

OVERTOPPING HAZARD MITIGATION: EXPERIMENTAL INVESTIGATION OF LIVE SALT MARSH GRASS EXPOSED TO BORE FLOW

Joshua Bagg, The University of Auckland, jbag568@aucklanduni.ac.nz

Mark Battley, The University of Auckland, m.battley@auckland.ac.nz

Colin Whittaker, The University of Auckland, c.whittaker@auckland.ac.nz

Tom Allen, The University of Auckland, tom.allen@auckland.ac.nz

Tom Shand, Tonkin + Taylor Ltd., The University of Auckland, t.shand@auckland.ac.nz

INTRODUCTION

Extreme weather events and sea level rise will continue to increase the frequency and intensity of coastal hazards (Paulik et al. 2020). Hybrid solutions, which combine an engineered structure with a nature-based solution, offer the potential to manage risk and achieve greater socioeconomic and environmental benefits (Blakely et al., 2023, IPCC, 2022). However, implementation is hampered by a lack of robust and definitive design guidance (Burmeister and Pomeroy, 2021). Blakely et al. (2023) identified that native Aotearoa New Zealand saltmarsh grass, oioi (*Apodasmia similis*), when placed on the crest of coastal protection structures, may be a feasible hybrid solution for mitigating wave overtopping hazards. Given the difficulty to accurately represent vegetation at scale, Blakely et al. (2023) concluded that future physical model tests using live, full-scale vegetation under wave overtopping conditions are fundamental for understanding the true interaction between vegetation behaviour and overtopping flow. Therefore, in this study, experiments were conducted with live, prototype scale vegetation in a flume that replicates prototype scale green-water overtopping bore flow. The aim is to investigate the relationship between vegetation response and flow parameters. The experimental data set is proposed to be used for developing preliminary design guidance and numerical model validation.

METHODOLOGY

Experiments were conducted using the dam-break flume in the Fluid Mechanics Laboratory at The University of Auckland (Figure 1). The reservoir capacity is 33.6 m³.

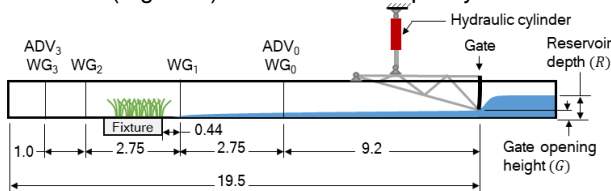


Figure 1 - Flume schematic. Dimensions in m.

The oioi were obtained in 5 L pots of diameter 0.226 m. The stem height was 0.7 m and stem diameter of 2 mm at the base, tapering to 1 mm. The pots were arranged in a regular grid, with neighboring pot rims in contact. Five pots spanned the 1.2 m flume width. Different array lengths were tested by incrementally increasing the number of rows of pots in the flume length direction, from a single row (array length = 0.226 m) up to six rows (array length = 1.356 m). The array fixture was directly mounted to two load cells, which measured the drag force. The flow depth $h(t)$ was measured using

capacitive wave gauges (WG). The bore front speed was calculated by the time-of-flight method between consecutive wave gauges. The transient velocity $u(t)$ was measured with a side-looking Nortek Vectrino Acoustic Doppler Velocimeter (ADV) located at 10 mm elevation from the flume floor. All instrumentation began logging upon a single trigger event and with a sample frequency of 200 Hz. The ADV was placed at the same along-flume position as WG₀ or WG₃ to calculate the instantaneous flow rate $q(t) = h(t) \times u(t)$. The total volume V was calculated by integrating the flow rate.

WAVE OVERTOPPING COMPARISON

The flume's flow parameters were compared to those of the full-scale Dutch mobile overtopping simulator (van der Meer et al. 2011). Figure 2 illustrates that within the experimental range, the data aligns with the empirical relationships, therefore there was no need to reduce the vegetation geometric scale.

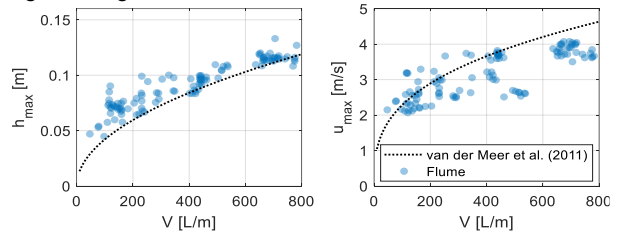


Figure 2 - (a) maximum flow depth (h_{max}) and (b) maximum flow velocity (u_{max}) vs total bore volume (V).

VEGETATION RESPONSE

Upon bore impact, the vegetation deflects. Part of the incident bore is reflected, and the remaining volume is transmitted over the deflected vegetation and between the stems. The vegetation then returns to approximately its original configuration. The magnitude of maximum deflection was qualitatively categorised by observation of video footage (Figure 3).

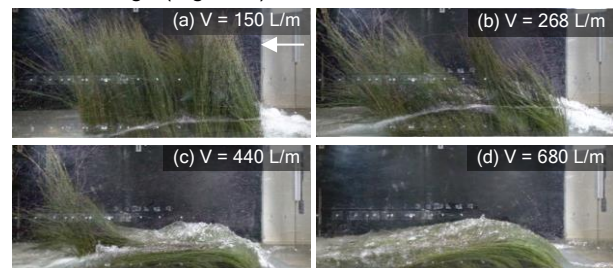


Figure 3 - Maximum deflection of five rows of oioi for different flume conditions resulting in the deflection categories (a) small (b) medium (c) partially streamlined and (d) fully streamlined. Arrow indicates incident flow direction.

