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Effects on the various rubber fenders of a tripod offshore wind turbine substructure collision strength due to boat

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ABSTRACT

An analysis is conducted to minimize the damage to tripod type offshore wind turbines substructure caused by collisions with boat. The impact of a wind turbine and a boat takes a complicated form. ANSYS LS-Dyna, a commercial FEM tool, is employed for the impact analysis. The FE model generated using equivalent beams for the blades which are verified the method through the results of static and dynamic analysis between full 3D blade model and equivalent beam model. The investigation is conducted in order to determine the influences of various boat speeds, which result in different loading conditions, and various rubber materials for the fender on strain energy, total deformation, plastic strain, internal energy, and permanent deformation. Natural rubber, composite rubber, and neoprene are modeled using Mooney–Rivlin constants, which are determined by material tests, and a time-marching analysis is conducted to account for their nonlinearity. Based on the analysis results, the minimum thickness of a rubber fender is suggested to decrease the effects of impact for the structures. This study provides relationship trends between the structure thickness and the rubber fender thickness, which may be useful in developing the structural design of a tripod type offshore structure.

1. Introduction

This study is conducted as a fundamental research to establish measures for preventing impact damage to fixed type offshore wind turbines. A collision with a ship can be a catastrophic event for an offshore structure. Several ship-offshore structure collisions have occurred within the last few years. Therefore, offshore structures have to be prepared for ship collisions as well as severe weather conditions at sea. It is usually a complicated dynamics problem that involves time-dependent nonlinearity. A highly nonlinear problem, such as plastic deformation, may be considered in terms of a permanent failure strain of the structure. An offshore wind turbines have a heli-deck or fender structures of service boat for the periodic maintenance, only service boat is allowed to access to the structure. Many studies regarding accidental collision problems in offshore structures such as an offshore platforms and commercial vessels are found. The regulations for service collision are adopted in various design codes (API (2000), DNV (2000), NORSOK (1998), AASHTO (1994)). Lee and Park (2012) suggested a minimum thickness of rubber fenders of the met mast structure to measure wind, wave, current data etc. To avoid complicated behaviors of impact structures, equivalent static analyses are common instead of direct impact simulation. Kitamura (2002) performed nonlinear finite element simulations of ship-to-ship collision and ship-to-rock stranding. Petersen (1982) studied a procedure for time simulation of the outer dynamics in ship collisions. Woisin (1988) examined an external analysis of ship–ship collisions and evaluated the loss of kinetic energy. A comprehensive evaluation procedure was developed for assessing the damage effects to an offshore jacket platform structure due to collision by a large barge (Jin, 2005). As the scale of the offshore wind farm increasing, the study on the the fender system is of practical importance in the view point of accidental limit state (ALS) design. The offshore wind turbine is always exposed to collision with service boat for operation and maintenance. In recent years, several collision incidents have been reported. This paper considers various collision scenarios and provides the proper size and materials of the rubber fender of tripod shaped offshore wind turbine using nonlinear finite element analysis. In addition, a rational designing process of the rubber fender is also suggested. This study investigates the influence of impact on the structure and feasibility of a rubber fender as an impact prevention measure. The analysis is conducted using ANSYS LS-Dyna version 12.0.

2. Equivalent blade beams

The structural design process of the rotor blade that this study considers is shown in Fig. 1. The FE model reflects the blades as

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equivalent beams following the coordinate system and rigidity generation model shown in Figs. 2 and 3. In order to simulate the dynamic behavior of the wind turbine more accurately, the equivalent model of the blade structure consists of an equivalent stiffness model and an equivalent mass model. The equivalent stiffness model uses an elastic beam element that does not account for bending stiffness, torsion stiffness, or mass. The equivalent stiffness model has three degrees of freedom: flap-wise translation, edge-wise translation, and torsion, as shown in Eqs. (1)–(3). On the other hand, the equivalent mass model uses a box and a lumped mass element that accounts for inertia, as shown in Eqs. (4)–(6). The equivalent model maintains an error of within 3% compared to the 3D shell model. The material property of wind turbine blade to perform the analysis of static and dynamic is shown Table 1 and the comparison results between 3D full model and beam model is shown in Table 2. The CDB340 has a 25%, 25%, and 50% distribution of +45, −45, and 0 fibers, respectively. The Spar Cap mixture is composed of alternating layers of triaxial and uniaxial fabric and the Spar Cap laminate has 70% uniaxial and 30% off-axis fibers by weight. The comparison

