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Design methodology for crash occupant protection in cabin design of the high speed vessel

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ABSTRACT

Expansion of marine transport and growing number of high speed vessels travelling in the neighbourhood of the coastline significantly increase the risk of the crash on the sea. Within the existing high speed craft legislations there are no regulations related to prediction of the vessel occupants injury and trauma. Former research has exposed the similarities between the high speed vessel crash and automotive collision enabling the transfer of advanced crash safety technologies between the automotive and marine.

This paper investigates the application of the most recent CAE automotive safety technologies to predict the injuries of high speed Cruise Logistics Ferry (CLF) occupants in 40 knots crash with a harbour peer. At first, the probability of occupant injuries was studied using a 50^{th} percentile HYBRID III standing crash test dummy model. The study considered various occupant positions within the boat cabin for two different cabin orientations. The investigation was then followed by computer analyses utilising the state of the art Total Human computer Model for Safety (THUMS) to evaluate the localised passenger traumatology. This model is the most advanced human computer model available, capable of computing injury risks at organ levels.

Results from the analyses using both models showed that the standing HYBRID III dummy was suitable to assess the overall risk of occupants' injuries in a cabin design context, while the THUMS model added detailed trauma injuries for selected occupant locations. The results of both investigation indicated very high risk of life changing injuries or even death to the boat occupant within the cabin.

A strong relationship between the probability of severe injury and the distance between the passenger and any obstacle in the cabin was found. In conclusion, the research is proposing a design methodology for cabin occupant protection based on the location of each individual passenger relative to obstacles and the associate risk of injury. This is in stark contrast to the general design guidelines of the High Speed Craft code (2000) which are based on threshold values of a global collision design acceleration.

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1. Introduction

Severe crash incidents on the sea do not happen very often. However, when they do happen they include very high number of fatalities. History of "on the sea" collisions, which include ship to ship (RMS Empress of Ireland (1914), SS Andrea Doria and S Stockholm (1956), MV Dona Paz (1987)), ship to iceberg (RMS Titanic (1912)), and finally ship to shore collisions (9 ships of US navy (1923), Costa Concordia (2012)), shows the substantial danger to human lives closely related to the crash accidents [1]. With increasing interest in the leisure marine and need for high speed freight the risk of the potential crash on the sea increases significantly. In order to allow passengers a safe evacuation two conditions need to be fulfilled. The first is the vessel integrity after crash, and the second, as much important as the first, is the survivability and mobility of the vessel occupants. The second condition can be only fulfilled if the risk of the injuries is as low as possible.

Accidents such as the Costa Concordia highlight the issues of structural damage due to crash impacts, either through grounding or involving other vessels. In such accidents the structural features, such as bulk heads are insufficient to mitigate the loss of hydrostatic stability due to structural buckling and failure. Vessel structural loading conditions are primarily determined from hydrodynamic loading in a range of sea states. The hydrodynamic loading does not take into account crash loadings. However, real life scenarios show that this type of loading cannot be neglected and should be considered within the design process.

According to the European Maritime Safety Agency, 1032 collisions and 1087 grounding/stranding accidents were reported between 2011 and 2014 [2]. This highlights the importance of considering crash loads in the design of marine structures. In fact, many researchers considered the crash on the sea as a significant danger to the ships and their occupants [3–5]. However, majority of the research focus only on vessels structural integrity and do not take into account the protection of occupant.

The Maritime and Coastguard Agency High Speed Craft (HSC) code (2000) [6] states that passenger craft shall be designed for global collision design acceleration (g_{coll}), which is determined from an empirical formula based on the following parameters: vessel displacement; hull material factor; length factor; kinetic energy. The collision design condition is based on head-on impact at a defined collision speed. The HSC only provides general design guidelines based g_{coll} threshold levels as follows: design level 1 where g_{coll} is less than 3; design level 2 where g_{coll} is between 3 and 12. An overview of these guidelines is shown in Table 1. The MCA maintain that for a design level 2 situation if seats are rearward facing then they should be of high seat back design, and that sofas are not acceptable. In terms of passenger restraints one-hand-release safety belts of three-point type or with shoulder harness are to be provided for all seats for all craft with the g_{coll} acceleration exceeding 3.

In terms of accommodation design the HSC code [6] states that public spaces, control stations and crew accommodation of high-speed craft must be located and designed to protect passengers and crew in the design collision condition. These spaces are not be located forward of a transverse plane, which is determined by an empirical formula for the plan projected area of craft energy absorbing structure forward of the transverse plane. The empirical formula is based upon the following parameters: total plan projected area of craft; material factor; framing factor; operational speed.

Recently, many researchers studied ship collision and grounding using the nonlinear FE analysis. These studies involved collisions between two ships [4,7] or ships and other structures [8,9]. However, these studies were only investigating low impact velocities, i.e. below 10 m/s. In these types of impacts, the accelerations acting on the boat occupants are low and they do not impose hazard of serious injuries. Impact outcomes, however, change for high speed vessels travelling at velocity of 30–55 knots. The accelerations acting on the occupants in case of the crash are approximately 15–20 m/s^2 and impose significant hazard to the passengers.

Operational velocity of the CLF is designed to be close to the Euro NCAP frontal impact test speed [10], consequently automotive crash safety protocols are adequate and can be implemented into the development stage of CLF. Nonlinear FEA can be used to predict the structural loading and assess the safety of the design in terms of the occupant protection. Safety features such as crumple zones, designed to absorb the impact energies, as well as a rigid safety cell, designed to protect the occupants, could be implemented into the structure of the CLF.

Table 1
Overview general HSC design guidelines [6].

Design level 1: g_{coll} less than 3	Design level 2: $g_{coll} = 3$ to 12
1 Seat/seat belts	1 Seat/seat belts
1.1 Low or high seatback	1.1 High seatback with protective deformation and padding
1.2 No restrictions on seating direction	1.2 Forward or backward seating direction
1.3 Sofas allowed	1.3 No sofas allowed as seat
1.4 No seat belts requirement	1.4 Lap belt in seats when no protective structure forward
2 Tables in general allowed	2 Tables with protective features allowed. Dynamic testing
3 Padding of projecting objects	3 Padding of projecting objects
4 Kiosks, bars, etc., no special restrictions	4 Kiosks, bars, etc., on aft side of bulkheads, or other specially approved arrangements
5 Baggage, no special requirements	5 Baggage placed with protection forward
6 Large masses, restrainment and positioning	6 Large masses, restrainment and positioning