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Pages 7

Fully integrated FE-analysis in SURMA (Survivability Manager Application)

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Finite element method has been an engineering tool for decades, and is beginning to replace the more simple methods used traditionally for structural analysis in the specialized software dedicated to vulnerability and survivability assessment. However, the naval designers still seem to be lacking a commercial tool for seamlessly integrating this sophisticated approach with other aspects related with survivability of a naval vessel.

Introduction

Survivability is a feature usually associated with naval vessels, and the classical definition states that survivability is the ability of a warship to maintain its functionality in a man-made hostile environment. Survivability can be divided into three components, namely susceptibility, vulnerability and recoverability. The first of these is related with defense mechanisms and specialized techniques of signature reduction, whereas the last is more or less dependent on crew actions, thus leaving the vulnerability as the most important aspect for a naval architect to consider when enhancing the survivability features of a vessel. Taken this viewpoint it is clear that the basic aspects of survivability are damage stability, longitudinal strength and the functionality of vital systems. In this respect survivability can be seen as a fundamental measure defining the ship's performance when subject to any encountered hazard in the designed operating environment.

As the question of survivability is well known, various means of assessment have been established over the years ranging from rules of thumb to highly sophisticated software systems. In the field of software, basically two different concepts can be found. The first approach is a software intended only for the survivability assessment, using a simplified geometric model created within the software and statistical and probabilistic methods to predict the vessel's condition after sustaining a hit. The other concept is based more on physical facts, hence direct calculation. It usually applies various models and software for numerical calculations (FEA, CFD), which are used to estimate the damage caused by a certain weapon effect in a certain part of the vessel. This detailed data from different sources is then gathered and the survivability of the vessel is assessed on a more general level. The benefit of this approach is that detailed information can be acquired. However, the need for various models and software makes it less straightforward and due to used numerical methods, this procedure may turn out quite time consuming. /1, 2/

This presentation introduces an approach for survivability assessment different from those mentioned above. The presented method is based on a 3-D product model, which enables the integration of the latest state of the art analysis tools such as the finite element method as part of the routine assessment procedure. The basic idea behind the development of this system is to find some sort of balance between the two concepts discussed previously to produce a rapid but reasonably accurate tool for the early design phase survivability assessment.

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SURMA - towards fully integrated survivability assessment

Survivability Manager Application

SURMA, Survivability Manager Application, is intended to be a practical design and analysing aid for the concept and the basic design phases of the vessels required to withstand the hazards presented by conventional weapons. The main aim is to assess the survivability of a given vessel against a known threat weapon by the applied vulnerability analysis. SURMA is meant to support the decision making regarding the different aspects affecting the survivability of the vessel throughout the iterative design cycles. Also the performance of the existing vessels in this sense can be evaluated and reported using the tools provided in the application.

The development of Survivability Manager Application started in 2006 on request from the Finnish Navy, which is also the pilot customer having the first version of SURMA in test use and supporting the ongoing development of the software. SURMA is based on the widely used NAPA product model, and uses extensively the features and calculation possibilities offered by this model.

