Extended summary - PhD Thesis

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Evaluation of the Post-Accident Load Carrying Performance of Hatch Covers and an Innovative Design Proposal

Introduction

One of the major topics to be investigated in the marine industry is accidents, considering their serious consequences on human life, the environment and the economy. Despite the developments in accident prevention methods and techniques, accidents continue to occur. In this regard, the evaluation of the post-accidental state of vessels becomes significantly important. By a prompt and accurate assessment, the residual structural capacity can be judged and necessary actions can be taken to save lives, avoid environmental hazards and minimise financial loss.

While accidental damage is crucial for the overall structure, the particular importance of individual structural elements is another topic to be investigated. For instance, the loss of bulk carrier M/V Derbyshire with 44 people on board, drew considerable attention to the catastrophic consequences of hatch cover failure, since it is one of the most probable loss scenarios [1]. Considering the criticality of hatch cover failure for vessel safety and high risk of impact load as a failure cause, the overall aim of this thesis is to investigate the post-accident load carrying performance of a hatch cover and propose an improved design alternative.

Methodology

In this thesis, the post-accident load carrying performance of a damaged hatch cover is evaluated through a number of simulations. M/V Derbyshire's hatch cover is selected as the reference structure in this thesis.

The methodology which is used within the framework of this thesis involves three stages: explicit dynamic analysis, transfer of the damaged structure and nonlinear static analysis. Dropped object case is selected as the accidental event where the dominant load type is impact. Three individual dropped object simulations are conducted. Although the geometry and properties of the object are kept the same, analysis settings and impact type are applied differently. In the first case, the object falls onto the hatch cover under the effect of the gravity and at the end of the simulation, the failed elements are preserved within the structure. The second case is almost identical to the first one, however, element erosion due to failure is allowed. The third simulation focuses on the influence of impact type, thus the dropped object is in a projectile motion which means it has a horizontal velocity in addition to the gravity effect. In further static analyses, after the transfer of the deformed geometry together with residual stresses and strains, a uniform lateral pressure is applied to the damaged structures and their performances are compared to the intact structure. The schematic representation of the methodology is given in Fig. 1.

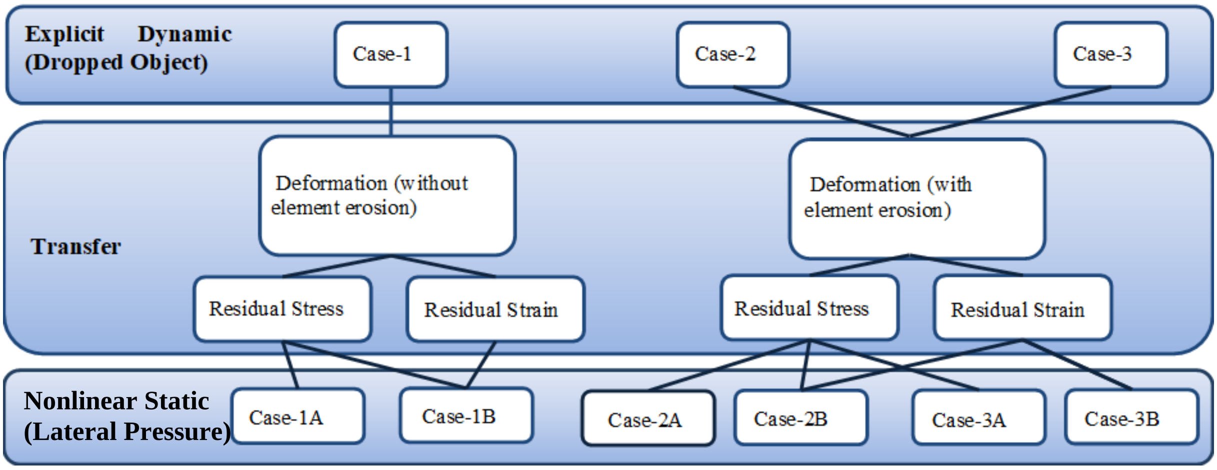

Figure 1: Methodology

Validation

The simulation process of dropped object events is verified, by referencing an experimental study [2]. Although explicit dynamic and nonlinear static simulations are included in this thesis, it is considered sufficient to present validation of only the explicit dynamic method due to its higher complexity and relatively less predictability. The simulation bodies are modelled in Ansys Workbench Geometry Modeler, based on the data received from the authors of the reference study. The material properties, boundary conditions and mesh are defined as described in the reference study and the simulation is conducted in Ansys Explicit Dynamics. As can be seen in Fig. 2 and Table 1 the results of the FE analysis in the selected engineering environment are in good agreement with the experiment results. The insignificant error magnitude of around 1.7% could be attributed to modelling limitations, as it is indicated also by the authors of the reference study [2].

