ABSTRACT

Mangroves can attenuate wave energy efficiently. However, the effect of a mangrove canopy on wave attenuation is controversial. A series of laboratory experiments under regular waves were conducted to investigate the hydrodynamic variations affected by varying mangrove morphology configurations of four kinds of models under two water depths, i.e. nearly emergent, and emergent. The formula of wave decay factor including canopy effects is proposed to characterize mangrove-induced wave attenuation when the mangrove canopy is submerged. The relationships between the bulk drag coefficients \( \text{Cd} \) and hydraulic numbers are discussed in detail. Finally, a new generic formula of the bulk drag coefficient \( \text{Cd} \) considering the effects of the canopy is induced.

KEY WORDS:  wave attenuation, mangrove canopy, drag coefficient

INTRODUCTION

With global warming and sea level rise, coastal hazards become more frequent and severer. To heighten and strengthen traditional hard coastal protection structures (i.e. sea dikes, breakwaters) becomes an unsustainable and uneconomical way to combat harsher environments. Nature-based solutions, as a kind of sustainable solutions with low environmental impacts and high resilience to climate change, have attracted increasing attention (Borsje et al., 2011; Temmerman et al., 2013; Scarano, 2017). Employing coastal vegetation to maintain a bio-shield as the first buffer line to reduce coastal risks has been admitted as a promising coastal protection solution (Maza, 1997; Tang et al., 2015).

The importance of ecosystem-based coastal protection (i.e. mangroves, salt marshes) has been revealed through historic events (Zhu et al., 2020). For instance, the ability to attenuate wave energy and reduce storm surges by mangroves was reported in many studies (Yanagisawa et al., 2010; Maza et al., 2015). Furthermore, mangrove forests can offer additional ecosystem services which benefit coastal communities, such as purifying water, offering nursery areas for flora and fauna, promoting biodiversity, and sequestering blue carbon (Alongi, 2008). Therefore, the coastal protection approach in engineering is gradually shifting from traditional costly grey structures to sustainable nature-based green solutions. To make full use of the coastal protection functioning of ecosystems, it is primary to understand the physical processes of coastal water-coastal vegetation interaction.

Mangroves, which dwell at the intertidal zones, have been proven to play a significant role in attenuating wave energy, retarding tidal flow, and reducing storm surges (Verhagen, 2019). Both the hydraulic conditions and mangrove properties affect wave attenuation by mangroves (Bao, 2011; van Hespen et al., 2021). Most previous studies ignored mangrove morphology effects on wave damping and simplified coastal vegetation as rigid cylinders (Wu et al., 2016; Lou et al., 2018). However, mangrove has a typical three-layered vertical structure, characterized by a leafy canopy, thick trunk, and interwoven roots. Therefore, it is crucial to properly parameterize mangrove morphology and quantify its influence on wave attenuation. Otherwise, the oversimplified cylinder shape of mangrove trees would introduce big uncertainties in evaluating wave attenuation by mangroves. In the last decade, some studies have tried to properly mimic complex mangrove structures on small scales, based on Ohira et al. (2013) proposed mangrove morphological model (Maza et al., 2017; He et al., 2019; Wang et al., 2022a, 2022b). In this study, we choose a 1:10 geometrical scale to fit the flume size. Referring to the morphological model of Ohira et al. (2013), two artificial mangrove models, i.e. with canopies and without canopies, and two cylinder models were employed to investigate the effects of mangrove vertical structure on wave attenuation.

The paper is organized as follows. In section 2, the theoretical background of wave attenuation by vegetation is introduced. The following Section 3 illustrates the setup of laboratory experiments and model configurations. Then, the results and discussion are given in Section 4. The main conclusions are summarized in Section 5.

METHODS

Theoretical Background

The wave decay formulas (Eqs 1-3) by vegetation proposed by Dalrymple et al., (1984), based on the conservation of wave energy, were employed to evaluate wave attenuation by vegetation under regular waves.

\[
\frac{\partial (\text{Ec}_d)}{\partial x} = -\text{Ec}_d \tag{1}
\]

where \( x \) is the wave propagation distance along the vegetation field, \( E \) is...