EFFECT OF SUBMERGED AQUATIC VEGETATION ON TRANSMISSION COEFFICIENT: NUMERICAL EXPERIENCES WITH THE SWASH MODEL

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Abstract

Coastal protection using Nature-Based Solutions (NBS), such as vegetation, has become a topic of increasing interest, especially due to the rising concerns over coastal erosion, flooding, and sea-level rise. Many studies have explored the reduction of wave height with the presence of marine vegetation. However, our understanding of this attenuation process is still in its early stages. To gain further insights, we assessed wave attenuation by vegetation based on the transmission coefficient. Initially, we compared the transmission coefficient of submerged breakwaters (SBW) between physical experiments and numerical modelling simulations with SWASH. Then, SWASH was used to compare the transmission coefficient obtained in a real beach profile between the SBW and a NBS, composed of aquatic vegetation place seaward to the closure depth. Results show that the transmission coefficient is reduced by about 30% in both cases when the vegetation patch is 200m long. This finding suggests that similar transmission coefficients can be obtained either using a SBW or a NBS, which advises a more in-depth analysis on the use of NBS for coastal protection.

Introduction

Coastal systems face threats from extreme waves and water levels, particularly during hurricanes and storms. These threats will increase by rising sea levels, putting significant pressure on coastal defence works (Meselhe, 2020). Such events can lead to structural failure and cause damage to infrastructure, property, and lifes.

Finding a balance between ecosystem health, culture, and the economy is a challenging task. Nature-based solutions (NBS) have gained increased attention as viable measures for restoration and protection (Temmerman et al, 2013). Mendes et al. (2022) analysed the impact of vegetation placed seaward the depth of closure on wave overtopping in two beach profiles. These authors found that wave overtopping can be reduced by more than 15% when the vegetation patch length is larger than 100 m, independently of the beach volume above mean sea level.

The accurate assessment of wave transmission is crucial for designing effective coastal protection structures (CIRIA, 2007). The transmissioncoefficient (K_t) relates the incident wave height (H_i) to the transmitted wave height (H_t). Thus, quantifying the K_t of a NBS is essential to understand its energy dissipation performance in the design of coastal structures.

Therefore, this work aims to investigate the effectiveness of vegetation in reducing the transmission coefficient. For validation, the model results are compared with experimental data to assess how well our model calculates the Kt. The latter analysis uses Praia da Vagueira (Vagos, Aveiro) as a case study, and aims to contribute to a better understanding of the NBS effect in the field of coastal engineering.

Methodology

In order to achieve the research objectives, numerical modelling was chosen as a major approach. This section describes the setup and configurations. First, a physical experiment which reproduces the wave attenuation processes by a SBW. Second, a numerical model was constructed and validated with the experimental data. Lastly, a study case was chosen to compare the effects of the vegetation compared with the SBW conventional solution.

Daemen (1991) experiments

Numerical simulations with the SWASH model were setup based on the Daemen (1991) experiments so that the numerical results could be compared to the experimental data. In summary, we used four experiments with a range of water depth (0.503 - 0.520 m), significant wave height - H_s (0.061 - 0.126 m), peak wave period (1.39 - 1.91 s), which results in relative crest freeboards (R_c/H_s) between -0.34 and -0.89. R_c is the vertical distance between the still water depth and the crest height. Negative R_c values are associated with submerged structures.

For Daemen (1991) experiments, a spatial resolution of 0.10 m was adopted after sensitivity tests on the computational mesh for the test with H_{si} of 0.117 m, water depth of 0.503 m, and a peak period of 1.44 s. The time step was chosen as small as 0.008 s and the simulation time was 5 min. The Manning coefficient was set to 0.015 $m^{-1/3}s$ on the beach profile and 0.030 $m^{-1/3}s$ on the SBW.

Vagueira numerical experiments

Praia da Vagueira was used as a case study for the numerical experiments carried out with the SWASH model. The beach profile of 23/11/2020 contains a submerged bar and a berm in the emerging part, the same used by Mendes et al. (2022). The beach profile was used to test a SBW with three relative crest freeboard (Rc/H_s), with values of -0.35, -0.50 and -0.70 and other experiments with vegetation to compare the *Kt* for both cases.

The vegetated experiments tested diverse vegetation lengths with a range of 25 to 200 m. The model setup follows the same parametrization of Mendes et al (2022). In this study case, we used H_{m0} of 5.0 m and a T_p of 13 s. The computational grid resolution was 0.50 m and the Manning's coefficient value was 0.020 $m^{-1/3}s$ on the beach profile and 0.030 $m^{-1/3}s$ on the SBW.

SWASH numerical model

SWASH is based on nonlinear shallow water equations, including a non-hydrostatic pressure term. In the present study, we applied the SWASH - 2DV model along a cross-shore profile with two vertical layers (Zijlema et al. (2011). This model allows to simulate the effect of vegetation on wave propagation (Suzuki et al., 2019).

Results

SWASH verification Daemen

Figure 1 illustrates the numerical results design to reproduce the Daemen (1991) physical experiments. The SWASH model could reproduce the wave phenomena in all test cases, as we can see in the Figure 1 A-D. The SBW caused wave breaking, which resulted in a significant reduction in H_{m0}. However, the energy dissipation from the structure was larger in numerical simulations than in physical experiments, as observed in Figure 1.

The differences between the simulated results and the measured data are less than 0.02 m for H_{m0} and around than 0.1 for K_t. It is possible to verify the model's ability to reproduce the K_t in the simulations. It is in agreement with the very high correlation coefficient (r = 0.96), the low root mean square error (RMSE = 0.19) and Bias (-0.095). This comparison allows to conclude that SWASH can simulate the K_t with a range of R_c/H_s values between -0.35 and -0.70.