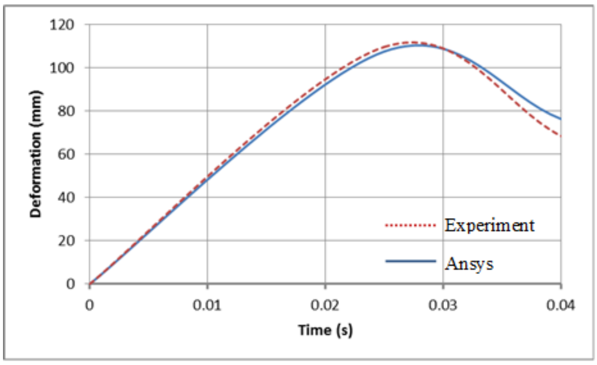

Figure 2: Comparison of deformation results

Table 1: Maximum deformation

Deformation		
Experiment	**Ansys Explicit Dyn.**	**Error**
109.28 mm	107.42 mm	~0.017

FE Model

The hatch cover model has main dimensions of 11000 mm panel length and 14720 mm panel breadth. The thickness of the plate is 10.5 mm. Support structures are one centre transverse girder of T 920x10.5x75x25 mm, two side girders T 560x10.5x100x25 mm and ten longitudinal stiffeners T 635x10.5x280x25 (spacing b=994 mm). A hypothetical rigid rectangular prism of 18 t is modelled as the dropped object and located at 6.5 m height from the upper surface of the hatch cover which is assumed as z=0. The element type is defined by the Ansys Workbench as default and assigned as SHELL 181 to all structural components of the hatch cover and SOLID 186 to the dropped object. 200 mm mesh element size is assigned, since it is the recommended upper limit for impact analysis [3]. The shell body that represents the hatch cover consists of 9012 nodes and 8906 elements. The boundary conditions can be found in Fig. 3 and Table 2 presents the material properties which are assigned to the hatch cover. Bilinear isotropic material model is applied in all simulations.

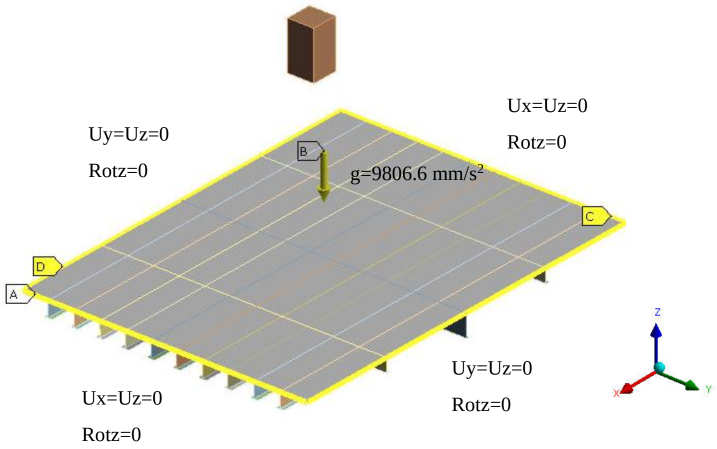

Figure 3: Boundary conditions

Table 2: Material properties

Mild Steel	
Density	7850 kg/m
Elasticity modulus	210 GPa
Poissons`ratio	0.3
Yield strength	0.0130
Tangent modulus	672 MPa

"Body interactions" is automatically defined by the software in explicit dynamics analysis system as contact type for two bodies; the hatch cover and the dropped object which are interacting. The friction coefficient is set as 0.3 in compliance with previous studies [2].

