B109

マングローブを用いた波浪減衰評価における耐波浪評価

Estimation of critical wave conditions of mangrove

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Mangroves can attenuate tsunamis, storm surges, and waves and significantly reduce coastal hazards. Their protective functions as natural barriers have drawn attention as a prime example of green infrastructure/Ecosystem-based Disaster Risk Reduction (Eco-DRR)/Nature-based Solution (NbS) for coastal resilience. While hydrodynamic models are commonly used to estimate wave attenuation by mangrove forests,　critical thresholds for mangrove tree failure under wave impacts and the associated wave conditions remain underexplored and are often excluded from such assessment. This study investigates the maximum bending moment of the mangrove tree, mainly *Rhizophora stylosa*, based on a field survey conducted on Iriomote Island, Okinawa, Japan. A practical estimation formula is developed by integrating field data with linear small amplitude wave theory. The results, including empirical relationships for critical wave conditions leading to the bending failure of mangroves, offer valuable insights for designing and optimizing mangrove-based coastal protection strategies.

１． Introduction

Among coastal vegetation, mangroves stand out as one of the important coastal vegetation species for coastal flood reduction. The mangrove has complex prop root systems, which differ from the other simple-shaped terrestrial trees like pines. Therefore, there are many studies investigating the quantification of wave attenuation by the mangroves with prop root structures. Their unique prop root structures effectively reduce flow velocity and dissipate wave energy (e.g., Tanaka et al., 2007; Zhang et al., 2015), underscoring the importance of the accurate representation of mangroves in numerical modeling (e.g., Maza et al., 2015). Many numerical models rely on the Morison-type formula to estimate wave attenuation, where the drag coefficient CD is a critical parameter to represent the shape of mangrove (e.g., He et al., 2019; Chang et al., 2022; Zhang et al., 2024). While significant progress has been made in understanding wave attenuation by mangroves, critical knowledge gaps remain, particularly regarding the structural limits of mangroves under wave forces.

To optimize the mangrove function for coastal protection, it is critical to understand the wave loads that could lead to tree failure. Such critical wave conditions are necessary to design and protect mangrove forests against extreme storm waves, storm surges, or tsunamis, where the leading edge of a mangrove forest is subjected to the highest wave forces and may require supplementary protection through engineering or non-engineering methods (e.g., Mai Van, 2021). Therefore, critical wave conditions must be considered when designing, installing, and maintaining mangrove-based coastal flood protection.

This study aims to address these gaps by focusing on Rhizophora sp. to estimate the critical wave conditions leading to bending failure. Field surveys were conducted to measure the maximum bending moment of mangrove trees, with analyses exploring the relationships between tree diameters and bending moments. Using linear wave theory and field data, maximum loads and moments were estimated.

2. Outline of field survey and measurements

A field survey was conducted in 2022 to investigate the resistance forces on mangroves and their geometrical structure. The survey site was located in natural mangrove forests along the bridge near the river mouth of Urauchi River on Iriomote Island, Okinawa, Japan.

Fieldwork included measuring representative parameters of mangrove shape characteristics, such as trunk diameter at breast height (DBH), tree height, and others. Furthermore, loading tests were conducted to determine the critical loads and estimate failure conditions.

3. Results and summary

This study investigated the failure mechanics of *Rhizophora stylosa*, a dominant mangrove species, on Iriomote Island, Okinawa, Japan. A field survey was conducted to analyze root geometry and establish empirical relationships between key parameters. The maximum bending failure mode of *R. stylosa* was estimated using field loading tests and linear wave theory, providing valuable insights into integrating mangrove effects into coastal hazard mitigation strategies.

The loading test revealed that mangrove failure is primarily driven by bending moments rather than shear stress. Maximum bending moments from the ground exceeded 5 kNm for specimens with a diameter at breast height (DBH) greater than approximately 50 mm. Time-averaged wave-induced forces and moments were calculated using the Morison-type equation and compared with observed values. The estimated threshold for maximum moments was parameterized as a function of wave height H, wave period T, water depth h, DBH, and drag coefficient CD. Results showed that the maximum moments observed in the field are greater than theoretical predictions for typical linear wave conditions.

Here, we summarize an illustration of wave attenuation and load-bearing capacity based on the Morison-type equation. We further illustrated wave attenuation and load-bearing capacity in mangrove systems. As shown in Figure 1, the incident wave height H_0 decreases as waves propagate, attenuated by mangroves. Assuming the frontal projection area of a mangrove tree A is described by empirical formulas, wave attenuation can be parameterized as a function of wave height H, wave period T, water depth h, DBH, and drag coefficient CD. The maximum bending moment of mangroves can then be estimated. When the maximum moment exceeds the threshold determined, a condition likely to occur near the leading edge of the forest, trees in this red-shading zone (Figure 1) may require additional protection or maintenance considerations. Given that tree height and trunk diameter increase with tree age (Mori et al., 2022), this study provides valuable data for long-term assessments of mangrove contributions to coastal hazard mitigation.

Variations in prop root structures among mangrove species may lead to differences in maximum bending moments. Further field surveys encompassing a wider range of species and environmental settings are necessary to refine these findings. Additionally, more field data is needed to estimate the range of uncertainties in the limits of forces better. Specifically, the maximum bending moment is influenced by soil foundation conditions, emphasizing the importance of examining the relationship between bending moments and foundation stability in detail. Future studies should also aim to parameterize maximum bending moments under extreme wave conditions, such as mega-tsunami or extreme storm events, to enhance predictive models for mangrove resilience and coastal hazard mitigation.

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

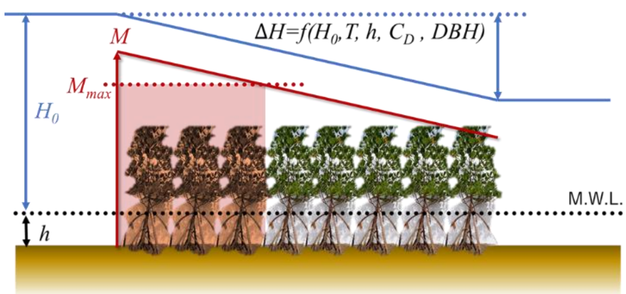

Figure 1. Conceptual illustration of load-bearing capacity and wave attenuation by mangroves