure of the prehistoric landslide was different from what was previously thought. The main result of the recent geological re-examination of the 1963 Vajont landslide is the identification of a thick shear zone (40-50 m) located at the base of an overlying unstable block. The occurrence of the basal shear zone, made up of limestone angular gravel, clay lenses and displaced rock masses, permitted a rapid seepage inflow triggered by the reservoir filling and also favoured the unusual en-masse movement of the upper unstable block. In particular, two specific unfavourable geologic conditions played an important role in the 1963 catastrophic event: the high permeability of the thick shear zone and the considerably low shear strength of some very thin clay lenses. Without considering this recently acquired geological data, it is very difficult to perform hydromechanical analyses or more sophisticated numerical models capable of reproducing the catastrophic Vajont slope failure and its unexpected final en-masse movement.

True 3D Kinematic Analysis for Slope Instability Assessment in the Siq of Petra (Jordan), from High Resolution TLS, page 527

Claudio Margottini, Daniele Spizzichino, Giovanni Gigli, Heinz Ruther, and Nicola Casagli

Abstract: The present paper describes a specific research performed in the framework of the project "Sustainable monitoring techniques for assessing instability of slopes in the Siq of Petra, Jordan" carried out by ISPRA from July 2012 to May 2015. Focus is given to true 3D kinematic analysis for slope stability assessment in the Siq from high resolution terrestrial laser scanning (TLS). The effectiveness of the model and its algorithm implemented for the analysis has been verified and tested after the May 2015 rockfall. The sudden rock collapse, affecting a portion of the Siq cliff, was previously identified by the model as potentially unstable. This knowledge, associated to the outcome of the stability analyses, also through a numerical model, will help in identifying the most sustainable actions to be realized to mitigate the risk of collapse in such a vulnerable and complex context

Susceptibility to Sea Cliff Failures at Cala Rossa Bay in Favignana Island (Italy), page 537

Roberto Iannucci, Salvatore Martino, Fabio Martorelli, Luca Falconi, and Vladimiro Verrubbi

Abstract: Since the Roman Age and until the last century, an intense quarry activity took place at Favignana Island (Sicily, Italy) that significantly changed the morphology of the eastern part of the Island. This mining activity produced an extensive network of open air quarries, underground quarries and tunnels, locally named "Pirrere", that are hosted into Pleistocene porous carbonate grainstones. The resulting effect is an impressive landscape which makes the Favignana Island a highly frequented touristic site. Although greatly influenced by past human activity, the sea cliffs are affected by diffused instabilities as proved by the evidence of wide block-size talus distributed all along the coast line. Slope stability analyses were performed on the sea cliff of the Cala Rossa bay, in the north-eastern part of the Island. The Cala Rossa cliff slope is a sub-vertical scarp with an elevation between 20 and 25 m and an extension of about 300 m. To constrain such analyses, detailed engineering-geological and remote surveys were carried out to reconstruct the geological setting as well as to characterise the mechanical properties of the rock mass joints. In addition, 10 sub-vertical quarry walls were surveyed to realise a 3D model of the joints net. The collected field evidences account for a mixed genesis of the intense joints net that involve the calcarenite as it results by both tectonic and gravitational effects. Based on the surveyed joints attitude and on their spatial distribution, a detailed kinematic-compatibility analysis allowed to identify three types of rock landslide mechanism (i.e. planar sliding, wedge sliding and toppling) that affect the sea cliff and 78 rock blocks particularly prone to failure were identified. Considering hydrostatic pressure related to joints saturation condition (dry, half-saturated and full-saturated joints) as well as pseudostatic forces due to earthquake (values of PGA associated with return times of 0, 50, 475 and 2475 years), a total of 12 hazard scenarios were analysed each of which was specifically considered for one of the sea cliff sectors. The results obtained at Cala Rossa sea cliff demonstrate that: i) planar and wedge sliding are more suitable landslide mechanisms respect to toppling; ii) the eastern sectors of the sea cliff show higher susceptibility to failures; iii) water pressures within joints play a more destabilising action respect to earthquakes. These represent a relevant contribution to manage protection strategies to reduce the landslide risk in the touristic site of Cala Rossa bay and to preserve the unique cultural heritage represented by the "Pirrere" quarries.

