Site characterization and mitigation of the coastal risks: the southern Sicily and the Maltese islands

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ABSTRACT: The southern coast of Sicily and the islands of the archipelagos of Malta are highly exposed to risks coming from the sea. Such coasts are subjected to fast erosion due to natural and anthropic causes which involve the failure of cliffs, the triggering of localized erosions and the possibility of flooding. In this context the Project *NEWS - Nearshore hazard monitoring and Early Warning System* - (INTERREG V-A Program "Italia-Malta") aims to tackle such problems through the development and use of smart technologies as well as traditional methods. The research activity aims to develop an integrated system, which includes monitoring, early warning monitoring and mitigation of the coastal risks, specifically aiming at advising the population about the risk of flooding, littoral sand erosions, cliff failures and at activating protection measures. To validate the proposed integrated system a campaign of investigation including geological field survey and geotechnical laboratory tests will be planned in four test sites. The test sites include different coastal stretches: the coast of Granelli (Pachino) characterized by a thin sandy coast; the coast of Santa Maria del Focallo (Ispica) in South Sicily; the high stretch of coast present in Selmun and Wied Il-Mielah in the archipelago of Malta. The paper focuses on the results regarding the geophysical and geotechnical characterization for a Maltese site. A basic equation for toe erosion by waves proposed by Sunamura [30] can be applied to study the phenomena on the test sites. This approach can be a useful contribute to begin to assess defense strategies for the erosion risk.

Keywords: coastal risk, erosion, cliff failure.

1. Introduction

In the last decades there was an increasing concern about the occurrence of natural hazards, especially regarding the risks coming from the sea. This is mainly due to the increased human exposure. The social and economic costs of natural hazards are substantial, not only as damages costs, but also due to recovery.

This paper would like to be a "first step" in the direction of improving the general knowledge of erosion problems and cliff failure within two coastal sector in the South Sicily (Italy) and in the Maltese archipelago. Obtained results are useful information to develop an integrated coastal erosion management program aimed to partially solve erosion problems and review location of human activities and arrangements.

The test sites include some areas: i) the coasts of Granelli (Pachino) and Santa Maria del Focallo (Ispica) in South Sicily, characterized by thin sandy coast; ii) the high stretch of coast of Selmun and Wied Il-Mielah in the archipelago of Malta. These areas are located in a geological and geomorphological context that makes them particularly vulnerable to natural events (landslides, floods, coastal erosion, etc.) and that requires an accurate knowledge of the issues related to natural instabilities. This study has been developed within the Project *NEWS - Nearshore hazard monitoring and Early Warning System* - (INTERREG V-A Program "Italia-Malta") which is focused on the erosion problems of coastlines.

Coastal retreat is the landward displacement of shoreline because of marine erosion or flooding [1]. Usually, it is contrasted by protection works constructed on very specific sites, to solve concrete and urgent problems. Most of them constitute a temporary remedial without a general erosion management plan [2, 3]. According to [4-6], coastal erosion management must be organized at fully scales (i.e. at a large, regional scale) in which the dynamics of the whole coastal system is represented. In this sense, [7-9], affirm that for a deeply understood of coastal erosion problems it is important to know the areas of inputs, transfers, storage and outputs of sediments.

Cliff failures are predominantly linked with the lithology, the structure of the rocky mass [10] as well as the weather conditions and the wave action [11].

The factors, affecting intrinsically the stability of cliffs, are therefore the lithological, stratigraphic, structural and morphological (slope and aspect of the wall, etc.) settings and the hydrogeology and the mechanical properties of the rocky mass. However, the external factors are represented by impact of sea waves, currents and tides, as well as meteorological agents, the biological activity of marine micro and macro organisms and, finally, by human activities.

In order to analyze the destabilizing effect of the waves on the cliff, it is necessary not only to consider the most violent storms that occurred in the study area, but also to examine the frequency of the wave motion, since just the not very energetic but extremely continuous waves cause the erosion of the coastal slopes [12, 13], also associated with mechanisms of failure, due to cyclic stress of the rocky mass [14-16].