Explicit Dynamic Analyses – Dropped Object Case

After modelling the geometry, material and boundary conditions as described, three dropped object cases are simulated. In Case-1, the system is solved only under the gravity effect and erosion of the elements which exceed the plastic strain limit is not allowed, thus the collapsed elements are kept in the structure. In order to obtain a more realistic damage form and compare the influence of element removal on the results, Case-2 is simulated. This case is a duplication of Case-1 with the activated element erosion function which removes the distorted elements. In this study, the distortion limit is represented by failure strain, which is calculated as 0.08435, based on previous studies [4]. In Case-3, the response of the hatch cover is investigated when the dropped object has also a horizontal velocity of 4.11 m/s in -x direction, in addition to free-fall motion due to the gravity. The rest of the analysis settings are the same and element erosion is allowed. The plastic strain and deformation plots are given in Fig. 4. It can be deducted from the results that keeping the failed elements in the structure could cause a strongly conservative evaluation of the residual state of the structure. Moreover, the influence of the impact type on results is significantly high.

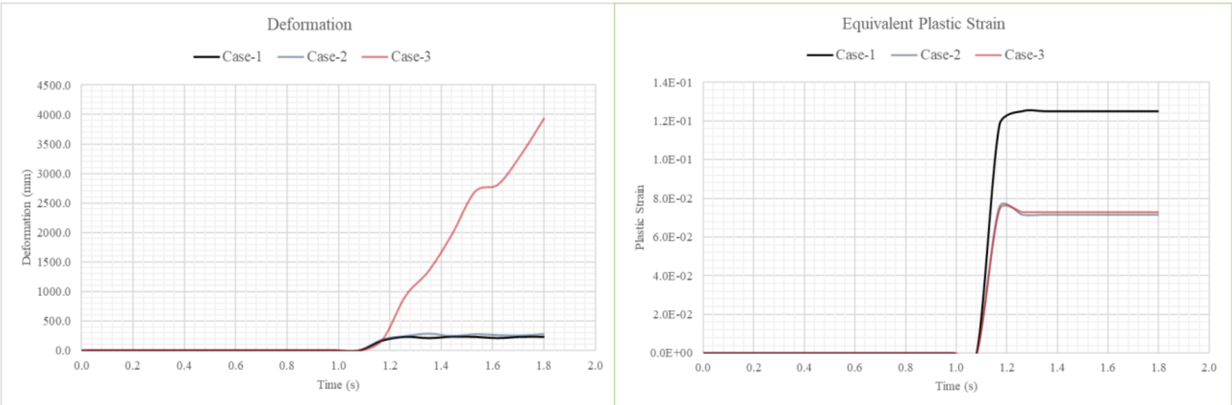

Figure 4: Plastic strain and deformation plots of drop cases

Post-Impact Load Carrying Performance

Following the accident simulations, the damaged structures are investigated under static loads, which are chosen as 0.01743 MPa design load and 0.05403 MPa collapse load of M/V Derbyshire`s hatch cover. The deformed geometries from the explicit analyses are transferred to nonlinear static analysis systems, residual stresses and strains are imported and the load cases are applied gradually and individually as lateral pressure, while the boundary conditions and mesh definitions are kept the same. Fig. 5 presents the comparison plots of nodal displacements and plastic strain results of the analysis cases with consideration of only residual stress and intact structure, since residual strains require further investigation.

