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Analysis and design of offshore tubular members against ship impacts

Zhaolong Yu[a,b,*], Jørgen Amdahl[a,b]

[a] Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Norway
[b] Center for Autonomous Marine Operations and Systems (AMOS), Norwegian University of Science and Technology (NTNU), Norway

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ABSTRACT

Ship collisions may be critical to the operational safety of ships and offshore structures, and should be carefully designed against. This paper investigates the response of offshore tubular members subjected to vessel bow and stern impacts with the nonlinear finite element code LS-DYNA. Two 7500 tons displacement supply vessels of modern design are modeled. Force-displacement curves for bow and stern indentation by rigid tubes are compared with design curves in the DNV-GL RP C204. Next, both the ship structure and the tubular braces/legs are modeled using nonlinear shell finite elements, and the effect of ship-platform interaction on the damage distribution is investigated. A parametric study of the denting mechanics with respect to the length, diameter and wall thickness of tubular members is described. An existing analytical denting model is extended to account for distributed loads and is verified against simulation results. Existing requirements to resist excessive local denting are discussed, and a new concept 'transition indentation ratio' is introduced. The concept helps to understand the governing deformation patterns of tubular members given different tube dimensions, and is useful to unify existing cross section compactness criteria for braces/legs, providing a theoretical support for the R_c criterion in the new version DNV-GL RP C204 standard. Finally, new design compactness requirements for tubular members against impacts from ship bow, stern corner and stern end are proposed.

1. Introduction

The current DNV-GL RP C204 standard for the design of ships and offshore structures against accidental ship collisions were developed decades ago [1]. Many procedures were based on simplified plastic methods, and some of the requirements seem to be outdated now. A noticeable example is that a significant increase of the design impact energy may be needed according to Kvitrud [2], who summarized collision accidents in Norway in the period 2001–2010. Recently, a new version of the DNV-GL RP C204 standard for ship impacts is under preparation in DNV-GL, and the NORSOK N004 appendix A code [3] may be revised as well in the near future. The purpose of this work is to provide useful suggestions for improvements of the new standard. This will be done through simulations of tubular braces/legs impacted by a ship bow and two ship sterns using the nonlinear finite element code LS-DYNA.

In the design of offshore structures against accidental loads, significant damage can be allowed provided that the damage shall not impair the main safety functions such as the global load bearing capacity of structures and the usability of escape ways. The energy to be dissipated in ship collisions can vary with different displacements and velocities of the striking vessel. Based on risk analysis, the

* Corresponding author. Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Norway.
E-mail address: zhaolong.yu@ntnu.no (Z. Yu).

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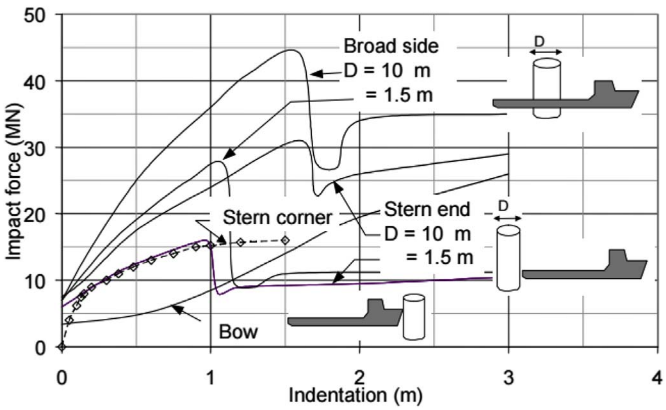

Fig. 1. Recommended force-displacement curve for beam, bow and stern impacts [3].

present DNV-GL RP C204 standard [4] suggests a standard vessel with a displacement of 5000 tons travelling with a speed of 2 m/s. This gives a kinetic energy of 11 MJ for bow/stern impacts and 14 MJ for broad side impacts considering the hydrodynamic effects with simple added masses. More considerations regarding the hydrodynamic effects during ship collisions can be found in Refs. [5–7]. The recommended deformation resistance curves for side, bow and stern impacts are given in Fig. 1. However, with the sizes of supply vessels increasing significantly to 7500–10000 tons and the impact speed higher than 2 m/s as identified in Kvitrud [2], the current design energy is considered too low. In addition, the validity of the current design curves can be questioned by the modern design of ship structures and advanced simulation tools.