The impact of the waves and the littoral currents on the cliff also depends on the morphology and roughness of the seabed, which is able to modify the effect of wave trains. In particular, the changes in the underwater topography may induce the dissipation or, conversely, the concentration of the energy only in some zones of the coast [17, 18].

Another important factor is the orientation of the wave fronts respect to the coast line, because the actions and the energy that they transmit on the cliff depend not only on characters of the waves, but also on the direction of propagation [19]; it is a function of the height of breaking wave and the angle between the wave front and the coast [20]. So, as the direction of propagation results to be orthogonal to the coastline, the higher will be the energy that is transferred by waves on the coastal wall [21].

2. The research project NEWS: an overview

The Project NEWS - *Nearshore hazard monitoring and Early Warning System* - (INTERREG V-A Program "Italia-Malta") focuses on fast erosion due to natural and anthropic causes which involve the failure of cliffs, the triggering of localized erosions and the possibility of flooding with reference to the southern coast of Sicily and the islands of the archipelagos of Malta.

To achieve this goal, it is necessary the acquisition of local knowledge on issues related to coastal erosion and landslide trigger also by the development of smart technologies. The advances in cloud computing have opened new opportunities also in natural early warning systems and emergency management issues.

In particular, the project aims to develop an integrated system, including monitoring, early warning and mitigation of the coastal risks, advising the population about the risk of flooding, littoral sand erosions and cliff failures. An information system based on an Open Source Cloud Computing platform following a PaaS (Platform as a Service) and SaaS (Software as a Service) approaches will be realized (Fig. 1).

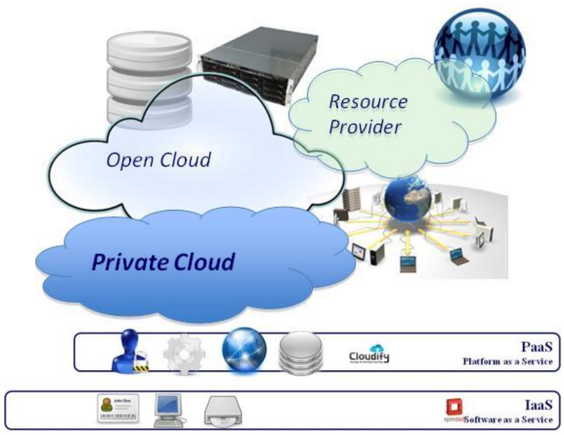


Figure 1. Open source cloud computing platform.

The scientific community has recognized the added value of a geo-analytic approach in complex decision, making processes for critical situations due to natural events such as coastal erosion, landslides and cliff failures.

In this case SaaS services are devoted to the evaluation of risk and active people participation in monitoring and preventing hydro-geological risk by the modeling and simulation of social dynamics in the prevention and management of emergencies.

The PaaS Service consists in implementing a GIS platform which allows the adoption of analysis techniques to perform calculations on a large number of parameters, with the possibility to overlap and cross-referencing spatial data. This task aims to expand the potential of traditional GIS, creating a horizontal platform that allows the simultaneous management of both data from consolidated data-bases, and data from the monitoring network. The information stored in the GIS will be exposed through open services.

Informative applications based on real time risk maps, to support citizens and technicians in alert and emergency, for risk prevention and/or emergencies management will be developed. The application is an advanced system which combines weather forecasts with the probable impacts on the territory, providing a forecast of the risk of occurrence of phenomena (Fig. 2) and providing warnings on staying in specific areas.

Figure 2. Network based on sea/ground base instrumentations.

3. The research project NEWS: the test sites

The study focuses on different sites regarding low and high coasts: i) the coasts of Granelli (Pachino) and Santa Maria del Focallo (Ispica) in South Sicily (Fig. 3), characterized by thin sandy coast; ii) the high stretch of coast of Selmun (Fig. 4) and Wied Il-Mielah (Fig. 5) in the archipelago of Malta, characterized by high cliffs and rocky arch.

