A NEW FORMULA FOR PRESSURE TRANSMISSION INSIDE RUBBLE MOUND BREAKWATERS PROTECTING LAND RECLAMATIONS

Aggelos S. Dimakopoulos, University of Patras, a.dimakopoulos@upatras.gr
William Allsop, William Allsop Consulting Ltd, william.allsop51@outlook.com
Ian Chandler, HR Wallingford Ltd, I.Chandler@hrwallingford.com
Tim Pullen, HR Wallingford Ltd, T.Pullen@hrwallingford.com

INTRODUCTION

Recent land reclamation projects where maximization of land use is crucial have resulted in the appearance of types of coastal defenses that have not been extensively studied. Rubble mound breakwaters with open filters or geotextiles are increasingly used in reclamation projects. Due to placement of landfill material (e.g. dredged sand with silt) close to the rubble mound, these structures are potentially vulnerable to internal erosion and material loss through the coarser breakwater layers, a process which is often characterized as suffusion. Several past studies have highlighted these issues (Cantelmo et al 2011; Polidoro et al 2015). Incipient of sediment motion in the landfill area is highly dependent of the pressure gradients developing and reliable prediction of pressures is of great importance. Some available methods (Burcharth et al 1999, Troch 2002, Muttray and Oumeraci (2005), Vanneste and Troch 2012, Tomasicchio et al 2020) are reliable for generic rubble mound breakwaters, but have weaknesses with respect to breakwaters protecting land reclamation areas, where a reflective interface is formed. These weaknesses are discussed in Dimakopoulos et al (2023).

This work presents a methodology for modifying existing formulas for estimating internal pressures in rubble mound breakwaters in the presence of reflective surfaces. The methodology follows a relatively simple concept and is applied to correct predictions of the formula proposed by Burcharth et al (1999). The corrected formula is compared against numerical modelling predictions published in Dimakopoulos et al (2023). Comparison and further verification of the formula will be performed following additional numerical (CFD) model simulations and experimental data.

METHODOLOGY

The methodology can be applicable to existing empirical formulae for estimating pore pressure amplitude. A representative sketch of the breakwater cross-section is shown in Figure 1.

In order to correct the pore pressure amplitude estimation, the following steps are taken:

1. Calculate the pore pressure amplitude at the reflective interface with one of the available equations for the incident wave field.
2. By assuming 100% reflection, set the reflected wave field with initial pore pressure at the reflective interface equal to the pressure calculated in step 1
3. Apply the same pressure attenuation formula, starting from the reflective surface to estimate the contribution of the reflected wave field, using as initial pressure the one calculated above.
4. Sum the total and reflected wave field to acquire the final pressure dissipation formula

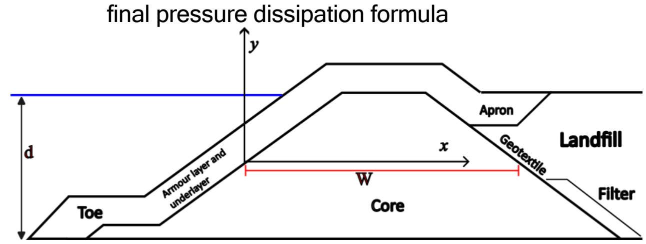

Figure 1 - Typical cross-section of rubble mound breakwater protecting landfill areas

Herein, we will present an example based on the formula from Burcharth et al. (1999).

EXAMPLE

According to Burcharth et al (1999), Troch (2002), the pore pressure amplitude attenuation inside the rubble mound breakwater core is as follows:

$$p_i(x) = P_o \exp(-\delta \cdot \frac{2\pi}{L'} x) \quad (1)$$

where p_i is the pore pressure amplitude, x is the horizontal distance from the interface with the seawards protective layers (see Figure 1), $L' = \sqrt{1.4}L$, with L being the wavelength at the toe of the structure, δ the damping coefficient and P_o the initial pressure at the interface between the core and seaward protective layers. The initial pressure and damping coefficients can be calculated following the relationships proposed by Troch (2002). This pore pressure can be correlated with the incident wave field.

Considering the pressure amplitude attenuation at the mid-level of the breakwater, then we can set the width of the core at that level equal to W (See Figure 1). According to Eq. 1, the pressure at the reflective interface between the landfill and the core is

$$P_w = P_o \exp(-\delta \cdot \frac{2\pi}{L'} W). \quad (2)$$

For the reflected wave field (assuming 100% reflection) the pressure amplitude attenuation equation will be as follows:

$$p_r(x) = P_w \exp(-\delta \cdot \frac{2\pi}{L'} (W - x)) \quad (3)$$

Summing up the incident and reflected pore pressure and substituting equation (1) to (3), we can acquire the total pore pressure as follows:

$$p(x) = P_o \exp(-\delta \cdot \frac{2\pi}{L'} x) \left(1 + \exp\left(-2\delta \cdot \frac{2\pi}{L'} (W - x)\right)\right) \quad (5)$$

The relationship above is valid for $0 \le x \le W$ with the amplification term being bounded between $(P_W/P_o)^2$ and 1.

