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On the accuracy of fracture estimation in collision analysis of ship and offshore structures

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A B S T R A C T

This paper discusses the fracture response in a collision scenario together with the discretization of the model, and it compares various approaches suggested by current design rules and proposed by researchers using a validation approach with different model scales; including material tests, indentation experiments and simulations of an actual full-scale collision event. Calibration of the fracture criteria is performed based only on data that can safely be assumed to be available in a design situation, namely, those from a uniaxial tensile test. This approach reveals the behavior of each criterion as it would be in a design situation and avoids the possibility of calibration toward a known solution. The robustness of the fracture criteria, i.e., their ability to simulate fracture given varying stress states and mesh sizes, are investigated based on simulations of experiments. The statistical variations for the various criteria are shown.

1. Introduction

Considering collision events during design has long been a standard practice in both ship and offshore design. Collision events are herein considered as Accidental Limit State (ALS) loads with an

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annual probability of exceedance of less than 10^{-4}. How these events are considered is a matter of considerable variation. For ships, the traditional method has been to consider the robustness of the damage stability of the vessel in terms of certain prescribed damage zones, e.g., 20% indentation of the vessel beam. For the damage stability of offshore structures, the actual extent of damage and the residual strength after the collision should typically be considered, though minimum prescriptive requirements still apply. In addition, unique design challenges related to specific hazards, such as oil and LNG tanks, hazardous cargo etc. should be considered for all types of marine structures.

Collision requirements regarding the damage stability of a structure are typically prescriptive, stipulating a damage zone of, e.g., 1.5 m indentation into the structure over a certain height and width. In formulating such a requirement, it is inherently assumed that the extent of damage from a probable collision is limited to the prescribed zone. Many offshore installations are designed with internal watertight compartments in accordance with such prescriptive damage stability rules, and their designs may therefore not sufficiently account for many probable damage scenarios, which, in turn, can have a considerable effect on their actual safety level. Several questions arise: Will a prescribed damage zone cover more stringent requirements on the severity of the design impact event for applicability in future designs? How consistent is the damage zone with damage caused by unconventional bow designs with sharp and protruding bows that are capable of piercing the platform? Do the damage zones include the effects of puncturing the side of the ship in the regions of both the bulb and the stem? Might the modern trend toward sharp bow designs cause vertical fractures that connect the bulb and stem zones?

The increasing possibilities for efficient numerical analysis of collision events lead designers to perform complex nonlinear finite element analysis (NLFEA). Sometimes, they may have limited knowledge of the fundamental challenges associated with modeling a highly nonlinear collision in an accurate and reliable way. In addition to the establishment of realistic impact scenarios, a number of issues must be addressed, including the required discretization level of the model, the contact formulations, the actual material strength and the numerical representations of the plasticity, rate dependence and strain- or stress-state dependence of the fracture behavior.

Current regulations, such as NORSOK N-004 [1], DNV RP-C204 [2] and RP-C208 [3], provide some guidance concerning how to address these challenges, but because of their generality, they are either difficult to use or overly simplified in a prescriptive manner. Accidental limit state scenarios allow for significant damage to a struck body, provided that it does not lead to progressive collapse of the structure or prevent safe evacuation due to loss of stability. The correct use of NLFEA enables increased confidence in the results and better utilization of the actual structural capacity compared with simplified methods. It has rapidly become a widely adopted tool for the simulation of such accidental impacts.

A good material model for the simulation of elasto-plastic behavior and fracture becomes important for properly capturing the structural response and ensuring that the obtained results are not overly optimistic with respect to the struck vessel's strength. In this manner, the structural safety level can be evaluated, and measures can be taken during both the design and operation stages to minimize the risk of unacceptable consequences from a collision event.

It should be kept in mind that real collision events will differ substantially from design collision events with respect to the shape and structural layout of the striking ship, structural imperfections, the impact location and velocity, and the material strength. Accurate simulations of idealized collision events can never remove this uncertainty. However, inaccurate simulations will add significantly to the total uncertainty. Fracture initiation and propagation are key factors in such simulations.

This paper assesses some of the current state-of-the-art fracture criteria that are applicable to coarsely meshed shell structures through comparison with various indentation experiments and a full-scale collision event. In this context, a coarse mesh is a mesh that is not able to resolve all strain gradients and is typically a shell element with length >> plate thickness. The focus is placed on the robustness of each criterion applied in a design situation, i.e., to what extent the criterion can be trusted to yield reasonable results for a wide range of applications when calibrated to only the data from *a uniaxial tensile test*.