FLOW-VEGETATION INTERACTION

The relationship between incident volume and deflection response is shown in Figure 4. Generally, the magnitude of deflection increases with incident bore volume. It is important to identify the onset of streamlining, as this results in an increase in volume transmission, which is undesirable for hazard mitigation. The threshold at which the entire array streamlined occurred at $V = 180 \text{ L/m}$ for 1 row, at $V = 440 \text{ L/m}$ for 2, 3 and 4 rows, and at $V = 680 \text{ L/m}$ for 5 and 6 rows. The onset of full streamlining for 5 and 6 rows is above the tolerable overtopping limit of scour to grass embankments ($V_{\max} = 500 \text{ L/m}$) and pedestrian safety ($V_{\max} = 600 \text{ L/m}$) (EurOtop, 2018).

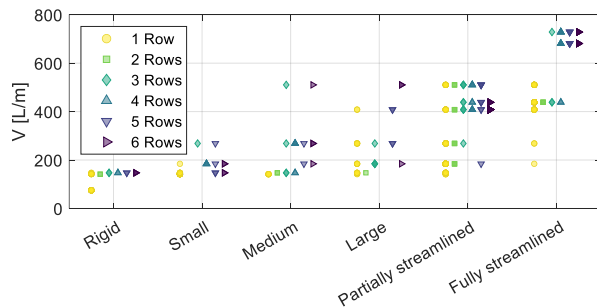


Figure 4 - Incident bore volume (V) vs. deflection category by plant rows.

Additional flow parameters can further explain the hazard mitigation capacity. Figure 5 shows a relationship between the deflection categories and the depth and velocity transmission ratios. The generally low transmission ratios show the benefit of emergent saltmarsh grass such as oioi. As the deflection increases, the transmission ratios approach $K = 1$, thus reducing the mitigation capacity. When streamlining occurs, K_u can exceed 1, which could be explained by the acceleration of flow down the landward side of streamlined vegetation.

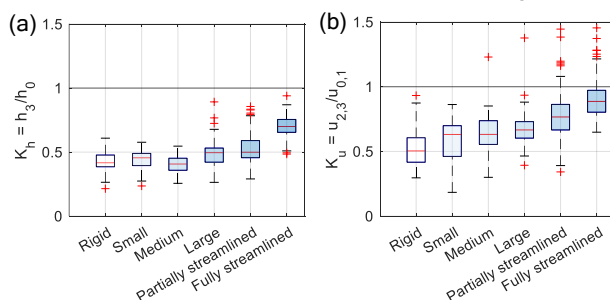


Figure 5 - Transmission ratios of downstream to upstream (a) maximum flow depth and (b) bore front speed vs. deflection category.

Empirical models have been fitted to explain downstream flow parameters using upstream flow parameters, which could be used for preliminary design and numerical model validation. Additionally, a semi-empirical drag force model has been derived as a function of upstream flow parameters and array length. This could be used to calibrate vegetation parameters in numerical models that do not simulate flexibility.

However, the dependence of flow parameters on deflection, particularly the change in flow response with streamlining, requires the use of modelling approaches that can simulate the fluid-structure interaction.

CONCLUSION

Oioi has demonstrated its ability to mitigate overtopping hazards by reflecting bore volume and reducing maximum downstream flow depths and velocities. This reveals the broad mitigation potential of placing various salt-tolerant vegetation species and configurations on a structure's crest. This experimental approach has enabled the use of live vegetation, allowing a realistic representation of hydroelasticity. The deflection categorisation is a simple method for describing vegetation response and for drawing relationships with flow parameters. The conference presentation will offer more insights into scale effects, additional parameters that describe mitigation capacity, and the empirical equations. The results are proposed to be used for preliminary design guidance and for validating numerical modelling methodologies, moving toward robust design of hybrid protection solutions.

REFERENCES

- Blakely, Whittaker, Shand (2023): Vegetation for Wave Overtopping Mitigation: A Laboratory and Numerical Investigation, Australasian Coasts & Ports 2023 Conference
- Burmeister, Pomeroy (2021): Working with Nature - A practical approach, Australasian Coasts & Ports 2021 Conference, https://www.coastsandports.org/papers/2021/069_burmeister_finalpaper.pdf
- EurOtop (2018): Manual on wave overtopping of sea defences and related structures. Van der Meer, Allsop, Bruce, De Rouck, Kortenhaus, Pullen, Schüttrumpf, Troch, and Zanuttigh. <http://www.overtopping-manual.com/>
- IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, Roberts, Tignor, Poloczanska, Mintenbeck, Alegria, Craig, Langsdorf, Löschke, Möller, Okem, Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., <https://doi.org/10.1017/9781009325844>
- Paulik, Stephens, Bell, Wadhwa, Popovich (2020): National-scale built-environment exposure to 100-year extreme sea levels and sea-level rise. Sustainability, vol. 12, <https://doi.org/10.3390/su12041513>
- Schüttrumpf and van Gent (2003): Wave overtopping at sea dikes. Coastal Structures 2003, pp 431-443 [https://doi.org/10.1061/40733\(147\)36](https://doi.org/10.1061/40733(147)36)
- van der Meer, Hardeman, Steendam, Schüttrumpf and Verheij (2011): Flow depths and velocities at crest and landward slope of a dike, in theory and with the wave overtopping simulator. Coastal Engineering Proceedings, vol. 32 <https://doi.org/10.9753/icce.v32.structures.10>