様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Quantitative Evaluation of Coastal Forests on Natural Disaster Mitigation - Considering the Complexity of Vegetation Structures

研究課題名（英文）Quantitative Evaluation of Coastal Forests on Natural Disaster Mitigation - Considering the Complexity of Vegetation Structures

研究代表者
張　哲維（Chang, Che-Wei）

京都大学・防災研究所・特定助教

研究者番号：２０８６６８２６

交付決定額（研究期間全体）：（直接経費）　　3,200,000円

研究成果の概要（和文）：本研究では、現地調査においてマングローブの形態を表すパラメータ間の相関関係を発見し、それに基づいて新たなパラメータ化を提案した。マングローブの根の構造を再現した3Dモデルを用いて、波とマングローブの相互作用を研究し、マングローブの抵抗力係数の経験式を確立した。実験室で得られた力係数の経験式を用いて、マングローブの抵抗をブシネスク型モデルでパラメータ化し、水波をシミュレートした。モデルの結果、抗力と慣性の両方の効果を考慮することで、キャリブレーションに頼ることなく、実験測定値の精度が向上することがわかった。

研究成果の学術的意義や社会的意義
現地調査での測定は豊富なデータベースを構成し、他の研究者が数値シミュレーションでマングローブをパラメータ化するのに利用できる。実験室実験により、波とマングローブの相互作用や波浪減衰に対するマングローブの効果について、根の構造を含めた詳細な情報が明らかになったことは、環境保全や沿岸保護にとって非常に重要な発見となる。開発したマングローブ効果を組み込んだ数値モデルは、将来のリスク評価に利用することができる。

研究成果の概要（英文）：The study discovered correlations between morphological parameters of mangroves in field surveys, based on which a new parameterization was proposed. Using 3D-printed scale models that replicated the exact root structure of mangroves, we studied wave-mangrove interactions and established the empirical formulas for force coefficients that represent mangrove resistance. By inspecting fluid velocity and turbulence surrounding mangroves, we identified the blockage effects and the enhanced turbulent kinetic energy induced by mangrove roots, which highlighted the importance of mangrove roots to hydrodynamics. With the empirical formulas of force coefficients from laboratory experiments, we parameterized mangrove-induced resistance in a Boussinesq-type model to simulate water waves through mangroves. The model results showed that accounting for both drag ad inertia effects improves the model simulation of experimental measurements without relying on calibration.

研究分野：海岸工学

キーワード：海岸林　波浪減衰　沿岸災害　気候変動適応策　マングローブ　Eco-DRR　水理模型実験

１．研究開始当初の背景

Coastal communities are prone to flooding caused by tropical cyclones, storms, and tsunamis. Waves and surges can erode shorelines, making coastal environments more vulnerable. Climate change, along with sea level rise, is projected to exacerbate the situation in the next few decades. To mitigate coastal hazards and enhance coastal resilience, we need efficient and sustainable strategies. Gray infrastructure is costly to maintain and detrimental to local environments. Alternatively, green infrastructure is eco-friendly and capable of adapting to changing climate. Coastal forests, as a major type of green infrastructure, were found effective against tsunamis and storm surge. However, a lack of quantitative and systematic investigations and over-simplification in existing physical and numerical studies leave a gap between the scientific progress and practical applications.

２．研究の目的

This study aims to systematically evaluate the effectiveness of coastal forests, with a special focus on mangroves, for coastal protection, quantifying their capacity to reduce wave energy and coastal flooding by considering the complexity of vegetation structure. To achieve that, the objectives of this project include to understand the morphological characteristics of mangroves, investigate the impacts of mangrove structures on water waves, and develop a numerical model incorporating mangrove effects on wave attenuation.

３．研究の方法

(a). To understand the ecological and morphological characteristics of mangroves, we collaborated with ecologists from the National Institute for Environmental Studies and the International Society for Mangrove Ecosystems in Japan, conducting field surveys in Iriomote island, Japan and South Tarawa, Kiribati. In the fields, we collected field data on mangroves, including their morphological parameters, mechanical properties, and LiDAR-scanned images.

(b). We conducted laboratory experiments to investigate the impacts of vegetation structures on water waves and vegetation-induced wave attenuation. We first used the typical idealized vegetation, rigid cylinders, without considering the root structure of mangroves as a control set to study wave-vegetation interactions. We also collaborated with the Port and Airport Research Institute, using 3D-printed scale models that replicated the exact root structure of mangroves in the laboratory to study wave-mangrove interactions under various conditions. In the experiments, we measured fluid velocity and turbulence intensity by Acoustic Doppler Velocimeters, wave profiles by wave gauges, and wave forces on mangroves by a force transducer. Based on the measurements, we established the empirical formulas for force coefficients of mangrove resistance.

(c). We applied a Boussinesq-type numerical model to simulate coastal wave propagation and hydrodynamics through mangrove forests. Based on the experimental findings on mangrove resistance, we developed a module to incorporate mangrove effects in numerical simulations of coastal waves.

４．研究成果

(a). From the field measurements, we discovered strong correlations between representative morphological parameters of mangroves, e.g., trunk diameter at breast height vs. frontal area of the roots, trunk size vs. tree age, and tree height vs. tree age. Based on these empirical relationships, we

proposed a new parameterization incorporating these relationships which can be useful when incorporating mangrove morphology and its variety in numerical simulations. Additionally, the measured mechanical characteristics will reveal the breaking conditions of real trees under critical/extreme wave conditions. The field measurements constitute a rich database, which we intend to make open access for other researchers to parameterize mangroves in numerical simulations. Part of the results have been published in:

Mori, N., Chang, C.-W. et al., 2022. Parameterization of mangrove root structure of Rhizophora stylosa in coastal hydrodynamic model. *Frontiers in Built Environment*, 7: 782219.