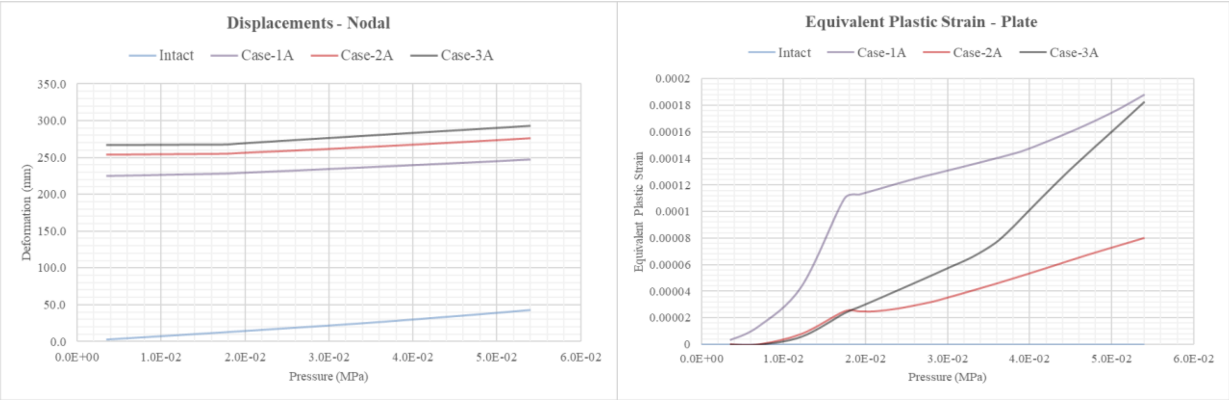

Figure 5: Plastic strain and deformation plots of post-accident performance

It is observed that the severity of damage has a strong effect on further deformation and plastic strain values, under static pressure. Results also confirm that accurate and sufficiently detailed damage modelling is crucial for post-accident evaluations because more realistic accident simulations lead to less conservative post-accident performance.

A New Hatch Cover Design Proposal

Finally, an innovative design hatch cover design concept, composed of corrugated segments as the primary structure, is proposed for competitive structural performance and weight reduction. Through a section modulus based iterative approach, optimum dimensions are determined. The corrugated hatch cover concept and the dimensions of the segments can be seen in Fig. 6.

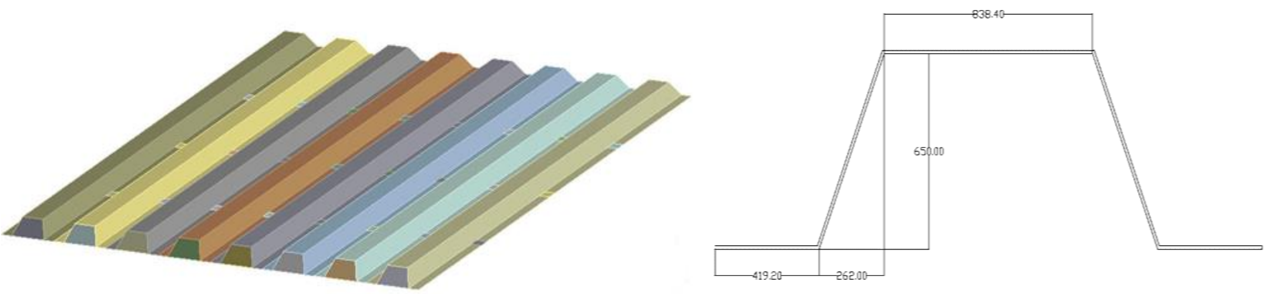

Figure 6: Corrugated hatch cover

The trapezoidal configuration causes water accumulation problem on the hatch cover. For the solution of the problem, covering the steel structure with a solid PVC foam material is proposed as the initial idea, which would require enhancement in further studies. In order to assess the performance of the new hatch cover concept, the abovementioned analysis procedure of Case-3, is applied and the results are compared with the original structure`s. The deformation and plastic strain results of dropped object case are given in Fig.7, while Fig. 8 contains post-accident evaluation results.

