

Original Paper

Progress in Research on the Hydrodynamic Mechanism of Nearshore Plant Wave Dissipation

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Received: January 18, 2026

Accepted: March 9, 2026

Online Published: March 16, 2026

doi:10.22158/asir.v10n1p126

URL: <http://dx.doi.org/10.22158/asir.v10n1p126>

Abstract

Coastal salt marsh plants protect shorelines from erosion and damage by dampening incoming waves. Scholars at home and abroad have studied the wave attenuation characteristics of ideal vegetation by using a series of mathematical models and physical model experiments with comparative research methods, taking into account relevant wave conditions, plant parameters, and other factors, which has important ecological and environmental value. Furthermore, the introduction of dimensionless parameters such as Ursell number, Reynolds number, and KC number in standard fluid conditions is significant for evaluating wave dissipation by different vegetation and explaining the hydrodynamic characteristics of plant-induced wave attenuation. However, the hydrodynamic conditions and vegetation considered in existing model studies still have certain limitations. Taking into account wave breaking, random wave conditions, and more refined flexible vegetation simulations will be the main focus of future research.

Keywords

flexible plants, wave attenuation, dimensionless parameters

1. Introduction

In recent years, nearshore plants represented by mangrove plants and intertidal plants represented by Rice plants, can not only effectively change the turbulence characteristics of water bodies, reduce the erosion and damage of waves to the coastline, but also further construct good offshore ecosystems, which have been increasingly used as research objects for ecological revetment.

At present, the research methods for plant wave dissipation mainly use numerical simulation and physical model experiments. The research on numerical simulation is mainly based on the grid model, and the fluid-structure coupling model of plant and wave conditions is established for numerical simulation

calculation. The physical model test simulates the interaction between waves and plants in the actual fluid environment, observes the wave height and flow velocity, and calculates and analyzes the hydrodynamic characteristics of plant wave dissipation. In terms of the mechanical properties of the research object itself, it can be divided into rigid plants represented by mangrove plants and flexible plants represented by *S. alterniflora*. The study of rigid plants focuses more on macroscopic structure and test scale, while the study of flexible plants should further study the elastic modulus and detailed structure of the plants themselves. Furthermore, the influence of different plants on Ursell number and Reynolds number under different fluid conditions is further studied by dimensional analysis, and the hydrodynamic characteristics of plants are further explained.

2. Rigid Plants

2.1 Influence of Wave Conditions

Wu Weicheng (2015) studied the attenuation law of irregular waves passing through non-submerged rigid vegetation. The experimental results show that under shallow water conditions, plants are more effective at dissipating high-frequency waves; as the relative water depth increases, the degree of wave height attenuation increases, indicating that when the nonlinearity of waves is enhanced, plants are more effective in wave dissipation. Augustin Lauren N. (2009) conducted physical experiments to study wave attenuation under near-submerged and non-submerged rigid vegetation. The results show that the wave dissipation effect of non-submerged rigid vegetation is better than that under near-submerged conditions; the drag coefficient of non-submerged rigid vegetation has a greater correlation with the Reynolds number.

2.2 The Influence of Plant Community Shape and Distribution

The shape of rigid plant roots and stems, as well as the distribution density and pattern of plant communities, have significant impacts on the flow field distribution within the plant community. Therefore, studies on wave dissipation by rigid plants need to consider the effects of plant shape and distribution density. Chen Jie (2021) through research on rigid, non-submerged plant belts, found that the higher the incident wave height and the smaller the relative water depth, the more obvious the wave dissipation effect. When the plant density does not reach a certain threshold, the plant belt's obstruction to waves shows a significant positive correlation with density, and wave-induced flow is still mainly influenced by roots, with stems playing a weaker role. Regarding the impact on the internal flow field velocity distribution, the stems of plants have a damping effect on the root mean square oscillatory flow velocity.

To further study the impact of rigid plant community distribution on the flow field, Chen Ming (2022) and others built a three-dimensional flume model containing rigid submerged plants, based on Flow-3D and an improved porous structural plant community model, to simulate the hydrodynamic characteristics of waves of different heights passing through plant areas. The study found that the presence of plants reduces wave velocity, and the magnitude of this reduction is positively correlated with plant density.

The greater the plant submergence, the better the wave dissipation effect. In plant communities with uniform vertical density, the forward velocity at the top of the canopy is increased; however, in plant communities with non-uniform vertical density, this phenomenon is not obvious due to the interactions among plants at different heights, indicating that plant height distribution is also important for the flow field.

