BREAKING WAVES IN SOFT ROCK CLIFF RECESSION IN SOUTH-WEST SARDINIA, IT

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INTRODUCTION

The rapid recession of soft cliffs has recently attracted considerable attention from civil engineers that have developed simplified models of the multiple factors that control the process. Sunamura (2012) provided a state-of-the-art review about present-day recession processes on soft-rock cliffed coasts, developing and applying a model derived from the reanalysis of previously published data. In this paper, an improvement of Sunamura's model is proposed and applied to the cliff of Portu Maga, Sardinia (IT).

METHODOLOGY

The mechanisms of cliff toe erosion is based on the comparison between two forces: the assailing force of waves (F_w) and the resisting force of rocks (F_R). Erosion occurs only when the assailing wave force surpasses the rock-resisting force.
Melis et al. (2023) described the Sunamura's model features. Specifically, they presented the main limitations as that model:

- assumes that variables F_w and F_R are known with no random deviations;
- uses simplified mathematical conceptualization of the mechanisms;
- uses the same average value of parameter for the whole cliff;
- considers a single, measured or generated, storm.

The F_R of the sea cliff rock is determined by the mechanical strength of the material without discontinuities. Compressive strength, a widely used index with well-established testing criteria, is an appropriate parameter for the resisting force of rocks:

$$F_R = BS_c \tag{1}$$

where S_C is the compressive strength (Budetta et al., 2000) and B is a dimensionless coefficient.
F_w at the cliff toe exerts two kinds of actions on its face—a hydraulic and a mechanical one. Hydraulic action of compression and tension can be determined from analytical formulations and is the only component that can be evaluated in this approach.
Little is known about how to evaluate the fatigue limit of a rock mass under the action of waves in the field. Sunamura (2015) examined the Fw of laboratory breaking waves. He derived the force from the kinetic energy of water particles at the crest of breaking waves against the cliff face as:

$$F_W = A\rho g H_{S,f} \tag{2}$$

where $H_{S,f}$ is the significant wave height at the cliff toe, g is the gravitational acceleration, ρ is the water density and A is a dimensionless coefficient.
This paper presents a susceptibility index SI to erosion in the following form:

$$SI = \frac{F_W}{F_R} = \frac{A}{B}\frac{\rho g H_{S,f}}{\sigma_c} \tag{3}$$

B is closely associated with the structures, and the presence of discontinuities such as cracks, joints, faults, and bedding planes were accurately surveyed. This allows to estimate the effect produced by discontinuities on compressive strength reduction, through compression tests by crushing rock specimens. The Rock Mass index RMi has been developed in order to characterize the rock masses strength. It describes the method of determining the RMi for a rock mass using various common field observations and provides a measure of the reduction of intact rock strength caused by discontinuities, given by RMi = B · σ_c.
Great attention has been paid to improve the model of the physic characteristics of the impact pressures due to breaking waves on a vertical cliff. Specifically, A was calculated as the product of three factors:

$$A = \prod_{i=1}^{3} A_i \tag{4}$$

Where A_i represent:

- The wave asymmetry and skewness in the pressure diagram (A_1);
- The impulsive breaking wave pressure (Goda, 2010) (A_2);
- The relations between representative wave heights (A_3).

CASE STUDY

The study area is near Portu Maga beach (39.567°N; 8.458°E) on the southwestern coast of Sardinia (IT). The coastal strip is currently characterized by 5-10 m high cliffs, with scattered sandy pocket beaches and little bedrock promontories. The Portu Maga cliff, which is exposed to high energetic waves from NW, is currently affected by retreating processes (Figure 1).
The retreat speed is linked to the lithological characteristics of the Pleistocene series, which are mainly scarcely and irregularly cemented eolian sandstones. Furthermore, weathering processes lead the evolution of differential erosion morphosculptures. Sea spray, dissolution and aloclasm are added to continental processes (rainsplash, karsism, sheetwash erosion, rilling, gullying etc.).