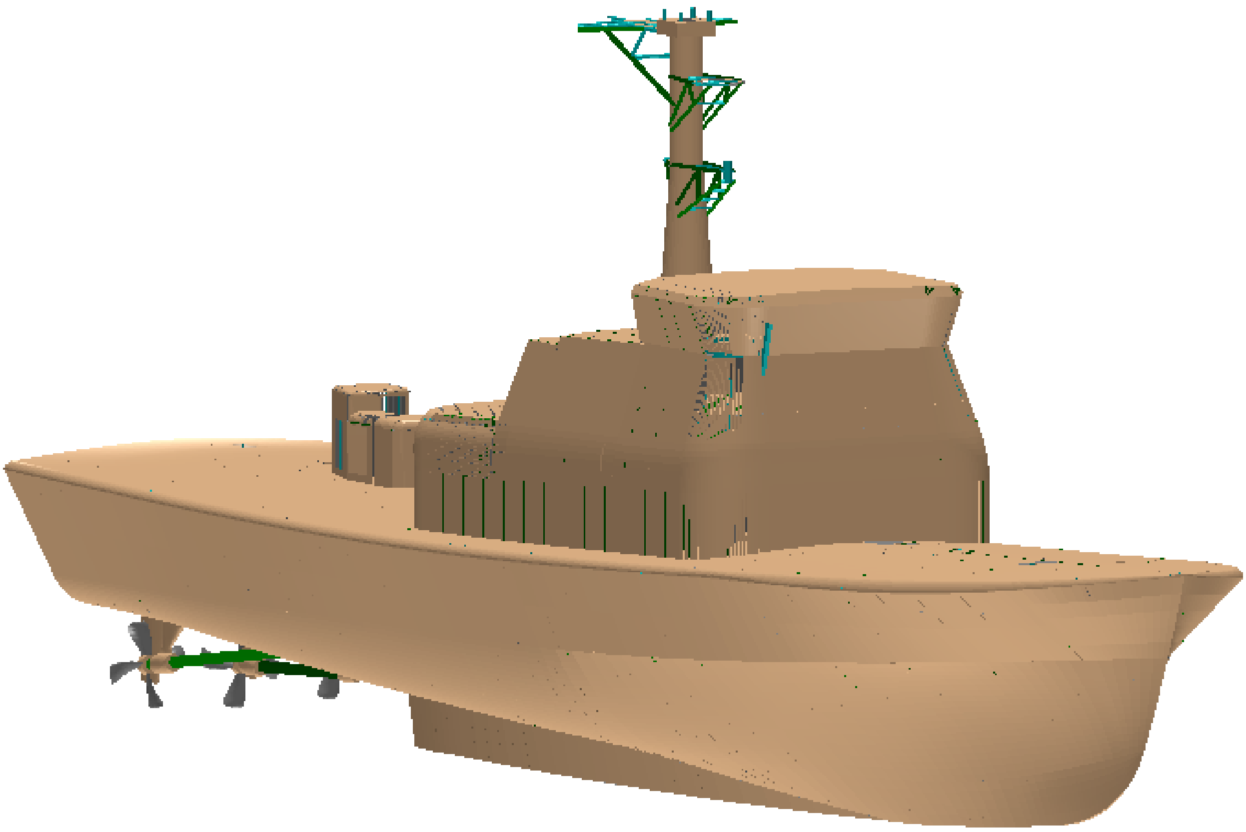

Figure 1: Structural model used in SURMA

As mentioned, only the effects of the conventional weapons are considered. At the moment the scope is further limited to the fragment and pressure effects of the warheads detonating in the air, hence not under water. Currently all susceptibility and recoverability related measures, e.g. the signature reduction or the crew action after the damage, are disregarded. Some of these unattended aspects are reviewed further in the section discussing the future development of SURMA. As the susceptibility and the recoverability are neglected, the vessels survivability is assessed by means of the following three indicators:

– Damage stability
– Longitudinal strength
– Functionality of vital systems

This is achieved by first conducting the applied vulnerability analysis using e.g. semi-empirical formulations for pressure and fragment perforation calculation and utilizing single degree of freedom systems for the local structural analysis. Then the above mentioned indicators are evaluated based on the resulting damage. Overview of the capabilities of the current version is illustrated in Figure 2.