Numerical Simulation on Gentle Dip Slope Deformation Caused by River Erosion, page 557

Tien-Chien Chen, Feng-Long Chou, and Cheng Meng Hsieh

Abstract: This study investigated the creep deformation of a gentle dip slope induced by river erosion. In the Ai Liao River (Southern Taiwan), more than 20 rainfall events have induced massive landslides in the dip slope terrain as a result of lateral erosion of the river channel. Numerical simulations revealed that when the riverbank cutting angle is less than 30°, only circular slip and creep folds occur in the slope, with multiple small folds occurring from the toe to the top of riverbank (but no rapid damage occurs). When the river cutting angle is between 30° and 45°, drag bending folds are likely to occur on the contact surface between the surface and bottom layer, and a sliding surface appears along the contact surface. Finally, when the river cutting angle is more than 45°, slope movements occur, leading to significant, rapid block damage.

III-15. Livelihood by Landslide Damming in Jure Village

Tien Pham

Photo abstract: A deep-seated catastrophic landslide was triggered by heavy rainfall around 2:30 AM, Saturday morning on 2 August 2014 in Jure Village, Sindhupalchok District, Nepal. The rapidly moving landslide not only killed 156 people but it also demolished a large number of houses in the Jure community. The massive movement of the landslide rushed down to the Sunkoshi River, stopped at the toe and formed a huge natural dam with an impoundment capacity of 11.1 cubic meters. The impounded water in the upstream area induced a disastrous flood inundation that seriously affected to households living along the right bank of the river. The landslide dam was breached by overtopping and piping phenomena on September 7, 2014. Although the disaster had caused extensively human and economic losses, the damping has been providing benefits to poor people by creating a livelihood from sand exploitation activities. By damping the river course, several hundred thousands of cubic meters of sedimentary material were accumulated on the river bed behind the dam in the upstream area. For poor people in the landslide-affected area of Jure village, sand exploitation brings more economic advantages for their daily lives. This landslide case has not only shown for the first time the positive aspect on human lives but it has also presented human adaptability to landslide hazards by exploiting construction sand.

III-16. "Pirrere" quarries and unstable sea cliff in Cala Rossa bay (Favignana Island, Italy)

Roberto Iannucci

Photo abstract: In Favignana Island (Sicily, Italy) a mining activity was actuated since the Roman Age and until the last century, significantly changing the morphology of the eastern part of the Island. In fact, this mining activity produced an extensive network of open air quarries, underground quarries and tunnels, locally named "Pirrere", that are hosted into Pleistocene porous carbonate grainstones. Currently the landscape shows sea cliffs greatly modified by these abandoned quarries and affected by diffused gravity-induced instabilities. In Cala Rossa bay, the landslide process is led by a lateral spreading phenomenon due to the presence of a Pliocene clay under the Pleistocene calcarenites: the horizontal deformations affecting the clayey materials induce cracks in the overlying stiff rock, favouring the detachment of single rock blocks by typical rock landslide mechanisms (i.e. planar sliding, wedge sliding, toppling and falling).

III-17. Attabad Landslide

Sajid Ali

Photo abstract: The Attabad landslide is located along the Karakoram Highway (KKH), North Pakistan. The landslide body was composed of boulders of granodiorite of Karakoram batholith and matrix. Its occurrence resulted into burial of one big village, dammed Hunza river (20 Km long lake) and submerged the KKH (24 km). This landslide was triggered by Astore earthquake (2002; M=6.2). Due to the formation of lake around 30 village were vacated and road communication between Hunza and rest of the country was totally disrupted.

III-18. Debris Dam formed on the River Kanaka (Tributary of Tista)

P Thambidurai

Photo abstract: On 13th August 2016 the Kanaka tributary of Tista River had been blocked by the rock debris from slide on the left bank of the river at Mantam village at 4th mile on the way to upper Dzongu in North Sikkim, India (27° 32.291'N, 88° 29.664'E). The length of the slide is 875km from crown to Toe and 350m of width. The debris consists of gneissic boulders and flakes of biotites and Muscovite. The landslide caused due to heavy precipitation at high degree of dip angle more than 400 where intense weathering observed across the slope. At the time of landslide, debris flow has made 65 meters