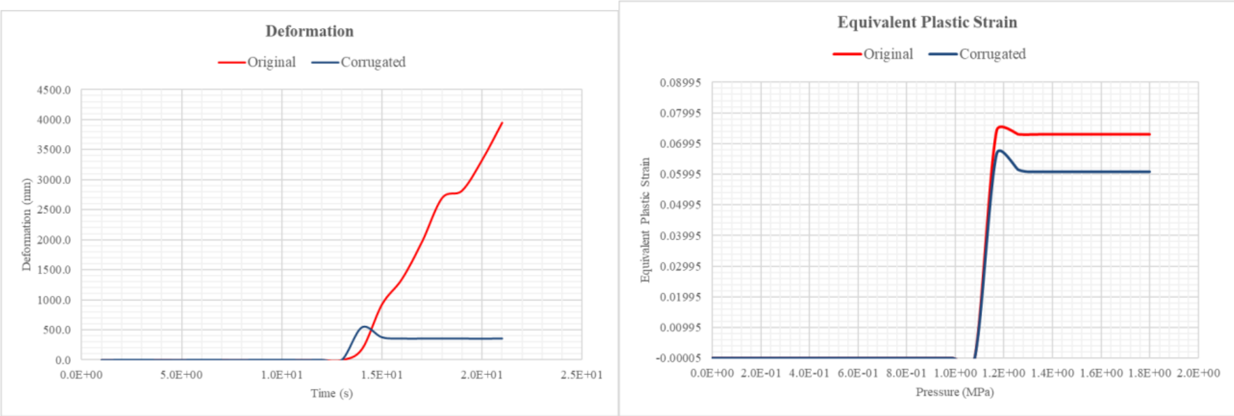

Figure 7: Accident simulation results of corrugated and original structures

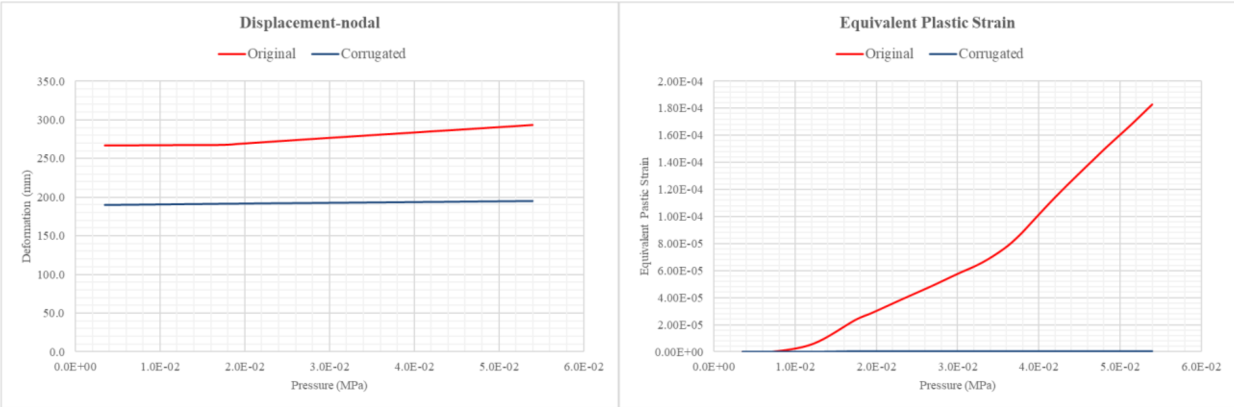

Figure 8: Post-accident evaluation results of corrugated and original structures

The results show that the original structure reaches high deformation levels due to the element erosion in the plate, whereas deformation of corrugated structure remains very low. Damaged corrugated hatch cover performs significantly better than the damaged original structure under lateral static pressure.

Conclusion

This thesis presents a more realistic assessment of the post-accident load carrying performance of hatch covers. The applicability of the use of a single engineering environment is verified for an accurate, prompt and practical post-accident evaluation. Furthermore, the thesis proposes an alternative hatch cover design concept that promises a competitive structural performance while ensuring weight reduction and maintenance ease.

References

[1] UK Parliament Commons Debates. 2000. MV Derbyshire. Vol:356. (Ref.[3] in the thesis)
[2] Kim KJ, Lee JH, Park DK, Jung BG, Han X & Paik JK. 2016. An Experimental and Numerical Study on Nonlinear Impact Responses of Steel-Plated Structures in an Arctic Environment. *International Journal of Impact Engineering*. Vol:93: 99-115. (Ref.[24] in the thesis)
[3] Zhang L. Egge ED & Bruhns H. 2004. Approval Procedure Concept for Alternative Arrangements. *3rd International Conference on Collision and Grounding of Ships*, Tokyo, Japan. (Ref.[38] in the thesis)
[4] Scharrer M, Zhang L & Egge ED. 2002. Final Report MTK0614, Collision Calculations in Naval Design Systems, Report Number: ESS 2002.183, Version 1/2002-11-22, *Germanischer Lloyd*, Hamburg. (Ref.[52] in the thesis)