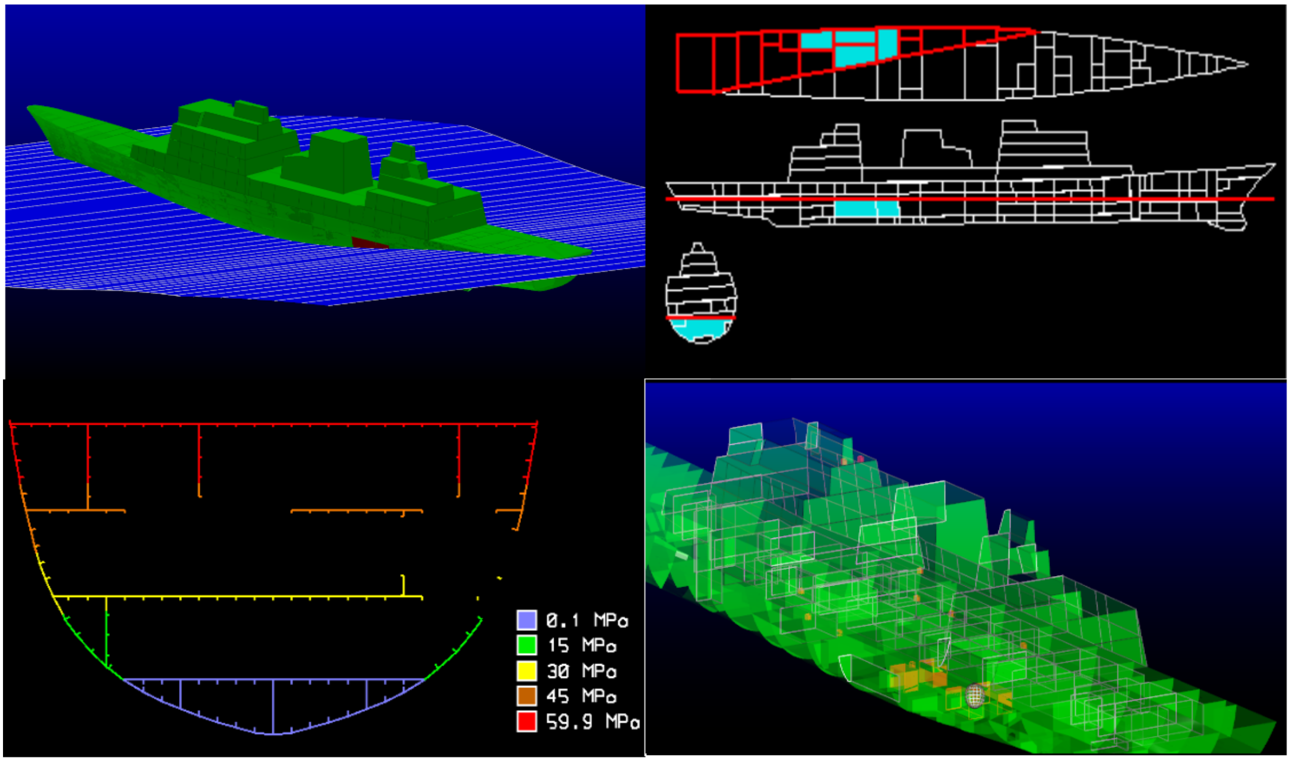

Figure 2: Screen captures from SURMA after AIREX damage

Finite element analysis

As mentioned in the beginning, the finite element method has become a standard engineering tool for various calculation purposes, and is beginning to replace the more simple methods used traditionally for structural analysis. However, usually a totally separate model is required to achieve this. The FE-models are normally created within another software, dedicated to the sole purpose of finite element analysis, which at the best can make some use of the existing geometry in other systems. In most of the cases, quite a lot of additional work is needed to prepare the FE-models in terms of idealisation, mesh creation and definition of boundary and loading conditions.

The product model that SURMA is using, supports direct creation of finite element meshes which are based on the structural arrangement of the observed vessel. This model also contains all relevant data for defining the the boundary and loading constraints as well in the intact, as in the damaged condition. This is to say that the changes in hydrostatic loads due to holing and flooding and the reduction of structural strength can be taken into account. Figure 1 shows the structural model of a vessel and Figure 3 the finite element mesh generated from that.