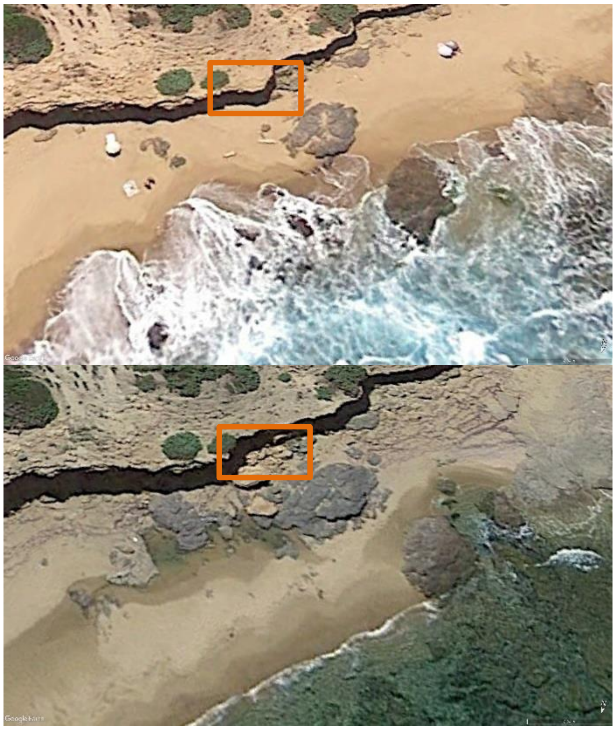

Figure 1. Orthorectified satellite images at Porto Maga cliff in 2015 (up) and 2017 (below). Orange box focuses on a major landslide in late 2015.

Low magnitude landslides occur on a seasonal or annual basis, involving volumes of less than 10 m^3 with metric or sub-metric retreat niches. Major landslides, with a 5 year frequency, affect the cliff over 4/5 meters, involving hundreds of m^3.
Morpho-topographic surveys were performed using multitemporal and multiscale aerial and UAV data processed through a GIS support. The analysis of the gravitational events frequency along the entire cliff point to an overall cliff retreat speed of 4 cm/y.
The rock geomechanical parameters are linked to the waves energy that triggers deep furrows of maximum run up at the base of the cliffs. This interaction results in numerous gravitational events (rock fall and toppling).
The retreat of the Portu Maga cliff due to a landslide is linked to base wave undercut processes at the base (runup notch) groove in the aeolian sandstones (Late Pleistocene), characterized by compressive strength of 18 Mpa and specific weight of 1.9 g/cm^3.
The numerical analysis allows to determine the cliff recession speed. The model parameters used for the cliff of Portu Maga are summarized in Table 1. σ_c was estimated for eolian sandstones with weak calcite cementation (Upper Pleistocene) (specific weight: γ_g = 1900 Kg /m^3).

Table 1. Model parameters at Portu Maga cliff

σ_c [Mpa]	RMi [Mpa]	A_1	A_2	A_3
18	3.2	1.5	9	2

Here, we processed wave data from an oceanographic buoy of the Italian Data Buoy Network (RON) (40°33′11′′ N; 08°07′00′′ E). The available time series covers the period between July 1989 and April 2008. The extreme wave analysis (EWA) of the geographic transposed data was performed with the Weibull distribution and estimated with the least square method (Sulis et al., 2017).

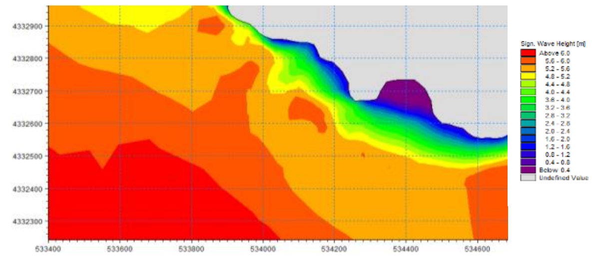

Figure 2. Map of significant wave height (H_s) simulated by DHI's MIKE 21 SW

The model was applied with a confidence interval of 95% (Δ95) to estimate from EWA the wave return period at 10 m depth, with $F_w > F_R$ and erosion occuring at the cliff toe. The 5-year wave height was therefore selected as the one whose properties could define the conditions of potential collapse due to overturning of the rock mass under an assigned level of uncertainty.
Results are compatible with geomorphological data on cliff retreat process, which, by considering a return period of 5 years, produces over 20 successive events an average retreat of the entire cliff of about 4 m in 100 years (i.e., with a retreat rate 4 cm/y).
Further improvements of this research will include both a model upgrade to the assessment of the impulsive breaking wave pressure and an extensive sea wave monitoring in shallow water at the cliff toe at Portu Maga.

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