3. Flexible Plants

3.1 Influence of Plant Properties

Cavallaro Luca (2018) used polyethylene as material to fabricate artificial aquatic flexible plants according to a scale of 1:4, completed the physical model experimental study of the interaction between surface waves and aquatic flexible plants, and calculated and analyzed the wave height attenuation and flow velocity changes during the interaction between aquatic flexible plants and waves (Lei, 2019). The experimental results show that with the increase of Reynolds number, the drag force coefficient in the plant area shows a significant decreasing trend. The flexibility of plant leaves and its influence on the wave dissipation effect are described by the Cauchy number and the drag force coefficient of the plant area, in the range of Cauchy number less than 500, the drag force coefficient decreases with the increase of Cauchy number, and when the Cauchy number is greater than 500, the drag force coefficient slowly decreases and approaches a fixed value.

Yin Zegao (2018) found that the relative wave height of the plant area decreased significantly and the wave dissipation effect of the plant area was significantly enhanced with the increase of the submersion degree of the plant area, the relative density of the plant area distribution, and the relative width of the plant area. With the increase of the relative length of the plant area, the relative wave height of the plant area increases slowly, and the wave dissipation effect of the plant area weakens, but the correlation between the two is weak. With the increase of wave Ethel number, the relative wave height along the plant area decreases, and the wave dissipation effect is enhanced, and the correlation between the two is good (Yin, 2020).

3.2 The Impact of Wave Conditions

Ozeren (2014) conducted a comparative experiment on the wave dissipation characteristics of plants under two wave conditions, regular wave and irregular wave, and studied the effects of plant species and wave conditions on the wave dissipation effect of plants using three test objects: rigid plant model, flexible plant model, and real plant. The results show that under the condition of certain wave parameters, the wave height attenuation caused by the interaction between real plants and waves is greater than that caused by rigid plant models and flexible plant models. Plant distribution density is an important factor in studying wave height attenuation. Based on the above experimental studies, Maza (2015) investigated the effects of plant parameters and water depth on the wave dissipation effect of seaside alkali grass under the action of regular and irregular waves. The experimental results show that with the increase of planting density, the wave height attenuation caused by seaside alkali grass increases. With the increase of water

depth, the wave height attenuation caused by coastal alkali grass decreases, which is consistent with the conclusion of Ozeren (2014).

Wang Haojian (2022) analyzed the correlation between wave steepness, relative water depth, Ursell number and overall drag coefficient in the process of interaction between waves and flexible plants. It is found that the overall drag force coefficient of the plant area increases with the increase of relative water depth. Since the nonlinearity of waves is affected by wave height, wavelength and water depth, the Ursell number considering the influence of the above three parameters is currently the best parameter for studying the degree of wave nonlinearity. The overall drag force coefficient of the plant area decreases with the increase of the Ethel number, which indicates that the drag force coefficient decreases with the increase of wave nonlinearity.

4. Main Development Trends

Current research often starts from linear wave theory and focuses on exploring the wave attenuation mechanism of vegetation under the action of individual waves. However, the waves and currents in the actual ocean are more complex. Therefore, studying the wave attenuation mechanisms of vegetation under theories related to focused waves, solitary waves, wave breaking, and random waves is an urgent subject for research. In addition, research on the wave attenuation mechanisms of vegetation mainly concentrates on the case of the action of waves alone. The study of mechanisms under the combined action of waves and currents is also limited to regular waves and steady flow conditions. The wave attenuation mechanisms of vegetation under the combined action of random waves and unsteady flow (Wang, 2021) will be a key focus of future research.

In physical model experiments, it is necessary not only to investigate the similarity between the simulated materials of vegetation and actual plants but also to consider the wave elements of the actual sea area. However, due to the limitations of flume scale and wave generator capabilities, it is currently difficult to effectively unify the geometric scaling of vegetation with the scaling of wave elements. Therefore, future physical model experimental studies on vegetation wave attenuation should pay more attention to large-scale simulations and the simulation of real plants.

At present, numerical simulation studies often simplify vegetation as rigid cylinders. In actual research, flexible plants represented by species such as *Spartina alterniflora* possess certain physical properties such as elastic modulus and deflection. Considering the mechanical properties of plant stems and the combined action of stems and leaves in vegetation wave attenuation is of greater research value.

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