As concerns the impact responses of tubular members in offshore structures like jack-ups and jacket platforms, an idealized model for the deformation may be described as follows: the tubular brace/leg deforms firstly with local denting and absorbs energy. At the same time, the plastic bending capacity of the dented brace is reduced due to the detrimental effect on the section modulus. When a certain indentation is reached, the brace starts to collapse as a beam via a three-hinge mechanism. Upon further crushing of the brace, axial membrane forces will occur and get dominant up to fracture if adjacent structures are capable of providing sufficient strength against the pull-in. Local denting may either cease or continue in the beam deformation stage.

The governing parameters for the impact response of a brace/leg are quite a few such as tube length, diameter, thickness, material properties, contact width, restraint conditions at tube ends, axial preloading, striker geometry, impact locations, etc. The high number of parameters makes the deformation mechanics of tubular members complicated. Extensive studies have been carried out to understand the underlying mechanics by means of experiments, numerical simulations and theoretical derivations. A few theoretical models have been proposed and verified through experiments, such as the denting models by Furnes and Amdahl [8], Amdahl [9] and Wierzbicki and Suh [10], the beam bending model by Soares and Søreide [11], and the models containing both denting and bending by Ellinas and Walker [12], Jones and Shen [13] and Buldgen et al. [14]. Experimental data can be found in Amdahl [15], Jones et al. [16] and Sherman [17], etc. Existing theoretical models and experiments are generally based on the idealized scenario that a rigid indenter with a certain shape (typically wedge-shaped or rectangular) strikes into a tube with clamped ends. However, ship collision situations may include various striking geometries, contact widths and boundary conditions. The problem can be even more complicated considering the relative strength between the struck brace/leg and the striking ship. It can be questioned whether the theoretical models can be applied in real ship collision analysis and crashworthiness design, and second, how accurate are they.

With respect to the distribution of strain energy, three categories are often assumed: strength design, ductile design and shared-energy design. Normal seized jacket braces are not strong enough to resist the ship impact forces, and hence ductile design is often applied for tubular braces where the installations are assumed to dissipate most of the collision energy. As the design collision energy in the new RP increases significantly, a single tubular member cannot absorb the whole collision energy in general. If several tubular members are assumed to absorb the energy, the global integrity of the platform may be threatened and the platform may collapse. A noticeable example is the well workover vessel Big Orange XVIII that collided with the Ekofisk 2/4 jacket platform with a kinetic energy of about 60 MJ, which is far beyond the design energy 11 MJ. The accident causes severe damage to the three legged jackets and also the bow [2], see Fig. 2. Several braces of the jackets are ruptured and the jacket had to be dismantled.

The design energy has increased significantly in the new version NORSOK N003 standard [18]; unless further evaluations are performed, the kinetic energy should be 50 MJ for bow impact, 28 MJ for broad side collisions and 22 MJ for stern collisions. This represents a substantial increase of the demand for collision resistance of an offshore structure. Ductile design may not be appropriate as the braces and legs will otherwise be subjected to very large deformations as shown in studies by Amdahl and Johansen [19], who simulated high energy ship bow-jacket collisions with kinetic energy in the range of 40–50 MJ. It is therefore necessary to go for strength design or shared-energy design for braces/legs, where the ship should deform and dissipate considerable energy. Braces/legs shall not suffer major local denting if the shared-energy design is assumed. Unfortunately, we can hardly find commonly agreed requirements from the literature and design standards for a brace/leg to maintain compactness during deformation. Existing requirements to resist local denting are generally obtained by observations of either experimental results or numerical simulations. Theoretical supports are lacking.