To develop an integrated coastal erosion management program it is necessary to analyze the evolution of coastal erosion and cliff failure, to identify correlations between piezometric levels, rainfall and landslide with the aim to obtain the localization of potential risk areas.

4. The Maltese test site

The Maltese Archipelago is situated in the Mediterranean Sea, about 290 km northeast of Tunisia and 90 km south of Sicily. It consists of three major islands: Malta and Gozo, the southerly and northerly islands, respectively, and Comino, which lies in the Comino Straits separating the two largest islands (Fig. 6).

Figure 3. Granelli and Santa Maria del Focallo (Sicily).

Figure 4. Selmun Bay (Malta).

Figure 5. Il - Mielaħ Window (Malta).

In this paper we present a preliminary study of the Maltese test site, mainly focusing on the risk of landsliding and rock falls. In particular, the combination of vulnerable geomorphological features, intensive land use and cultural/touristic importance implies that the study area is exposed to a considerable natural risk.

The Maltese islands are formed by limestones and clays of Oligocene and Miocene epochs that compose a sedimentary sequence of five main geological formation, from the oldest (Fig. 6a and Fig. 6b):

- Lower Coralline Limestone Formation (LCL), hard and compact grey limestone of Oligocene (Chattian), with thickness about 140 m, which shapes the steep cliffs in the southwestern part of the Malta Island;
- Globigerina Limestone Formation (GL), soft yellowish fine-grained limestone of Lower Miocene age (Aquitanian-Langhian) with a thickness from 20 m up to 200 m;
- Blue Clay Formation (BC), very soft pelagic blue or greenish grey marl and limey clay of Middle Miocene age (Serravallian) with a thickness varying approximately between 20 m and 75 m;
- Greensand Formation (GS), massive, friable brown to dark green glauconite and gypsum grain-rich bioclastic limestone of Upper Miocene (Tortonian), having thickness less than 1 m in Malta and up to 10 m in central sector of Gozo;
- Upper Coralline Limestone Formation (UCL), pale grey and orange fossiliferous coarse-grained limestone, up to 160 m thick, of Upper Miocene in age, composed by four different members.

The different mechanical properties of each geological formation induces a marked difference in the values of the S-waves velocity (V_s), as evidenced by a V_s profile for the Selmun area showed in Figure 6c.

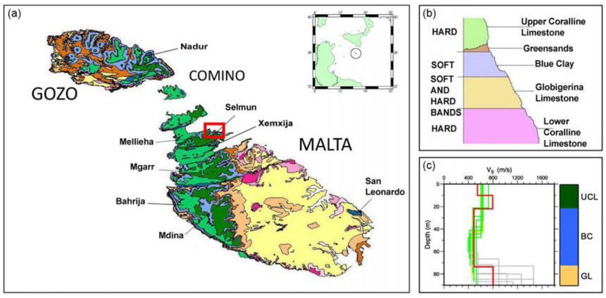


Figure 6. Geology of the Maltese Islands: (a) the geology map (the different shades of green correspond to the four different members of the UCL), the position of the Maltese islands in the Mediterranean Sea and the location of the Selmun Promontory in Malta (in the red frame); (b) sketch of the sedimentary sequence; (c) a V_s profile for the Selmun area.

The stratigraphic succession in the Selmun area (Fig. 7) is composed of 20 m of the UCL, 30 m of the BC and the GL, all with almost horizontal strata. This typical geological feature, characterized by the juxtaposition of stiff rocks on a plastic deposit (i.e. the stiff UCL on the plastic BC), leads to a lateral spreading phenomenon [22]. Lateral spreading shapes a plateau of stiff rock bordered by jointed unstable cliffs, favoring the detachment of single rock blocks by typical rock landslide mechanisms, i.e. planar sliding, wedge sliding, toppling and falling [23]. According to [24] and [25], the resulting landslide process should be defined as a complex type. Unstable cliff slopes cut in a summit plateau are the typical landscapes of the Malta Island [26].