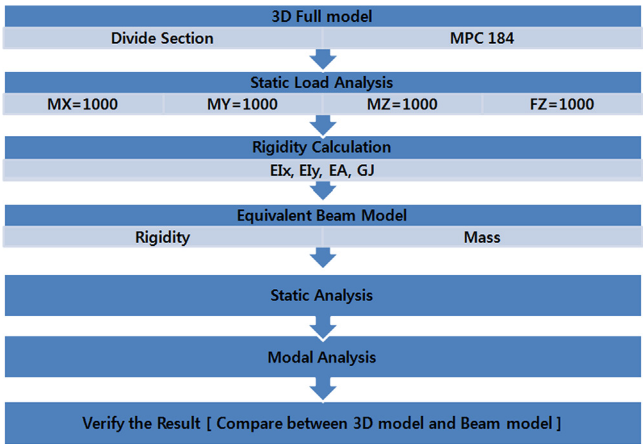

Fig. 1. Equivalent beam generation procedure of wind turbine blade.

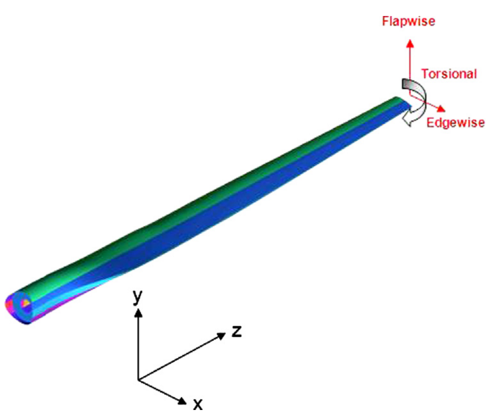

Fig. 2. Blade coordinate system for equivalent model.

Table 1
Material property of wind turbine blade.

Material	Density [g/cm^3]	Elastic modulus [GPa]			Poisson's ratio
		E_x	E_y	G_{xy} (shear)	
Gel coat	1.23	3.44	3.44	1.38	0.30
Random mat	1.67	9.65	9.65	3.86	0.30
Triaxial fabric	1.75	24.2	8.97	4.97	0.39
Uniaxial fabric	1.75	31.0	7.59	3.52	0.31
Spar Cap mixture	1.75	25.0	9.23	5.00	0.35
Balsa	0.144	2.07	2.07	0.14	0.22
Fill epoxy	1.15	2.76	2.76	1.10	0.30

Table 2
Comparison results between 3D full model and beam model.

Set	3D model	Beam model
1	0.83	0.84
2	0.91	0.89
3	2.13	2.13
4	3.59	3.56

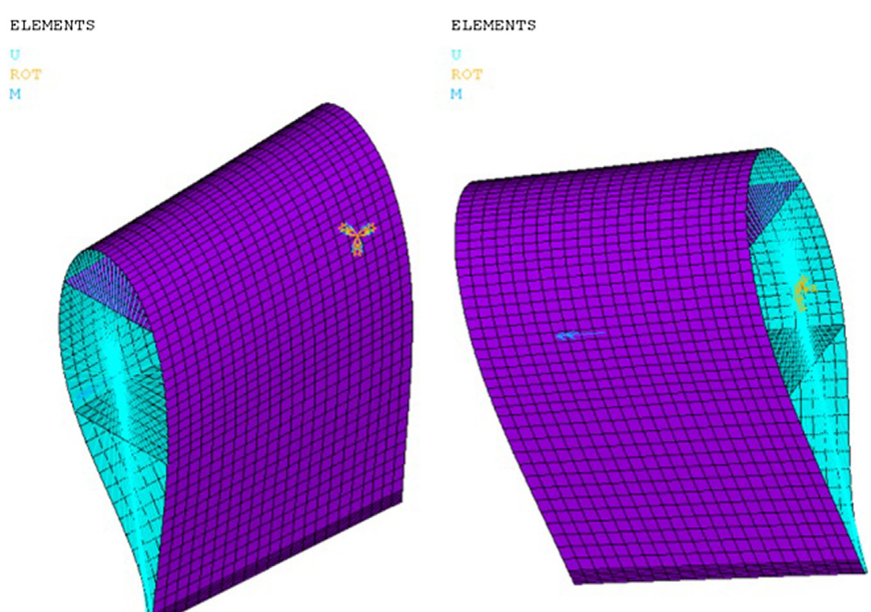

Fig. 3. Section model for rigidity.