

LESSONS LEARNT ON THE DESIGN OF A DYNAMIC COBBLE REVETMENT

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BACKGROUND

Coastal hazards are becoming increasingly prevalent with rising sea levels and severe storm events regularly occurring. As a result, there has been a growing need for long-term and resilient coastal protection solutions that also provide co-benefits such as social value, ecological benefits, and adaptability. In response to this, alternative coastal stabilization solutions are being implemented rather than the typical traditional coastal infrastructure, particularly nature-based solutions (NBS).

Coastal protection solutions are often divided into two main categories: hard infrastructure and soft solutions. Hard infrastructure encompasses fixed structures such as revetments, seawalls, etc. These solutions often have limited-service lives and eventually require replacement. In addition, these solutions are typically not designed for sea level rise and therefore, may not be effective in the future.

The second type of solutions include soft or NBS. These can include nourishment, use of vegetation, artificial reefs, etc. These types of solutions offer environmental and social benefits. However, they are challenging to successfully implement due to their sensitivity and because they are usually not effective in exposed, high-energy coastlines (Foss et al., 2023). The use of dynamic cobble revetments can be implemented for these types of high energy and open coastal environments.

Dynamic cobble revetments reduce erosion and coastal-driven flooding, by reducing wave runup and overtopping, which subsequently protects the shoreline and any landward infrastructure. In addition, cobble revetments are particularly adaptable as they reshape during storm events and self-maintain their elevation relative to extreme water levels (Bayle et al. 2020). Examples of successful cobble/ gravel revetments include projects at Flathead Lake, Montana, USA (Lorang, 1991), Yaquina Bay, Oregon, USA (Allan et al., 2012), amongst several others (Bayle et al., 2020).

This study includes the design and implementation of a coastal protection solution for 500 m of shoreline along a roadway that is undergoing erosion and flooding (Figure 1). The derived solution aims to not only stabilize the shoreline, but to also provide improved social and ecological benefits. The study site is located in Halifax, Nova Scotia, which is on the Atlantic Coast of Canada (Figure 2). The study area is highly exposed with little natural protection from the open ocean. Extreme storm events regularly impact the site including high energy swell and tropical storms/ hurricanes. Notably in recent years, Hurricane Juan (2003), Dorian (2019), and Fiona (2022) impacted Atlantic Canada, which were some of the most severe storms to hit the area.



Figure 1 - Photo of site during storm event illustrating overtopping and flooding.

The work presented here illustrates lessons learnt on the design process for developing a coastal stabilization solution that uses a nature-based approach, particularly dynamic cobble revetments. The objective of this study is to describe the full design process from a coastal engineering standpoint, to highlight the challenges in executing these solutions, and to outline the gaps in design guidelines, equations, and models for dynamic cobble revetments.

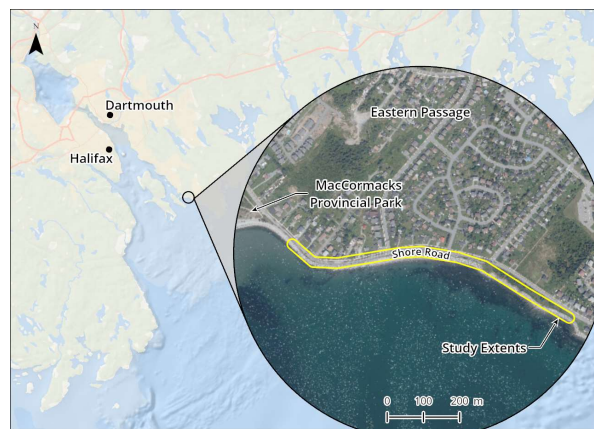


Figure 2 - Site extents and location in Halifax, Canada.