Figure 7. Selmun Promontory with the cliff slope showing the UCL-BC contact and blocks detached from the UCL plateau [27].

4.1. Geotechnical and geophysical survey

The study in the archipelago of Malta forecasts a detailed geological, geotechnical and geophysical characterization to reconstruct the geological setting of the cliff slope, as well as, to measure geomechanical properties of the jointed rock mass.

Furthermore seismic noise measurements can be used to investigate landslide-involved slopes or to characterize blocks of unstable cliffs through different approaches. At this step of study, literature available data regarding the area have been collected [28, 29, 30].

A dense joint net was recognized on the plateau surface and on the cliff wall. Combing information derived by a GPS device and field observations as direction and length of joint segments, the joints of the rock mass were mapped and reported on a satellite view.

Each joint will be characterized according to the ISRM standard [28] in terms of: attitude, spacing, persistence, aperture, filling, water flow, JCS coefficient (joint surface compressive strength, derived using the Schmidt rebound hammer) and JRC coefficient (joint surface roughness, obtained by the Barton comb).

All the collected parameters will be inventoried in a GIS database [31].

The rock mass matrix will be characterized through laboratory tests performed on cubic samples of the UCL. The literature available data of Selmun promontory regard the values of weight per unit volume of solid fraction γ_s equal to 26.37 kN/m^3 and of natural weight per unit volume γ_n equal to 21.05 kN/m^3.

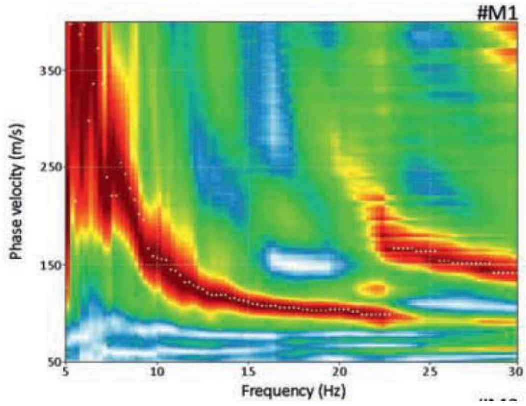
The point load test estimated a uniaxial compressive strength σ_c between 63.0 MPa and 79.8 MPa. Based on the Schmidt hammer and on the laboratory tests results, an average joint surface compressive strength of 41.0 MPa was estimated for the analyzed joints.

Combining all the available collected geomechanical data, it was possible to obtain a geotechnical model of the Selmun Promontory.

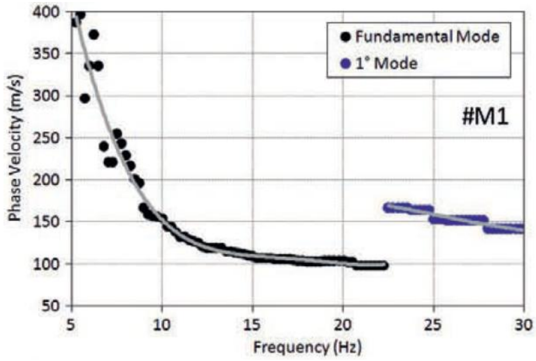
The dynamic properties of the main lithotypes outcropping in the study area will be evaluated through the non-invasive technique MASW. The results of MASW tests performed in several areas of Malta are available [32, 33]. Tests were carried out by a 12-channel seismograph equipped with 4.5 Hz geophones. A linear array having a length of 48 m, depending on the available free space at each site, was deployed using a 4 m interval pitch between the sensors. An 8 kg hammer source, with a fixed 10 m offset distance was used, recording five shots, 3 s length, with a sample rate of 512 Hz. Phase velocity vs. frequency contour plot spectra obtained from MASW tests are represented in Figure 8a for one site of Malta. The automatic picking of the dispersion curve was approximated through a regression to a polynomial curve of fourth/sixth degree according to the observed trend (Fig. 8b).