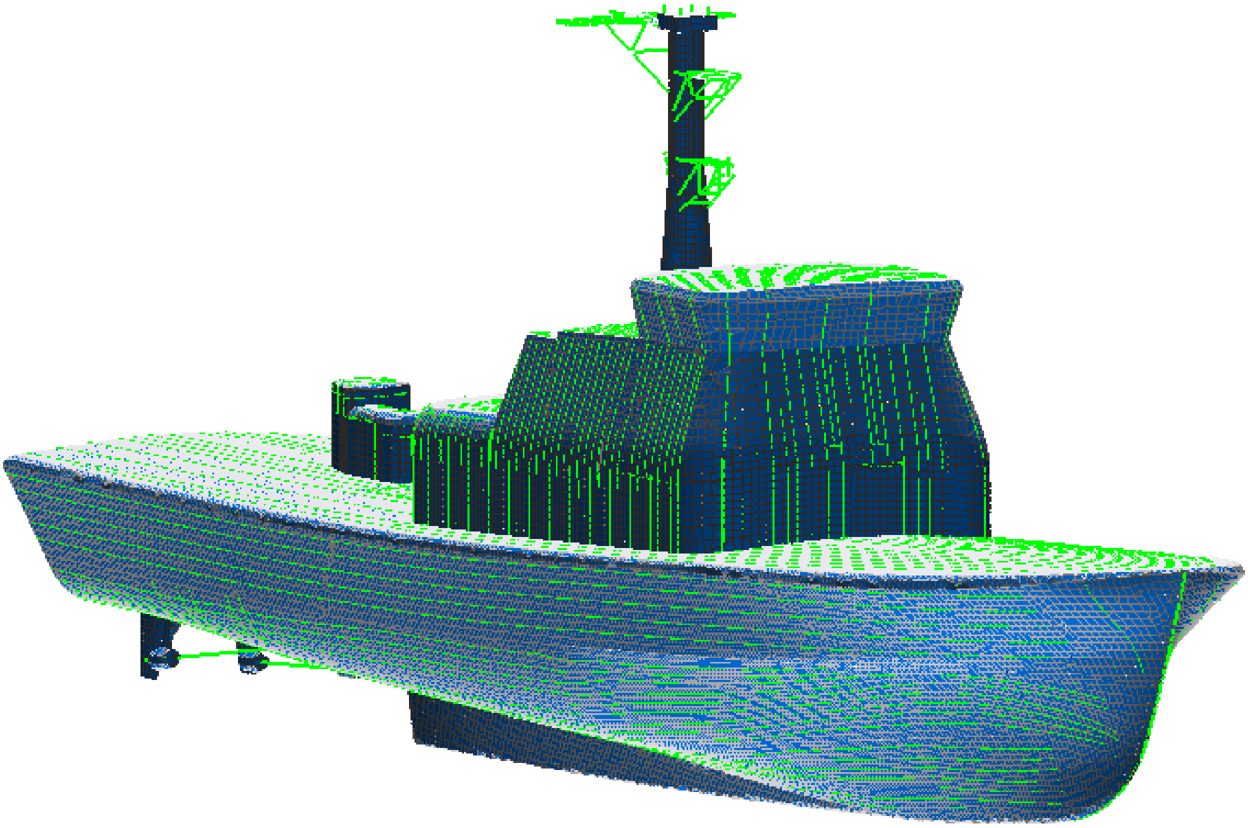

Figure 3: System generated global mesh

Even if the finite element model could be created with automatic procedures from the existing structural model, there still remains the question of solution time. Although the computational performance of computers, also of the normal work stations, has been increasing remarkably over the years, the numerical solution of these models may take from hours up to weeks depending on the type of analysis.

SURMA is intended to be a fast and robust tool, that enables changes that are based on the analysis results provided by it during the iterative design cycles. Considering this statement with the characteristics of the FE-analysis mentioned above, there seems to be a contradiction. However, one of the ideas behind SURMA is to find a practical balance between the current state of the art methods and the feasible procedures that are used in everyday engineering work. The following chapter explains how this challenge is currently handled in SURMA.

SURMA and FEA - the aim for balanced analysis

FEA in survivability assessment

A short literature review reveals that the finite element method is commonly applied to assist in vulnerability and survivability assessments concerning the naval vessels. The use cases vary on a wide range from small local models observing for example a new bulkhead configuration, to huge global models assessing e.g. the whipping modes of the hull girder. In most of the cases the latest available techniques facilitate the analysis, including full 3-D approach combined with the theory of large deformations and non-linear material behavior. /3, 4/

FEA usage in SURMA

As described in the beginning, SURMA uses an equivalent single degree of freedom system (SDOF) to perform dynamic analysis for the local structural elements to define the effects of a warhead detonation. The resulting damage is then incorporated in damage stability and longitudinal strength calculation, which yield the traditional GZ- and longitudinal strength curves.

