The role of gravel pocket beach on stability of urban rocky coastline

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1. INTRODUCTION AND INVESTIGATION SITE

Gravel beaches provide natural coastal protection along other ecosystem services to many coastal areas. By dissipating wave energy, they can contribute to stability of cliffs and coastal structures behind them. This paper investigates the effectiveness of gravel pocket beaches (GPB) for protecting urban coastline in the city of Rijeka, Croatia. Two beach systems were studied, a natural system comprised of a beach and a cliff (Sablićevo) and a man-made system (Ploče) comprised of an artificial beach and a sea wall. The rocky coastline around Rijeka is predominantly formed in carbonates (Benac *et al.*, 2013). A number of pocket gravel beaches can be found at locations of previously weakened carbonates, where a local erosion of coastal cliffs provides the sediment supply (Pikelj and Juračić, 2013). This is a micro-tidal environment with a tidal range between 20 and 50 cm. The coastline is exposed to wind-generated waves from the south-east (SE) to south-west (SW) directions, with the largest significant wave height of 3 m in the Rijeka Bay (Lončar *et al.*, 2014). The highest waves from the SE direction are usually accompanied by storm surges. The heights water elevation of 1.27 m CVD was recorded at the nearby tidal gauge in Bakar Bay, east of Rijeka, on 29th October 2018.

Sablićevo is a natural GPB, subject to moderate beach erosion visible on a 50-year scale (Fig 1). The beach was formed by the erosion of the rock mass. While cliff erosion provides beach sediment supply, it threatens local buildings and infrastructure. Hence, cliff was reinforced with gravity wall, steel netting and ground anchors to prevent further coastal retreat, which reduced sediment supply to the beach. Geotechnical works have been carried out on the beach on several occasions since 1980, but those interventions did not solve the problem and new rock fall would occur each time. Eroded beach in front of the cliff cannot reduce wave attenuation during storm surges and allows high waves to access the cliff face affecting its stability. There is also a negative impact of wave quarrying and abrasion (or corrosion) on rock. As result, the cliff erosion is continuing and the beach is eroding.

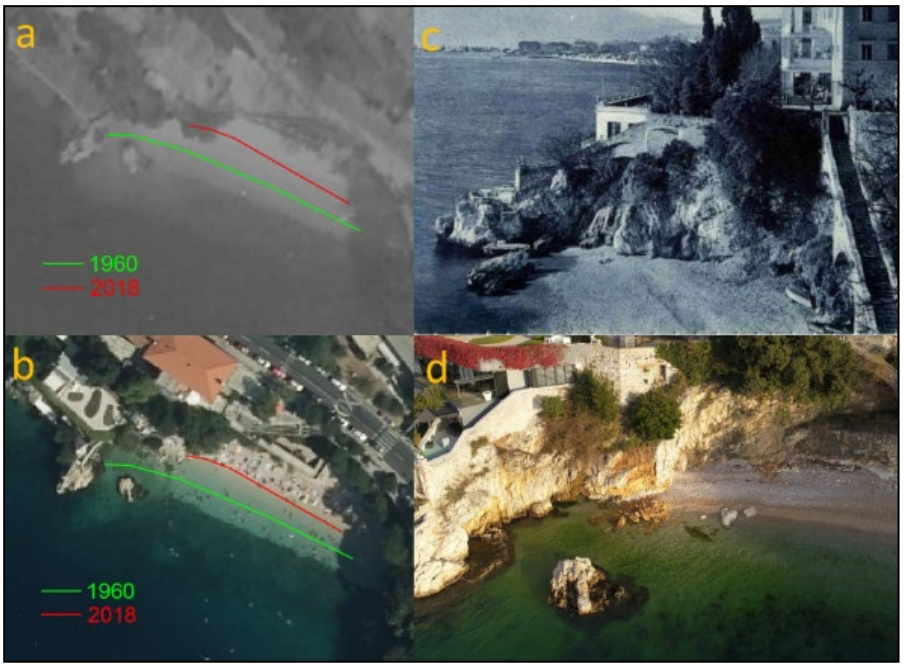

Figure 1: Estimation of beach coastline retreat (a, b). Sablićevo beach around 1930 (c) and 2018 (d)