The use of techniques based on the propagation of surface waves made possible to detect the $V_{S,30}$ features of the main outcropping lithotypes and consequently the classification of the investigated sites.

Additional geological, geotechnical and geophysical survey will be performed to analyze the slope stability of the Selmun cliff slope and Wied Il-Mielah.



(a)



(b)

Figure 8. (a) Phase velocity vs. frequency contour plot spectra; (b) polynomial regression curves obtained from the automatic picking [29].

5. Sea cliff stability and coastal cliff erosion

Wave-induced sea cliff erosion is a significant problem along many of the world's coastlines, and the gradual increase in mean global warming, will among other things lead to a rise in the sea level and to a worsening of this problem.

This increase will cause a marked rise in the coastal erosion of beaches and rocky coasts. For purposes of coastal planning and engineering mitigation, it is therefore necessary to assess the potential increase in erosion processes due to wave action, particularly if they can accelerate basal erosion and mass movements on rocky coasts [12].

The basic factors controlling erosion are the force of waves at the base of cliffs and the mechanical strength of rock masses, which is affected by joint patterns.

Additional factors are reduction in rock strength owing to weathering by sea spray, tidal action, temperature variations and material fatigue caused by cyclic loading of the wave action. Several papers, particularly the one by Sunamura [11], indicate that compressive strength best describes the mechanical strength of cliff material.

The basic driving mechanism of coastal cliff retreat is usually assumed to be wave erosion at the base of the sea cliff. When waves impact sea cliffs they exert hydraulic forces, including compression, and shear. When sand grains or cobbles are available as abrasion and impact tools , waves may also exert mechanical action.

This process, which often leads to undercutting and subsequent failure of the upper cliff, can be considered as a major cause of erosion for many sea cliffs of the test sites (Figure 9).

Figure 9. The retreat of coastline (GCSE - Geography Guide Coasts).

Although the natural process of sea cliff erosion is complex and is the cumulative result of numerous interacting variables that are significant at various spatial and temporal scales, wave erosion at the base of the sea cliff is usually assumed to be the basic controlling factor on the process of coastal cliff retreat. However , quantitative analyses of the relationship between wave energy and the erosion of rocky, have not been well established, and are necessary if we are to understand what controls the process of coastal erosion [21].

The physical properties of coast al cliffs influence erosion by either increasing or reducing the effectiveness of waves as an erosional agent.

Sunamura [11] divides the process of coastal erosion into two general factors under this premise: (1) the assailing force of waves upon the beach and the base of the coastal cliff, and (2) the resisting force of the beach and cliff forming material. The assailing force of the waves is dependent on the following parameters: (a) the water level as related to tidal variation; (b) beach sediment type and size; (c) shore face morphology; and (d) deep-water wave characteristics.

The stability of the coastal cliffs is normally analyzed similarly to that of the rocky slope, by geo-structural analyses [34] and stress-strain modeling, with a pseudo-static analysis of the action of wave motion incident at the cliff toe.

Nevertheless cliff failures are predominantly linked with the lithology, the structure of the rocky mass, as well as, to the weather conditions and the wave action. So, in the coastal area, the analysis about the morphological evolution and instability, that affect the cliffs, requires understanding of the complex framework of interactions between the internal characteristics of the coastal system and the external stresses, including sea wave action and weathering.

For this reason, methods to assess cliff erosion must take into consideration the possibility to include these aspects in the estimation of the rocky cliff stability.

With this aim, new methods can be elaborated considering the different factors contributing to the stability of sea cliff. These methods, generally, propose a modification of the classification system based on the Slope Mass Rating Index (SMR), through the integration of additional parameters such as wave action and rock mass conditions.