To maintain the speed and robustness of this kind of approach, the first implementation of full 3-D finite element analysis in SURMA is not directly involved with the structural damage but is meant to make this more reliable and accurate by supporting the generation of the SDOF-systems. The idea is to create one global model of the whole vessel in the normal operating condition. From this model the initially existing stress levels in different structural members can be defined, and the initial dead loads affecting the SDOF-system properties determined. Depending on the case, the effect of the dead loads on the deformation capacity of the structural element might be significant, thus influencing the total outcome of the assessment.

It can be noted that the presented approach requires only one reasonably rough FE-model of each vessel configuration without the need for smaller details to be considered. This means that even as the design of the vessel is altered, only major modifications call for a new FE-analysis, and the basic procedure remains fast. Although still in testing phase, this implementation shows remarkable promise regarding the potential this kind of approach gives with respect to utilizing FE-analysis in vulnerability and survivability assessment.

Pros and cons of the presented approach

The benefits of the presented fully integrated FE-analysis are apparent:

- The used FE-model is always consistent with the product model presenting the current design of the vessel.
- The additional work and time consumption for creating the FE-model can be minimized.
- This kind of approach is fairly straightforward in terms of widening the scope and extending the usage to other areas of application of FE-analysis.

Also some shortcomings related with the current implementation have to mentioned:

- The applied loading condition is static, i.e. still water condition, hence not taking into account the dynamics and thereafter increased loads related with ship motions in a seaway.
- When extending the procedure towards a more detailed structural analysis, the requirements on the product model are also increased and the automatic generation of the FE-mesh becomes complicated.
- The question of meaningful visualization of numerical results on the product model side is still open.

Development - current issues and beyond

Currently the development concerning the integration of FE-analysis is focused on making the above described first implementation work seamlessly with the existing SURMA machinery. The next natural step will be the damaged longitudinal strength analysis with the global model. The recent efforts to include also fire simulations in SURMA make this an interesting prospect for taking secondary damage effects such as fire into account also in the structural wise.