power with respect to landsliding. As a result, a multiple logistic regression model was obtained, which was applied to construct a continent-wide landslide susceptibility map for Africa. We applied Monte Carlo simulations to calibrate this model. Further validation was carried out, with independent landslide data, not used for the Monte Carlo simulations. The results show that topography, seismic activity (peak ground acceleration) and precipitation are the most significant variables, explaining the spatial distribution of landslides all over the African continent. Interestingly, our analyses showed that also seismic activity is a highly relevant factor in simulating spatial patterns of landslides across Africa. This is surprising, given the overall low degree of seismic activity and the limited occurrence of strong earthquakes, directly triggering landslides. These observations concur with several other recent studies, indicating that earthquakes may not only trigger landslides, but can also increase landslide susceptibility (e.g. by weakening surface lithologies).

P29. Influence of diatoms content in relation to the slope deformations and soil behavior in the cuts of line constructions (Forum Theme 5)

Pavlína Frýbová, Radka Drápalová, Věra Glisníková, Alexandra Erbenová

Abstract: Within the field of geotechnics, diatom clay soils are considered as one of the risk groups of soils because of their specific mechanical behaviour. Clay properties have been investigated depending on the content of diatoms. To investigate the effects of diatom microfossil content on the index properties of clay soils, measuring tests were performed on cohesive soils with different diatom microfossils content. Based on the observed nature of the soil's behaviour, it was possible to design a simulation of the mixture's behaviour for an established amount of diatoms in the mixture.

P30. LANDSLIDE DAMMING IN A HIGH RISK AREA

Guido Paliaga, Fabio Luino, Francesco Faccini, Laura Turconi, Peter Bobrowsky

Abstract: The landslide dam of Prato Casarile, in the Bisagno valley (Genoa metropolitan area) is a classic case study illustrating the interactions between degradation processes and structural stabilization interventions aimed to reduce the risk level in a densely populated area. The stabilization structures realized after the 1953 and 1970 disastrous events have been highly damaged by the recent ones, in particoulr in 2014. Actually the structures need important maintenance interventions and wider prevention actions are needed in order to control and mitigate the risk level in the highly populated area downstream from the landslide dam.

P31. LANDSLIDES AT ANGANGUEO (MEXICO): Shallow and deep reactivation from 2010 rainfall (Forum Theme 4)

Cecilia Irene Villaseñor Reyes, Víctor Manuel Hernández Madrigal, Sócrates Figueroa Miranda

Abstract: The 4th of February of 2010 the town of Angangueo, as all the Eastern part of Michoacán, was affected by climatological phenomena that produced heavy and prolonged rain in which the accumulated precipitation was of 300mm/48 hrs (33% of the annual precipitation in two days). These caused floods, debris flows, landslides, human losses, loss of crops, damage in infrastructure and economic loss. The investigations obtained by this investigation team allowed the elaboration of landslide inventory map of Angangueo and the numerical modelling of debris flow deposit (FLO-2D). Also, posteriori works of cartography-inventory and GPS monitoring have allow us to found the correlation of the extraordinary rainfall of 2010 with the reactivation of Deep Slides in Las Pilas and Jungapeo. Additionally, it was established that this rainfall event was the primary triggering factor in both kind of mass wasting, however, other factors as the lithology (slightly resistant, highly permeable and weathered) and the land use (especially perennial crops and its flood irrigation system) had the same importance.

P32. Landslide monitoring at the Cala Rossa sea cliff (Favignana Island, Sicily) (part of session 2.1)

Luca Falconi, Roberto Iannucci, Salvatore Martino, Antonella Paciello, Augusto Screpanti, Vladimiro Verrubbi

Abstract: Favignana Island is a historical and environmental attraction site frequented by tourists especially during the long warm season of the year. Over several centuries the sea cliffs have been exploited for the production of building stone. Currently, the quarries used for the rock extraction as well as the natural cliffs are undergoing extensive erosional and gravitational processes. Besides putting at risk the safety of the people attending the area, the widespread rock falls are likely to threaten sites of great historical and anthropological value that, once destroyed, can no longer be reconstructed. The rock mass quality assessment and slope displacement monitoring of cliffs were carried on to identify the most unstable areas providing a support to the local authorities in the implementation of effective and sustainable mitigation measures. If adequate measures will be taken in future, operators and users of the tourist circuit will have the opportunity to enjoy these amazing sites with a reduced risk.