Furthermore, to analyze the destabilizing effect of the waves on the cliff, it is also necessary to examine the frequency of the wave motion [35], since just the not very energetic but extremely continuous waves cause the erosion of the coastal slopes, also associated with mechanisms of failure, due to cyclic stress of the rocky mass.

For this purpose, measures like the ambient noise and strong-motion records, can be used to analyze the dynamic behavior of the cliff. The wavelets constituting ambient noise undergo reflections, refractions and trapping due to wave guide effects, as well as attenuations, which depend on the nature of the subsoil.

Ambient noise is present everywhere on the Earth's surface and is generated by environmental phenomena (ocean waves, wind), anthropic activity. Ambient noise is the result of a random activation of uncorrelated sources distributed at the Earth surface all around the measuring site and it involves very small oscillations (10-15 m/s^2 in acceleration), much smaller than those induced by earthquakes.

These information's are hidden into random noise and can be extracted through appropriate techniques. Horizontal-to-Vertical Spectral Ratio (HVSR analysis) is one of them (Figure 10).

This technique provides two basic pieces of information: identification of seismic resonance phenomena induced by the presence of sharp seismic impedance contrasts in the subsoil and the relevant resonance frequency. Strong-motion recordings, from 0.001 to 0.01 g upwards, are usually connected with near-source earthquake shaking, but a strong ocean storm could provide as well similar ground acceleration on a cliff.

The interpretation of these measures, related to the effect of the wave pulse and propagation on the cliff, can be supported by the mechanical characterization of the rocky mass (Figure 11), to individuate a correlation between the dynamic response of the cliff to the wave action and the structural properties of the rocky mass.

To validate this approach the solutions developed will be applied in the Maltese Islands, as well as, in the southern coast of Sicily (Italy): the coast of "Granelli" (Pachino) characterized by a thin sandy coast, and the coast of "Santa Maria del Focallo" (Ispica). In these regions there are centers of inestimable value, with a huge cultural tradition and historical importance.

These regions are situated in geological and geomorphological settling environments, particularly vulnerable to natural disasters (landslides, flooding, coastal erosion and so on). Cliffs 6,0-7,0 m in height are a quite common morphology along the coast (Figure 12).

Rocks with a low degree of resistance are constituted by the sandstones of the Pleistocene marine terraces and the Low Miocene marls that outcrop at "Pietre Nere" and at "Point Ciriga" (Figure 13).

These "weak" rocks are mainly affected by landslide

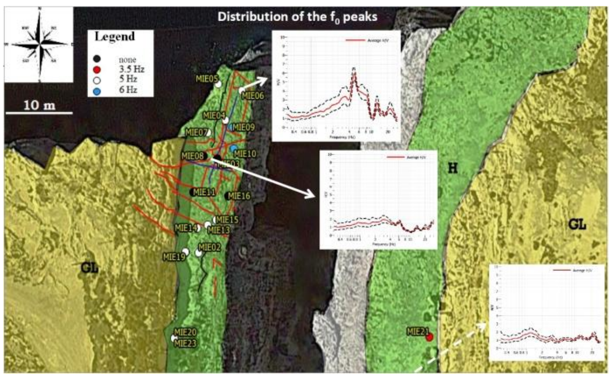
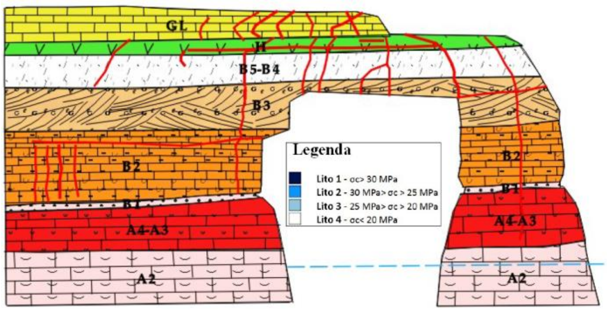


Figure 10. Seismic noise measurements: distribution of the f_0 peaks.