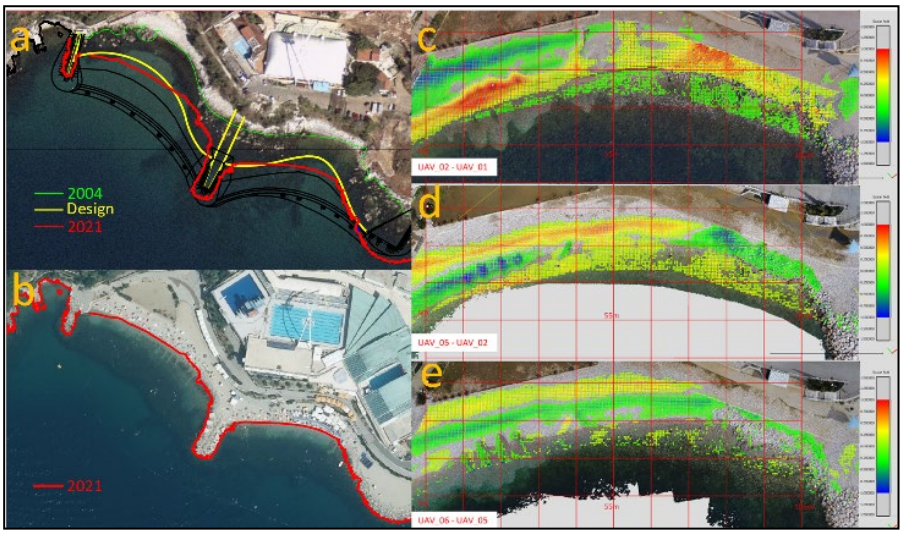

Figure 2: Ploče beach before (a) and after (b) construction. Results of beach monitoring, elevation difference: (c) after and prior of nourishment, (d, e) impact of the first storms

Ploče beach is an artificial GPB built in 2011. The beach consists of two pocket beaches, both about 130 m wide (Fig 2). These beaches are extensions of very narrow gravel beach strips in two small natural embayment, whose headlands have been extended by rock groynes. There is also a submerged sill offshore at a depth of 2 m. Before the Ploče beach was built, sea walls have often been damaged during storms.

3. METHODOLOGY

The beach surveys were conducted on both beaches using UAVs. The images were acquired in JPG format using the UAV DJI Phantom 4 Professional, FC6310 camera with 20-megapixel (4864 x 3648), 1" CMOS sensor, 8.8 mm focal length. The Ploče beach was surveyed 19 times between 17 January 2020 and 26 February 2021, while the Sablićevo was surveyed six times between 2017 and 2021. Point clouds were obtained from the sets of photographs processed using software Agisoft Metashape Professional, v1.7.1. The 3D point clouds were generated using the SfM-MVS photogrammetry technique. Additionally, a terrestrial laser scan (TLS) was deployed on Sablićevo beach in May 2021. The data was processed into 3D point cloud. QGIS was used for GIS analysis and CloudCompare for point cloud data processing. In addition, nearshore waves were simulated using the SWAN numerical model, for the different beach shapes (current, former, hypothetical nourished) and present and predicted sea levels.

4. RESULTS

The estimated retreat of the coastline at Sablićevo beach is between 3 and 7 meters. The estimate is based on the analysis of old images and orthophotos and a 3D point cloud of the beach (limitations: image quality, no tide data). The most recent rock erosion was recorded by monitoring in autumn of 2018. There are two rockfalls in the western part of after SE storm surge (Fig 1).

Figure 2 (c – e) shows the changes observed on the Ploče beach. Comparison of the point clouds shown in figure c shows the influence of beach nourishment. The material was deposited at the eastern end of the cell, and on the opposite side the sediment was pushed closer to the coastline from higher parts. The first waves caused longshore transport of the material from east to west (d). Heavy rain accompanying the storm waves caused local erosion where the fresh water flowed through the beach body. The final image (e) shows cross-shore changes caused by the highest recorded waves. The results suggest that the beach is relatively stable throughout the surveyed period and requires very small amounts of sediment for its maintenance, unlike some other artificial beaches in Croatia. The monitoring has been successful in detecting the locations of beach erosion.

The full paper will include results from further analyses of effectiveness of gravel beach for protection of eroded cliff. Analyses of the interaction between the waves - beach - cliff system are performed on 3D point cloud data. Implications of results for coastal management will be discussed.

4. CONCLUSION

This study shows that geotechnical measures for stabilising cliffs are not effective in protecting cliffs from erosion. On the other hand, carefully designed artificial gravel beaches and their nourishment can reduce impact on sea-walls. This informed the numerical study of beach-cliff interaction. It was found that gravel beaches in front of cliffs can reduce some of impact on cliffs. Hence it is recommended that these beaches are maintained and possibly expanded in line with SLR to keep providing natural protection of cliffs.

5. REFERENCES

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