MONITORING OF A DYNAMIC REVETMENT DURING A SPRING TIDAL CYCLE IN NORTH COVE, WASHINGTON STATE, USA.

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INTRODUCTION

A dynamic revetment is a cobble-gravel berm constructed around the high tide wave runup limit. These structures mimic composite beaches, which consist of a lower foreshore of sand and a backshore berm constructed of gravel or cobbles, which stabilizes the upper beach and provides overtopping protection to the hinterland. Dynamic revetments contrast with static coastal defense structures as they are “dynamic” and are expected to reshape under wave attack. The idea of a dynamic structure made of smaller material than a classic riprap type of revetment is not new, and previous laboratory and field research has investigated the use of dynamic revetments for coastal protection (Allan et al., 2016). However, applications of such a structure remain sporadic and often differ to each other in terms of their design and aim. Furthermore, few existing dynamic revetments have been monitored to evaluate their function, and therefore, the way they behave at the particle and global scale remains poorly understood.

In this study, 2D Lidar, GPS topography, particle tracking, and sub-surface particle composition data were collected on the dynamic revetment at North Cove, Washington State, USA, during a spring tidal cycle. Together they enabled investigation of the revetment dynamics and evolution in response to waves and water levels. In addition, this monitoring is proposed as a suitable protocol for short and long-term monitoring of dynamic revetments.

METHODOLOGY

The dynamic revetment at North Cove was built by the local community in an effort to halt persistent coastal erosion and loss of homes. Beginning in February 2017, poorly-sorted angular quarry rock material with a diameter ranging from millimeters to decimeters was incrementally placed in front of the coastal barrier sand scarp to protect it from direct wave attack.

The revetment was monitored over a 10-day period during a spring tidal cycle in January 2019 (Bayle et al., 2021). A 2D Lidar was mounted on top of a 5-m pole scanning cross-shore (Figure 1a. and b.). It was then used to obtain high frequency (25Hz) swash surface and morphology data throughout each high tide at high spatial resolution (O(cm)), enabling the interactions between waves and changing morphology to be monitored continuously. Manual digging at fixed cross-shore locations across the revetment was performed every day to identify the interface of gravel and mixed sand and gravel. This can be used to relate surface changes to the cobble-gravel layer thickness and sub-surface particle composition. In addition, a total of 70 cobbles were drilled and tagged using Passive Integrated Transponder (PIT) tags. These cobbles were placed to cover a wide area updrift, downdrift and at the Lidar position. This technique allows the instrumented cobbles to be tracked using Radio Frequency Identification (RFID) (Figure 1c.), enabling insight into the transport patterns of the cobbles across and along the revetment. Finally, full GPS topographic surveys of the revetment morphology extending 1-km alongshore were undertaken twice as part of a long-term monitoring plan.

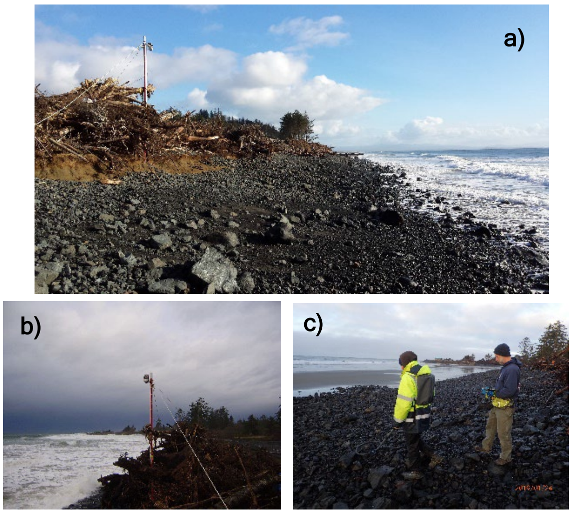

Figure 1: Photo of the mounted Lidar monitoring a single cross-shore line of the revetment at low tide, a) and high tide b). c) Photo of particle tracking survey using RFID detection and GPS.

OBSERVATION AND PERSPECTIVE

Observations during the experiment showed a rapid response of the revetment to the hydrodynamic conditions. The slope, particle sorting, and thickness of the cobble layer were highly variable, and changed rapidly from one high tide to another. In addition, the RFID monitoring demonstrated a dominant longshore transport, and enabled the identification of zones of cobble accumulation. The variation of the cobble layer and sand cover over the revetment showed that the sand can rapidly get washed seaward by the water percolating through the structure, but can rapidly recover and infiltrate the revetment under milder conditions.