(a)



(b)

Figure 11. (a) Wied il-Mielaħ (Maltese Islands); (b) engineering geological model.

and rock falls due to wave erosion at the foot of the cliff. The presence of rock blocks at cliff foot, remnant of previous falls, should have the function of reduce cliff erosion but, during heavy storms, sea waves overpass them and reactivate erosive processes [36].

In this context, the main goal of the research Project NEWS is to encourage interventions of Public Administrations about risk factors and to contribute for the analysis of the urban hazard [37], to pass the "best practices" of risk management and to lead to the preparation of strategies for the reduction of the risk related to the natural disasters [38, 39].

6. A basic equation for toe erosion by waves

Rocky coast landforms, from a global point of view, differ considerably in morphology, reflecting variations in wave climate, tidal range, local tectonics and hydro isostatic sea-level changes, as well as, lithological factors. Thus, model studies on the evolution of the cliffed coasts under stationary sea-level conditions have been intensively performed.

Common to the types of platform morphologies is that there is a cliff at their landward side.

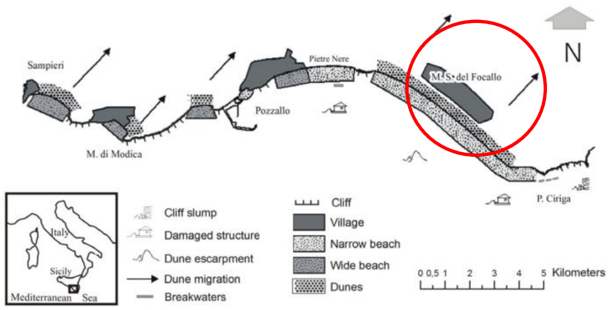


Figure 12. Landforms and human constructions along the Sicilian studied area [36].

Figure 13. "Point Ciriga" in the southern coast of Sicily (Italy) (photo by Massimo Calcagno).

The recession of the cliffs leads to the platform development. The most important driving force to cause cliff recession is wave action. It may be stated that no evolution of rocky coasts takes place without the action of waves.

Two crucial factors are involved in erosion of rocky coasts: wave action and rock resistance to erosion.

An important factor that always acts to diminish the rock resistivity is weathering.

Several studies have introduced the wave energy flow as a representative of the wave factor, and as a parameter for the cliff resistance, have incorporated the compressive strength of the rock.

Sunamura [30], for instance, developed the following cliff erosion equation based on the result of his wave tank experiment:

$$dX/dt = CF \tag{1}$$

where X is the erosion distance, t is the time, F is the erosive force of waves, and C is a proportional coefficient.

Waves always exert their assailing force on the face of a cliff, irrespective of their magnitude, whenever they act on the cliff. Once the assailing force exceeds the resisting force of cliff material, then waves possess the erosive force F to accomplish erosion.

Therefore, the erosive force is defined as the force which leads to actual removal of cliff substrate. Sunamura [30] proposed the following logarithmic function for F considering a threshold concept:

$$F = \ln (F_W/F_R) \tag{2}$$

where F_W is the assailing force of waves and F_R is the resisting force of cliff-forming rocks. This relation is valid only when $F_W > F_R$.

Through the selection of appropriate physical quantities for F_W and F_R, Eq. (2) can be applied to field studies and model calculations.

However, some difficulty is involved in the mathematical treatment of Eq. (2) due to the logarithmic function, so that a simpler relation for F has been proposed:

$$F = (F_W/F_R) - 1 \quad for \quad F_W \geq F_R \tag{3}$$

$$F = 0 \quad for \quad F_W < F_R \tag{4}$$

Waves exert hydraulic action, mechanical action and, on some occasions, wedge action. Almost simultaneous occurrence of these processes characterizes wave assailing force.

Considering that hydraulic action is directly related to wave energy, Sunamura [30] derived the force from the kinetic energy of water particles at the crest of broken waves rushing to a cliff. The result is given by:

$$F_W = A\rho g H_f \quad (5)$$

where A is a dimensionless coefficient, ρ is the water density, g is the acceleration due to gravity and H_f is the height of waves just in front of the cliff irrespective of breaking and broken waves.

