Abstract

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Quantitative Risk Assessment of Double Hull Oil Tankers in Collisions

In recent decades, the number of vessels that have navigating the seas and oceans increased greatly and are expected to continue increasing. A ship may be subject to potential risks during its lifetime, such as fire, explosion, collision, and grounding, which may derive to loss of human life, environmental damage and economic loss. Among those risks, collision risk is one of the most serious accidents that might lead to such severe consequences, as well as total loss of the ship in some cases, particularly when large tankers and/or gas carriers are involved in collisions. Based on the current statistics, it is obvious that the great development in collision avoidance systems and the related regulations has not contributed to prevent the ship–ship collisions as well. In this regards, more attention and considerations need to be taken into account to decrease the risk of collision by reducing the probability of accidents and ultimately mitigate prevent their consequences. These can be achieved by using methods of risk analysis that should be integrated into the design process. Quantifying the risk level of a particular design will lead to “risk-based design” (RBD). As a basis for supporting decision making, RBD plays an important role in the global maritime industry, which may make changes in the marine regulations and contribute to develop acceptable design guidelines that satisfy all stakeholders. By understanding the serious situation if large tankers are involved in ship–ship collisions, as well as the great significance of the RBD, this thesis developed a quantitative risk assessment (QRA) methodology for double–hull oil tankers that are struck in collisions using probabilistic approaches that can contribute in the early design stage of oil tankers. This was done in association with developing innovative methods that contribute to the main QRA methodology. A significant part of the thesis is dedicated to the work on the area of accidental scenario identification, which is challenging because the level of target safety cannot be achieved by dealing only with the worst case scenario that may lead to large values of design loads in some cases. One way to deal with this problem is to probabilistically identify accidental scenarios that can be considered to be a representative sample of all possible scenarios. Through the use of the probabilistic approach, an innovative method was introduced to define a relevant set of ship–ship collision scenarios by treating the accidental influencing parameters as random variables. Using the quantitative approach, the collision risk was calculated by performing collision frequency and consequence analyses. The collision frequency was individually calculated for each collision scenario by considering a full-scale hypothetical Suezmax-class double– hull oil tanker encountered different types of other ships. In order to predict the related structural damage to the struck ship, numerical simulations were conducted for each scenario by performing nonlinear explicit finite element analyses (NLFEA). The potential environmental damage was assessed by estimating the size of oil spill in each scenario. In addition, the potential sequenced expenses (i.e., economic losses) related to the property of the collided ships and environmental damage were calculated in terms of monetary units to be more understandable to the shipowners and operators. As a product of frequency and consequence, the risk was then calculated in two dimensions risk to assets and to the environment. Based on the calculated risks, exceedance curves were established that can be used to define the collision design loads in association with various design criteria. In addition, to give a more complete picture of the risk assessment, an innovative method was proposed for assessing the risk of ship hull collapse following a collision. The ultimate longitudinal hull girder strength of the hypothetical tanker’s hull cross-section was then calculated using the intelligent supersize finite element method (ISFEM). Besides, the residual strength capacity of the damaged models was presented in terms of residual strength index (RSI). Various bending loads were applied to the target ship’s hull crosssection: pure vertical and pure horizontal bending moments, and a combination of these, considering various loading ratios (i.e., ratios of horizontal to vertical bending moments). A probabilistic approach was then applied to establish the relationship between the exceedance probability of collision versus the RSI. Moreover, considering the combined effect of vertical and horizontal bending moments on the ship’s hull girder strength, the RSI was then calculated for individual loading ratios

at a particular exceedance probability of collision (i.e. the maximum tolerable risk). The results were then formulated in terms of the RSI and the loading ratio to produce R–L diagrams and design formulations for predicting the RSI of damaged ship hulls were derived in an empirical manner. Finally, the methods developed in this thesis could provide a useful guideline for ship designers during the early design stage of double–hull oil tanker, with consideration of the collision risk. In additions, these methods can also contribute to the International Maritime Organisation's (IMO) probabilistically based Formal Safety Assessment framework (FSA) as well as the probabilistic risk-based ship design paradigm for ship–ship collision.