The revetment surface elevation was observed to change by up to ±0.5 m over the course of the experiment. The largest changes were found to occur when the high tide water level, and hence - due to energy saturation in the surf zone - the wave height at the revetment toe was relatively large, with the offshore wave energy having only a secondary effect. The revetment adapted rapidly to changing wave conditions, reaching a stable shape and slope after four high tides and subsequently varying around a quasi-equilibrium state.

The revetment also demonstrated a dynamic stability by constantly reshaping over short timescales, but remaining a coherent structure despite losing some of its volume. The structure also showed a capacity to rapidly recover most of its volume after a period of erosion.

The instrumented cobbles showed a predominant longshore transport of cobble and no loss of cobble seaward of the toe, however a zone of accumulation around the toe of the revetment was observed. This may be due to the initial presence of large cobbles at the toe that restricted movement of small and medium-size cobbles due to strong interlocking. Alternatively, the hydrodynamic conditions could also cause this accumulation, as the small and medium cobbles may move landward and seaward within the revetment profile during a tide, but reside at the bottom after the tide has receded. Both hypotheses are plausible, and it would be necessary to monitor individual cobble movement in real time to conclude which process occurs.

The revetment was able to store sand underneath the cobbles, and protect most of it during energetic conditions and high water levels. Monitoring showed that during calm conditions, sand naturally accretes over the revetment face – accretion first occurs within the revetment until sand saturation – moving the visible toe landward.

The revetment behaviour was found to be influenced by variations in the cobble-sand matrix. The underlying sand dynamics – i.e., accumulation or removal of sand within the cobbles were found to govern the overall volume changes and were important to the overall stability of the revetment. Across the revetment face, the sub-surface sorted into three units of varying thickness and depth. The top unit, interpreted to be the most-active layer, consisted of pure cobble. A middle layer was composed of a vertically-sorted gradation of mixed gravel, pebbles, and coarse sand. The bottom layer was pure sand. The presence of these three sub-surface layers is important in the understanding of dynamic revetment behaviour as it makes their dynamics more complex than pure sand or gravel beaches.

A conceptual model of internal sand dynamics for dynamic cobble berm revetments and composite beach ridges was developed. The model describes two end states, the Depressed Subsurface Runoff Interface (DSRI) and the Elevated Subsurface Runoff Interface (ESRI), respectively characterized by a low and high runoff interface elevation. The lower part of the revetment is the most active part in all cases, with rapid sand saturation and erosion.

The internal sand dynamics were found to be a complex balance of accumulation and removal of sand within the cobbles, which varied depending on cross-shore location. The sand within the cobbles was also found to reach a stable state, which likely contributed to the overall structure stability. Significant internal sand variations were found to be enhanced by the rearrangement of large particles, mainly during periods of significant revetment shape and slope modification, while smaller variations were attributed to backwash flows (erosion) and kinetic sieving (accretion). While further investigation of the sub-surface layers and internal sand dynamics is required to understand the processes involved, there are technical barriers to obtaining real-time measurements of layer thickness, particle composition, and vertical gradation.

In summary, the dynamic cobble berm revetment showed a dynamic stability and remained a coherent structure under the storm conditions during this spring tide cycle. The maximum significant wave height measured offshore was just above 6 m with a peak wave period above 17 s, however due to energy saturation in the surf zone, the nearshore wave height was strongly controlled by water depth. The volume of the dynamic cobble berm revetment was not significantly affected, with minimal net volume loss due to internal sand loss and local cobble removal by longshore transport, but with almost no material lost offshore.

DESIGN GUIDANCE

The use of poorly sorted cobbles is important for underlying sand protection, and the use of angular material may aid with this protection through increased capacity for the interlocking of particles within the subsurface. When the mix of this material is subject to wave swash, it tends to become vertically sorted, with a layer with the largest material near the surface and finer material below. The smaller size material is needed to effectively form a natural filter layer, which limits loss of the fine native beach sand below the cobble surface. Using a limited size range of cobbles on top of the sand will make the revetment too porous and unable to sufficiently prevent the sand from eroding beneath it (Bayle et al., 2020). The use of rock at the larger end of the size range used here ($D > 0.3$ m) may not be advantageous. The presence of large rock tends to limit the movement of the toe because larger material is transported downwards by gravity during energetic conditions and then remains when the wave energy decreases.

With effective gradation of particle size to protect underlying sand, sufficient foreshore sand supply, and sufficient revetment thickness and elevation to accommodate waves and water levels, dynamic revetments offer effective coastal stabilization to prevent retreat of the hinterland. Under these conditions, cobble renourishment requirements may be limited to losses due to longshore transport and gradual attrition of cobble size due to rock fracturing and abrasion.

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