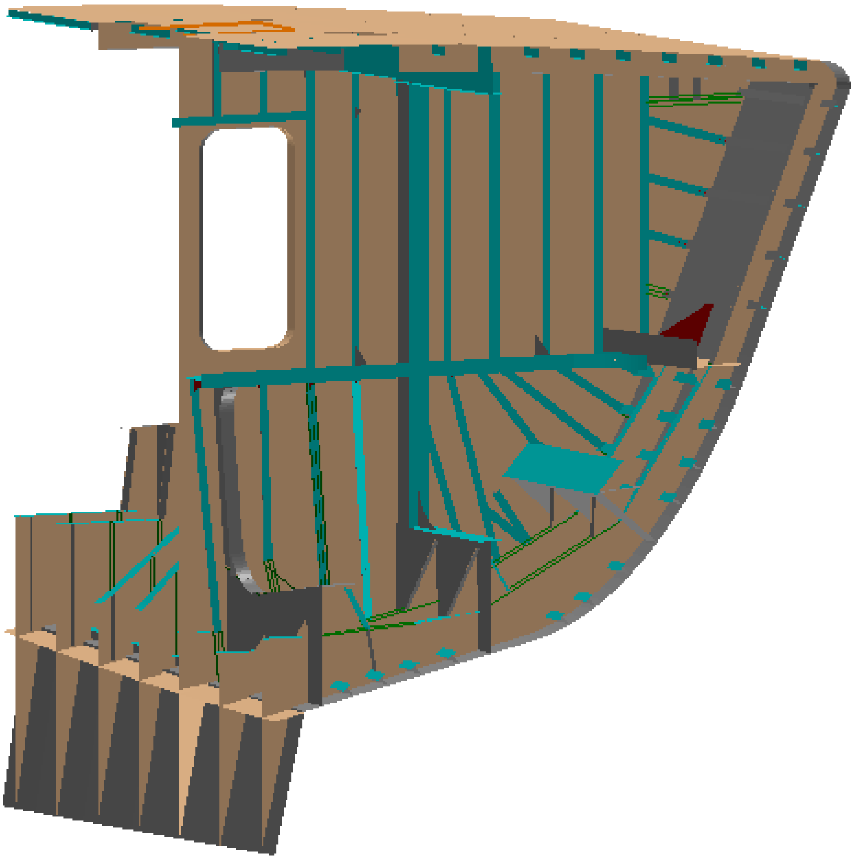

Figure 4: Local part of a structural model

Although the replacement of the SDOF-systems to an FE-model as a basis for the local structural analysis doesn't currently seem practical, the presented approach gives a possibility to create local FE-models of the selected structural members if these are considered necessary in further design stages. Figure 4 presents a local structure configuration and the finite element mesh generated from that is presented in Figure 5. Also the system functionality analysis could be enhanced to gain better resolution regarding the damage with the assistance of the FE-calculation. Some attention will be paid also to the utilization of the finite element method for other fields of application beside the structural analysis, such as the signature reduction. As one preliminary part of this we have been testing possible connection from SURMA to CAST. However, these are only issues subject to further consideration in the future.

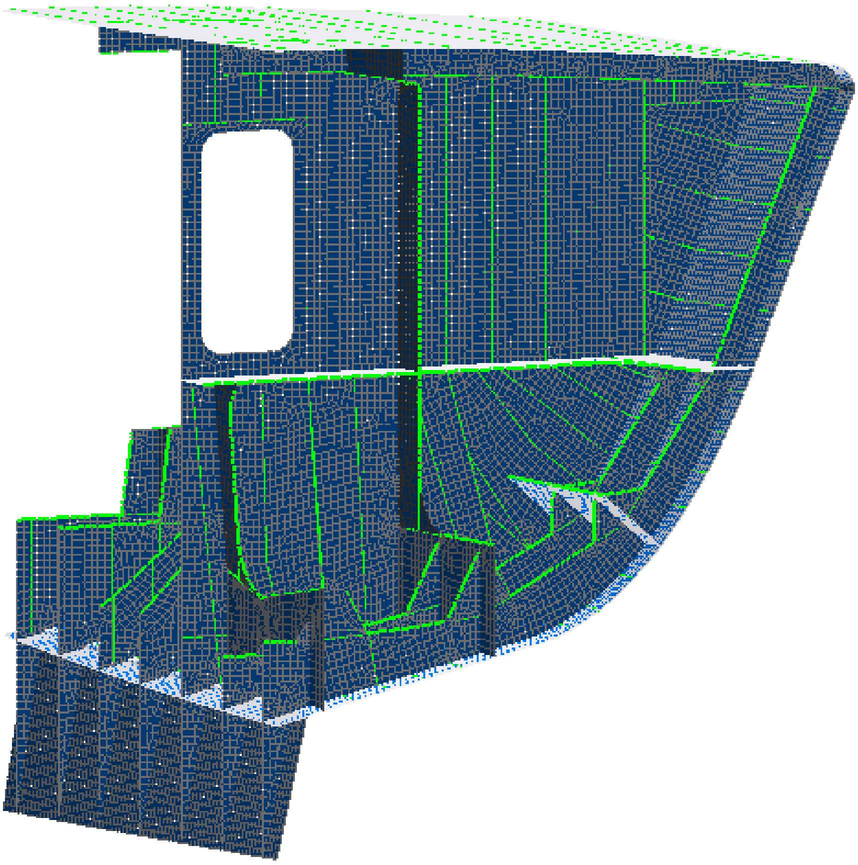

Figure 5: System generated fine mesh

Conclusions

The herein presented approach can be seen as a clear indication of the remarkable potential the modern analysis tools, e.g. FE-method, offer for the purposes of such a multi-objective analysis as the survivability assessment when integrated in a modern 3-D product model. This kind of rapid assessment tool could be used as a source for the first estimates also in other complex analysis problems involving dynamic structural response, damage stability, etc. such as grounding and collision.

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