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PHYSICAL MODELLING TESTS WITH FLEXIBLE WOODY VEGETATION MIMICS

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ABSTRACT

Riparian forests in front of dikes can dampen incoming waves and thereby contribute to flood safety. In real-scale flume experiments with live pollard willow trees (forming a 40-m-long forest), it was observed that during storm conditions, a maximum reduction of 20 % in incoming wave height could be achieved (van Wesenbeeck, et al., 2022). Notably, this amount of wave damping occurred at a water depth of 3 meters, aligning with the section of the trees with the maximum frontal-surface area. For a larger water depth, measured wave damping however declined. This is potentially partly caused by the natural tapering form of the trees. Typically, trees are characterized by smaller branch diameters and more flexible branches higher up in the canopy (McMahon & Kronauer, 1976); and flexible vegetation mimics are known to dampen less than rigid mimics due to motion (Van Veelen, T, Reeve, & Karunarathna, 2020). Hence, both the frontal-surface area and branch rigidity decrease along the height of the willow trees, potentially leading to less wave damping by the forest when subject to large waves at higher water levels.

Until now, most flume studies did not incorporate both of these elements into their vegetation models. Many of these studies used rigid cylinders as vegetation mimics (e.g., (Sonnenwald, Stovin, & Guymer, 2019)) or assumed inherently rigid tree components such as mangrove roots (e.g., (Maza, Lara, & Losada, 2019)). It is important to note that most studies that did incorporate effects of flexibility, focus on aquatic or salt marsh vegetation (e.g., (Luhar & Nepf, 2016); (Hong, et al., 2022)), which typically are more flexible than trees. Hence, effects of flexibility of woody vegetation, such as willows and mangroves , have largely been neglected. To improve existing analytical models for wave damping through the canopy of woody vegetation, we conducted flume experiments using conical shapes with differing degrees of flexibility. By doing so, we test the effects of (1) decreasing frontal-surface area, and (2) increasing flexibility along the height of the object.

Experiments with simplified branch mimics were conducted in a (1x0.8x40 m^3) flume at 1:10 scale (Figure 1A). The mimics were based on the live pollard willow trees in (van Wesenbeeck, et al., 2022); and therefore, consisted of a stiff cylinder (height= 10 cm, base diameter= 3.45 cm) to represent the trunk and a cone (length= 42.5 cm) to represent the canopy/branch. Two sizes of cones were tested with the following base diameters: 3.45 cm ('Thick' Cone), and 1.37 cm ('Medium' Cone), as shown in Figure 1A, and 1B, respectively. These two distinct thicknesses were tested to observe the effect of flexibility for different Reynolds regimes. Both cone sizes were 3D-printed using four different materials with varying E-moduli, namely: 5MPa, 7.5 MPa, 56 MPa and 3200 MPa (Stiff). The tested hydrodynamic conditions are shown in Table 1.

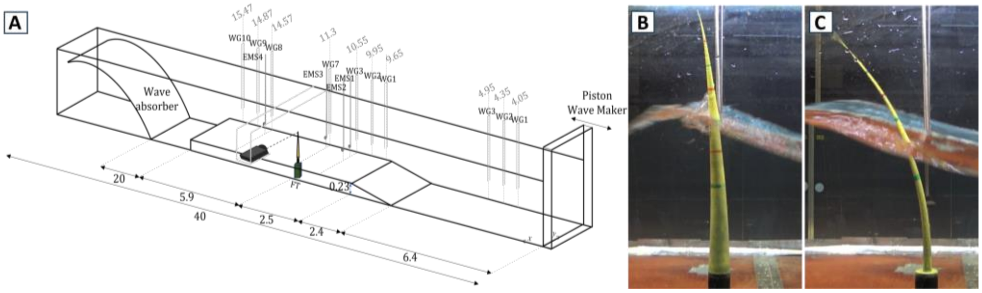

Figure 1. A: Overview test set-up and equipment along the flume; B: Thick Cone 5 MPa; and C: Medium Cone 5 MPa.

Table 1: Tested regular wave conditions, h_f the water depth at the tree location, H is the wave height; T the wave period and s the wave steepness, where $s = H/(gT^2/2\pi)$

Emerged conditions						*Nearly submerged conditions*				
Test	h_f (m)	H (m)	T (s)	s (-)		Test	h_f (m)	H (m)	T (s)	s (-)
1	0.3	0.05	1	0.03		11	0.45	0.05	1	0.03
2	0.3	0.1	1	0.06		12	0.45	0.1	1	0.06
3	0.3	0.14	1	0.09		13	0.45	0.14	1	0.09
4	0.3	0.1	1.23	0.04		14	0.45	0.1	1.23	0.04
5	0.3	0.14	1.23	0.06		15	0.45	0.14	1.23	0.06
6	0.3	0.18	1.23	0.08		16	0.45	0.18	1.23	0.08
7	0.3	0.05	1.77	0.01		17	0.45	0.05	2.1	0.01
8	0.3	0.1	1.77	0.02		18	0.45	0.1	1.77	0.02
9	0.3	0.14	1.77	0.03		19	0.45	0.14	1.77	0.03
10	0.3	0.18	1.77	0.04		20	0.45	0.18	1.77	0.04

The extent to which flexibility influences the forces on woody vegetation mimics will be analysed by mainly using the force and video data collected from these experiments. The tests with the rigid cones will serve as a bench mark. Dimensionless parameters (such as Cauchy) will be defined and quantified to verify whether these are reliable indicators for predicting behaviour of flexible cones when subject to regular waves. These indicators are useful when quick assessments for the wave damping performance of woody vegetation are needed.

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