(b). Based on the measured wave forces on mangrove models and fluid velocity in laboratory experiments, we established the empirical formulas for force coefficients of mangrove resistance. Compared to previous studies, the estimated drag coefficients for mangroves appeared more scattered that those for idealized cylindrical vegetation. By testing different water depths, we clearly identified that the varying submergence of mangrove roots directly affects the distribution of force coefficients. In addition, by inspecting fluid velocity and turbulence surrounding mangroves, we recognized the blockage effects and the enhanced turbulent kinetic energy induced by mangrove roots which highlighted the importance of mangrove roots to hydrodynamics. The experimental results and detailed discussions have been published in:

Chang, C.-W., Mori, N., Tsuruta, N., Suzuki, K. and Yanagisawa, H., 2022. An experimental study of mangrove-induced resistance on water waves considering the impacts of typical Rhizophora roots. *Journal of Geophysical Research: Oceans*, 127, e2022JC018653.

(c). With the empirical formulas of force coefficients obtained from laboratory experiments, we parameterized mangrove-induced resistance in a Boussinesq-type model to simulate water waves through mangroves. The model results showed that accounting for both drag ad inertia effects improves the model simulation of experimental measurements without relying on calibration. The preliminary model-data comparisons have been published in:

Chang, C.-W. and Mori, N., 2020. Application of Boussinesq modeling on water waves through mangroves. *Journal of Japan Society of Civil Engineers*, Ser.B2 (Coastal Engineering), 76(2): I_49-I_5

Manuscripts with more detailed comparisons and discussions are currently in preparation.

５．主な発表論文等

〔雑誌論文〕　計5件（うち査読付論文　5件／うち国際共著　1件／うちオープンアクセス　1件）

１．著者名 Chang Che‐Wei、Mori Nobuhito、Tsuruta Naoki、Suzuki Kojiro、Yanagisawa Hideaki	４．巻 127
２．論文標題 An Experimental Study of Mangrove‐Induced Resistance on Water Waves Considering the Impacts of Typical Rhizophora Roots	５．発行年 2022年
３．雑誌名 Journal of Geophysical Research: Oceans	６．最初と最後の頁 e2022JC018653
掲載論文のDOI（デジタルオブジェクト識別子） 10.1029/2022JC018653	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Mori Nobuhito、Chang Che-Wei、Inoue Tomomi、Akaji Yasuaki、Hinokidani Ko、Baba Shigeyuki、Takagi Masashi、Mori Sotaro、Koike Hironoshin、Miyauchi Miho、Suganuma Ryosuke、Sabunas Audrius、Miyashita Takuya、Shimura Tomoya	４．巻 7
２．論文標題 Parameterization of Mangrove Root Structure of Rhizophora stylosa in Coastal Hydrodynamic Model	５．発行年 2022年
３．雑誌名 Frontiers in Built Environment	６．最初と最後の頁 782219
掲載論文のDOI（デジタルオブジェクト識別子） 10.3389/fbuil.2021.782219	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 －

１．著者名 Hu Jie、Mei Chiang C.、Chang Che-Wei、Liu Philip L-F.	４．巻 168
２．論文標題 Effect of flexible coastal vegetation on waves in water of intermediate depth	５．発行年 2021年
３．雑誌名 Coastal Engineering	６．最初と最後の頁 103937～103937
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.coastaleng.2021.103937	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Chang Che-Wei、Mori Nobuhito	４．巻 63
２．論文標題 Green infrastructure for the reduction of coastal disasters: a review of the protective role of coastal forests against tsunami, storm surge, and wind waves	５．発行年 2021年
３．雑誌名 Coastal Engineering Journal	６．最初と最後の頁 370～385
掲載論文のDOI（デジタルオブジェクト識別子） 10.1080/21664250.2021.1929742	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

1．著者名 Chang Che-Wei、Mori Nobuhito	4．巻 76
2．論文標題 Application of Boussinesq Modeling on Water Waves through Mangroves	5．発行年 2020年
3．雑誌名 Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)	6．最初と最後の頁 I_49～I_54
掲載論文のDOI（デジタルオブジェクト識別子） 10.2208/kaigan.76.2_I_49	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計4件（うち招待講演　0件／うち国際学会　4件）

1．発表者名 Chang Che-Wei
2．発表標題 Experimental study of mangrove effects on coastal protection
3．学会等名 virtual International Conference on Coastal Engineering (vICCE 2020)（国際学会）
4．発表年 2020年

1．発表者名 Chang Che-Wei
2．発表標題 Mangrove and its impacts on water waves: a model-scale laboratory study using 3D replicas of typical Rhizophora
3．学会等名 37th International Conference on Coastal Engineering (ICCE 2022)（国際学会）
4．発表年 2022年

1．発表者名 Chang Che-Wei
2．発表標題 Recent investigation on the protective function of mangroves against coastal waves
3．学会等名 43rd Ocean Engineering Conference in Taiwan（国際学会）
4．発表年 2021年

１．発表者名 Chang Che-Wei
２．発表標題 Application of Boussinesq Modeling on Water Waves through Mangroves
３．学会等名 土木学会 海岸工学講演会（国際学会）
４．発表年 2020年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関