The Eq. (1) can be rewritten as fellowing:

$$dX/dt = K(\rho g Hf/Sc) \quad (6)$$

where H_f is the height of waves just in front of the cliff irrespective of breaking and broken waves, *Sc* is the compressive strength, ρ is the water density, g is the acceleration due to gravity and K is a coefficient.

Finally, the resisting force of cliff-forming rocks F_R is assumed to be proportional [11] to the compressive strength of the rock mass *Sc* or Uniaxial Compressive Strength (UCS). In particular, UCS is one of the most important parameters since it depends on physical properties of the rock (i.e. porosity, micro fracturing, texture, etc.). Spacing of discontinuities affects the degree of fracturing, while their orientation plays a significant role in the stability analysis.

Compressive strength values can be obtained through laboratory tests. Non-destructive tests are also available for assessing compressive strength by the use of the Schmidt hammer, widely employed in geomorphological research.

Examination of the validity of equation (6) requires several datasets that contain: (a) the rate of erosion, (b) the height of waves that caused erosion, and (c) the strength of cliff-forming rocks.

An interesting relationship between mean erosion rate, Schmidt hammer rebound values and total stability ratings was proposed by Benumof & Griggs [40].

7. Concluding remarks

In the Mediterranean area rocky cliffs represent widespread high-risk landforms, as they are highly frequented touristic places often interested by landslide processes.

In this context, Malta represents a significant case study as several cliffs located all around the island are involved in instability processes, as evidenced by wide block-size talus distributed all along the coast line. These diffused instabilities are related to the geological setting of Malta Island, i.e. the over-position of grained limestone on plastic clay deposits that induces lateral spreading phenomena associated to falls and topples of different-size rock blocks and is responsible for a typical landscape with stable plateau of stiff rocks bordered by unstable cliff slopes.

At the same time, in the southern of Sicily (Italy) the coast of "Point Ciriga" (Ispica) characterized by weak rocks are affected by landslides and rock falls due to wave erosion at the foot of the cliff.

In the framework of the research Project NEWS literature available data were collected to characterize the jointed rock mass and in the future new geological, geo-

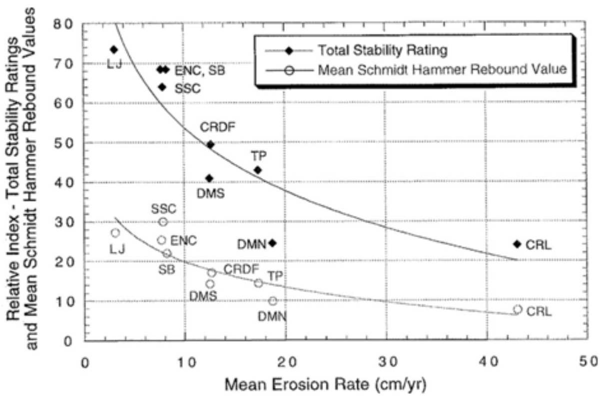


Figure 14. Relationship between mean erosion rate, Schmidt hammer rebound values and total stability ratings for the San Diego County CA [40].

physical and geotechnical investigation will be carried out. The detailed survey will be aimed to reconstruct the geological setting and to define the mechanical properties of the rock mass.

Based on the surveyed joint spatial distribution, single-station noise measurements could be used to cover both the unstable zone and the stable area.

It is possible to associate vibrational evidences to different instability levels, i.e. deriving the presence of already isolated blocks by the local seismic response.

The presented methodology can be a useful contribute to assess defense strategies for the Selmun and Wied Il-Mielah, in the frame of managing the landslide risk. At both sites, digital models of the main geological features have been created also using UAVs (unmanned aerial vehicles) equipped with different sensors (i.e. laser scanner, digital and thermal cameras, etc.).

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