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マングローブ Rhizophora stylosa の耐力限界と波浪条件の関係について
Limit load of wave conditions for the mangrove Rhizophora stylosa

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Mangroves are able to attenuate tsunamis, storm surges, and waves. Their protective function against wave disasters is gaining increasing attention as a typical example of the green infrastructure/Eco-DRR (Ecosystem-based Disaster Risk Reduction) in coastal regions. Hydrodynamic models commonly employed additional friction or a drag forcing term to represent mangrove-induced energy dissipation for simplicity. In this study, we conducted field surveys on the Iriomote Island of Okinawa, Japan, and Tarawa, Kiribati. By analyzing the data, significant correlations for hydrodynamic modeling were found among the key parameters such as the trunk diameter at breast height, the tree height, the height of prop roots, and the projected areas of the root system. We also discussed the correlation of these representative factors with the tree age. These empirical relationships are summarized for numerical modeling at the end. The limit load of wave conditions for the mangrove is also discussed.

１． Introduction

As natural barriers against coastal hazards, green infrastructures primarily regard coastal dunes, sandy beaches, coastal forests, mangroves, coral reefs, and wetlands. Coastal trees and mangroves are recognized for their protective function in terms of the reduction of wave/hydrodynamic energy during extreme events (e.g., storm waves, surges, and tsunamis). Based on several reports of the 2011 Tohoku Earthquake Tsunami, coastal pines can be critical in attenuating wave energy under small- to medium-sized tsunamis. Another major type of coastal vegetation, mangroves were identified as useful buffers in the tropics and subtropics during the 2004 Indian Ocean Earthquake Tsunami and other major natural disasters. In addition to their protective function against coastal disasters, afforestation and reforestation of mangroves have been adopted in Southeast Asia and the Pacific islands to improve the capacity for carbon storage and environmental recovery as a measure of climate change mitigation. Despite the findings in simplified analytical and numerical modeling of wave at

Attenuation based on the other vegetation study, the current scientific knowledge and modeling tools to assess the effectiveness of mangroves are relatively limited considering the realistic shape of mangroves (e.g., Chang and Mori 2021). Generally, a forcing term in the Euler equation or shallow-water equation is used to account for the energy dissipation by vegetation in various studies (e.g., Mendez and Losada 2004, and Mazda et al. 2005). The vegetation effects were integrated as enhanced bottom friction in some studies (e.g., Yang et al. 2015), while the Morison-type formula has recently been considered more straightforward to parameterize vegetation-induced resistance (e.g., Alagan Chella et al. 2020).

In this study, we conducted field surveys to collect the fundamental characteristics of mangrove tree shape by focusing on the Rhizophora species. Based on the field data analysis, the relationships among different geometric diameters and the tree age are examined, although the available field data is limited. The parameterization of the shape of Rhizophora species is proposed for the future development of coastal wave models.

2. Outline of field survey and measurements

Two sets of field surveys were conducted in 2019 and 2020 to investigate mangrove root structure. The field sites included natural mangrove forests in the Iriomote Island of Okinawa, Japan, and a planted mangrove area in Tarawa, Kiribati.

In both surveys, the fieldwork included the manual measurements of the representative parameters of mangrove root structure and the use of a 3D laser scanner for detailed root structures. In addition, the 2D projected visualization of mangrove root shapes was obtained by using a digital camera in Iriomote Island. As the 2D and 3D visualization measurements required space, we selected front trees of groups, but the basic tree characteristics (e.g., tree heights, DBH, or age) were measured both front and inside of trees in Tarawa. In this paper, we analyzed the field measurements and the 2D image visualization of mangrove root system structure. At the same time, the 3D scanned data will be presented in the forthcoming analysis along with further field surveys in future work.

3. Results

By analyzing the field data, we aimed to find out empirical formulas among the characteristic parameters of mangrove root geometry which are critical for the implementation of mangrove effects in numerical models for wave propagation.

Distinct relationships were found among the tree height, the spanning radius, the trunk diameter at breast height (DBH), and the frontal projected area $A(z)$ of the root system. Here, we summarize the estimated relationships of mangrove bulk characteristics in Figure 1. Based on Figure 1, we can estimate the root height, root width, and the number of the root system as well as the frontal projected area $A(z)$ as a function of tree age t. Although the upper system of the mangrove (i.e., leaves and branches) was not measured, we succeeded in obtaining several empirical relationships in terms of the representative factors of mangrove geometry as an example. One of the key factors to determine mangrove effects in wave modeling is the frontal projected area $A(z)$ of the root system.

To account for the potential impacts of the growth rate of mangroves, we also analyzed the relationship of the tree age with the tree height and the trunk diameter D (or DBH). Both the tree heights and trunk diameter showed monotonically increasing relationships with the tree age. This information is useful in future long-term assessment of mangrove effects, especially in the afforested or reforested areas.

The results of limit load by waves will be discussed at the presentation.

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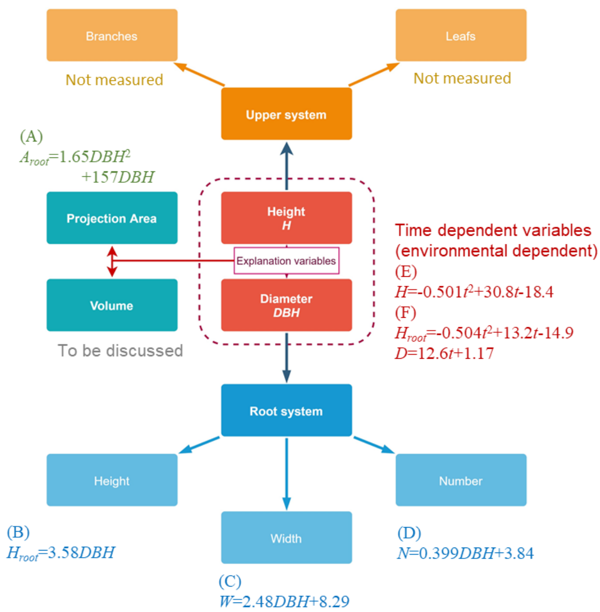

Figure 1. Summary of the geometric characteristics of mangroves (*Rhizophora stylosa*)