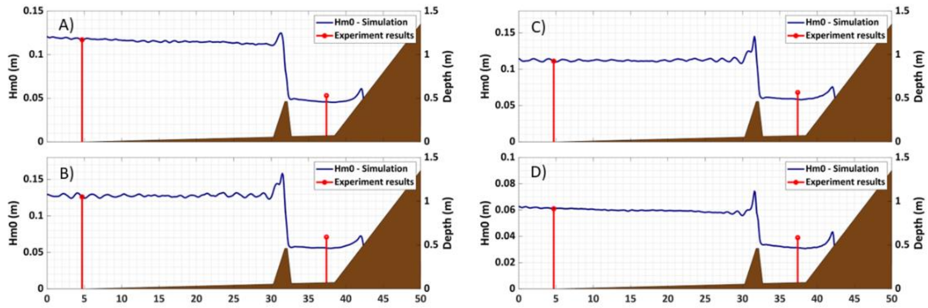

Figure 1: SWASH model validation against Daemen (1991) physical experiments.

Experiments with SBW (Vagueira)

Figure 2 illustrates the modelling results for numerical experiments with SBW and vegetation for Praia da Vagueira. The reduction of H_{m0} by bottom-induced breaking is found to start at 3500 m profile length, as observed in the undisturbed case (Reference - Figure 2A). This breaking become more evident when we observe the SBW cases, the wave energy dissipates fast, as we saw in the previous experiments in wave flume. In contrast to the previous scenarios, when we include vegetation in the beach profile, the wave dissipates energy through the vegetation patch length, but the wave breaks in the same area. After the break at the bar crest, H_{m0} assumes similar values in all simulated cases.

The introduction of vegetation seaward the depth of closure along 200 m reduces the H_{m0} value by about 27%. Despite this reduction, the H_{m0} value near the coast is lower, but similar to the case without vegetation. Increasing the length of vegetation also reduces the value of H_{m0} near the coast, and consequently, K_t.

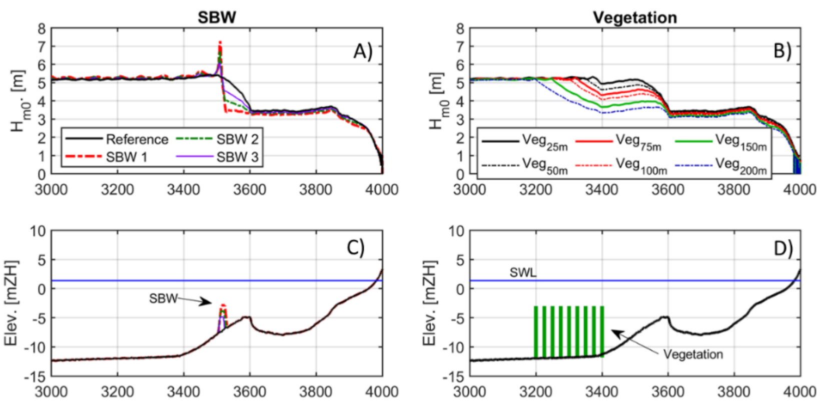

Figure 2: Simulations for Praia da Vagueira. The left refers to the scenarios with SBW, while on the right are the experiments with vegetation. Images A and B show the significant wave height. Images C and D represent the profiles geometry.

Table 2 shows the results for all simulations in terms of K_t, where the shoreward H_{m0} values were taken right seaward of the submerged bar crest (3550 m). The simulations that included a SBW showed that the K_t, as expected, tends to reduce with the height of the structure, i.e., the higher the structure, the lower the K_t. The analogue happens in terms of the vegetation, the K_t tends to reduce when we increase the length of the vegetation. It is important to emphasise that the lowest K_t for the application of a SBW occurred in SBW 1 (see Table 1), assuming a value of 0.65. This result showed that this K_t is equivalent to the Veg200 (K_t = 0.66) case where vegetation length of 200 m was used, as we can see in Table 1.

Table 1: Parametrization and K_t results for SBW and vegetation (Veg) simulations.

Simulations	SBW		Vegetation			Results
	R_c/H_{m0}	B [m]	Length [m]	Diameter [m]	Density [n/m2]	K_t
Reference						0.96
SBW 1	-0.3	10	-	-	-	0.65
SBW 2	-0.5	10	-	-	-	0.74
SBW 3	-0.7	10	-	-	-	0.83
Veg25	-	-	25	0.05	5	0.94
Veg50	-	-	50	0.05	5	0.89
Veg75	-	-	75	0.05	5	0.84
Veg100	-	-	100	0.05	5	0.80
Veg150	-	-	150	0.05	5	0.71
Veg200	-	-	200	0.05	5	0.66

Conclusions

In the present work, the SWASH numerical model was used to assess the effect of vegetation on the transmission coefficient over coastal protection works. From this analysis, it is concluded that:

- the SWASH model adequately simulates the parameter K_t over submerged breakwaters when compared to laboratory test results;
- submerged breakwaters placed shoreward the depth of closure reduces K_t values as a function of the height, reducing round 30%. While vegetation patches placed seaward the depth of closure can reduce the same proportion of the K_t for vegetation lengths equal to 200 m.

The present study demonstrates a reduction in the K_t values in coastal protection works promoted by the vegetation effect. In the future, physical model tests and the use of more detailed CFD models will allow better conclusions to be drawn. By analysing the impact of vegetation on K_t, this study makes progress towards understanding NBS use in coastal defences.

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