A Comparative Study on Model Order Reduction Techniques for Structural Health Monitoring and Prediction of Ship and Marine Structures with Detachable Mooring System

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Abstract

Structural integrity evaluation of ships and offshore structures has seen increasing interest in digital twin applications. Historically, structural safety was maintained through conservative design practices involving large safety factors and scheduled inspections. However, real-time assessment of structural performance is now achievable with digital twin technology. With the increasing demand for eco-friendly energy generation as well as general ships and marine structures, research on implementing digital twins for real-time structural health monitoring in floating offshore wind turbine is being actively conducted. This research explores the application of model order reduction(MOR) methodologies to develop digital twins for structural health monitoring (SHM) of ship and marine structures exposed to irregular wave loads in realistic ocean environments. Specifically, the floating offshore wind turbines in this study utilize a detachable mooring system, enabling efficient maintenance (e.g., damage prevention and repairs) by facilitating detachable mooring system without underwater intervention, thereby significantly reducing offshore operational time. Consequently, a digital twin is crucial for rapid structural damage detection and health assessment, enabling more effective structural maintenance. Model order reduction method offers the advantage of significantly reducing computational cost when analyzing large and complex structures, allowing for quicker estimation of structural responses. Moreover, reduced order model(ROM) facilitates the prediction of structural behavior based on available sensor measurements. In this study, both the Krylov Subspace method and the Proper Orthogonal Decomposition (POD) technique were applyed to generate reduced-order models of representative ship and marine structures. A comparative study was then performed, focusing on the accuracy of structural response predictions, computational time required by each method, and a detailed discussion of the strengths and weaknesses associated with each algorithm. Validation of the proposed techniques was achieved through comparison with experimental data obtained from model tests conducted at the Korea Research Institute of Ships & Ocean Engineering(KRISO).

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Furthermore, the structural response prediction performance of the reduced-order model (ROM) was analyzed with respect to the number of reduced orders. Compared to the full order model (FOM) with tens of thousands of degrees of freedom, the ROM achieved over 99% accuracy with as few as 20 reduced orders. Consequently, applying model order reduction to ship and marine structure simulations resulted in structural response predictions with an error of less than 1.19% compared to simulations of full order model, achieving over 99% reduction in simulation time. Acknowledgements: This research was supported by a grant from the Endowment Project of "Study on Concept Design of Small Modular Reactor(SMR) powered Ships and Offshore Platforms(2520000281)" funded by the Korea Research Institute of Ships and Ocean Engineering; and the Korea Institute of Energy Technology Evaluation & Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20223030020240).