DESIGN PROCESS

This project is a comprehensive study that includes data analysis, field data collection, numerical modelling, physical modelling, and the use of industry standard guidelines to develop and implement this design. This is a multi-phase project that began in 2022, which includes a baseline coastal assessment, conceptual design, design evaluation through numerical and physical modelling, design refinement, and eventually implementation. The design of the solution has been ongoing and will be finalized in the summer of 2024. Construction of the solution is expected to occur in 2024 to 2025.

A baseline coastal assessment was first completed to obtain an in-depth understanding of the site conditions. This included the analysis of historical site information, offshore metocean data, and recorded water level and

wave data. Using this analysis, a Spectral Wave and Hydrodynamic numerical model were developed to resolve the nearshore wave conditions, currents, and flood levels using MIKE21 (DHI, 2022).

Several conceptual level design solutions were developed based on the coastal assessment. An option analysis was conducted to determine the optimal solution in terms of effectiveness, resilience, and social and ecological value. The option analysis determined that the preferred solution is a dynamic cobble revetment, with an optional rock sill, as shown in Figure 4. The proposed design includes a sloped cobble layer and a fill layer of angular gravel. The optional rock sill would be submerged, with the purpose of reducing cobble loss. The necessity of the sill will be determined at the physical modelling stage. Riparian vegetation will be planted on the landside of the cobble berm to provide ecological value.

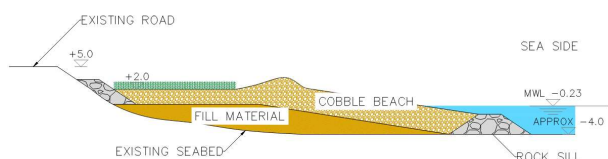


Figure 4 - Cross-section of the proposed conceptual cobble revetment.

The next step for this project is the development of the detailed design, which includes further numerical modelling, determining design parameters and geometries using guidelines, and physical modelling. The geometry of the cobble revetment will be based on various design principles as outlined in Bayle et al. (2020), including the use of critical mass theory (Ahrens, 1990) to estimate the minimum volume and the use of numerical modelling to determine crest elevation using non-hydrostatic XBeach simulations (Roelvink et al., 2009). Preliminary XBeach results with the conceptual design are shown in Figure 5. In addition, the reshaping of the revetment and potential cobble loss will be tested numerically.

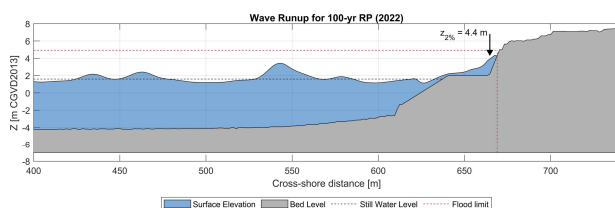


Figure 5 - Non-hydrostatic XBeach results for 100-yr return period in present-day with the conceptual design.

Physical modelling will include a 2D model of the dynamic cobble revetment in a Large Wave Flume (LWF). A model scale of 1:10 is planned to minimize scale effects and the model will be exposed to scaled wave conditions at various water levels. The flume will be equipped with instrumentation to measure wave conditions and detailed profile measurements will be taken with a 3D laser scanner during the test program. The results of the physical modelling will be compared to the results of the

numerical models. These steps are not finalized at this stage of the project but will be completed in the spring of 2024. Based on the results of the numerical and physical modelling, the design will be refined and finalized.

DISCUSSION

The design and implementation of dynamic cobble revetments includes varying challenges and complexities. Several lessons learnt from this on-going project include:

- It is vitally important to consider the coastal conditions of the site, particularly for high exposure wave environments, when developing NBS due to their higher sensitivity to storm events.
- The use of physical modelling can significantly improve the design of cobble revetments, relative to using numerical models, design guidelines, and empirical equations due to significant data gaps surrounding these types of designs.
- A multi-disciplinary approach is necessary for NBS to optimize not only the effectiveness of shoreline stabilization, but also the ecological and social value of these solutions.
- The development of guidelines for cobble revetments should be advanced, as there is significant uncertainty in their design methodology.

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