COMPARISON WITH DATA

A preliminary comparison is performed using the data presented in Dimakopoulos et al (2023), where the attenuation of pressure amplitude inside the core was compared with the Burcharth et al (1999) equation. The comparison showed discrepancies and these were attributed to the presence of reflective interface between the core / open filter and landfill. The wave climate corresponded to a typical extreme storm (significant wave height Hs=4m, peak period Tp=14s and water depth d=10m). The porous resistance coefficients were calculated using recommendations from Polidoro (2017), which resulted to similar P_o as in Burcharth et al (1999). The core porosity was considered to be equal to 40%.

Results are presented in Figure 2. It is observed that the correction does rectify to a significant extent the discrepancies between the uncorrected formula and the CFD model results. The RMS error between the CFD model results and the uncorrected and corrected Burcharth formula are 19% and 7%, respectively.

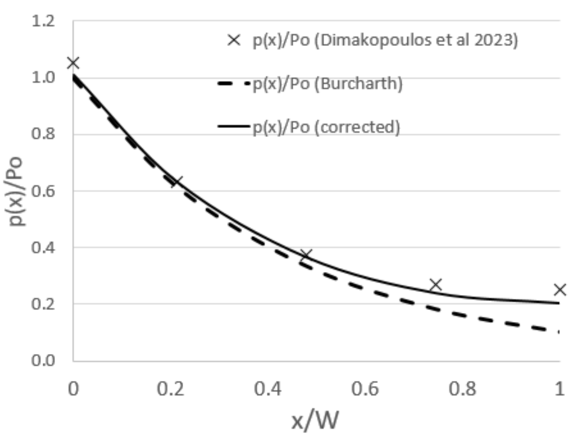

Figure 2. Wave pressure attenuation inside the core, for CFD model results (Dimakopoulos et al 2023), and Burcharth (1999), with and without corrections for reflection.

DISCUSSION

It is noted that the proposed correction for pore pressure amplitude equations has a solid physical basis, as it is derived from the superposition of incident and reflected wave fields, with the pressure amplitude for the incident and reflected wave fields reducing at the same rate, as both fields are travelling inside the same medium.

The proposed correction is tested with readily available data from Dimakopoulos et al. (2023) with an encouraging outcome. Anecdotal data from current CFD and physical modelling campaigns have confirmed the existence of wave reflections that modify the internal pressures inside the core, Ongoing studies are performed to address the following:

- Comparison of Burcharth's formula with CFD modelling results for typical breakwater sections (no landfill).
- The validity of the proposed correction on a range of wave conditions.
- The sensitivity of the formula predictions to different estimations of the porous resistance coefficients.
- The pressure distribution along the height.

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REFERENCES

Burcharth, Hans F., Zhou Liu, and Peter Troch. "Scaling of core material in rubble mound breakwater model tests." In Fifth International Conference on Coastal and Port Engineering in Developing Countries: Proceedings of the COPEDEC V: Cape Town, South Africa, 19-23 April, 1999, pp. 1518-1528. COPEDEC, 1999.

Dimakopoulos Aggelos, Pullen Tim, Allsop NH William (2023). Internal pressures in rubble mound breakwaters used in coastal protection – recommendations for assessing wave pressures with CFD models. In Proceedings of ICE Coasts, Marine Structures and Breakwaters 2023, Portsmouth

Cantelmo, Clemente, Scott Dunn, Giovanni Cuomo, and William Allsop. (2011) "Hydro-geotechnical stability of rubble mound breakwaters under wave action." In Coastal Structures 2011: (In 2 Volumes), pp. 972-982. 2013.

Muttray, M. O., & Oumeraci, H. (2005). Theoretical and experimental study on wave damping inside a rubble mound breakwater. Coastal engineering, 52(8), 709-725.

Polidoro, Andrea, William Allsop, and Tim Pullen. "Exploring the need for geotextile filters for rubble bunds retaining sand-fill islands." In Coastal Structures and Solutions to Coastal Disasters Joint Conference 2015, pp. 763-773. Reston, VA: American Society of Civil Engineers, 2015.

Polidoro, Andrea (2019). The effect of grain size distribution and bimodal sea states on coarse beach sediment dynamics. PhD Thesis, Oxford Open University (United Kingdom).

Tomasicchio, Giuseppe Roberto, and Sahameddin Mahmoudi Kurdistani (2020). "New prediction formula for pore pressure distribution inside rubble-mound breakwater core." Journal of Waterway, Port, Coastal, and Ocean Engineering 146, no. 3: 04020005.

Troch, Peter. (2001) "Experimental study and numerical modelling of pore pressure attenuation inside a rubble mound breakwater." PIANC bulletin 109.

Vanneste, Dieter, and Peter Troch. (2012) "An improved calculation model for the wave-induced pore pressure distribution in a rubble-mound breakwater core." Coastal Engineering 66: 8-23.