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COMMITTEE III.1

ULTIMATE STRENGTH

COMMITTEE MANDATE

Concern for the ductile behavior of ships and offshore structures and their structural components under ultimate conditions. Attention shall be given to the influence of fabrication imperfections and in-service damage and degradation on reserve strength. Uncertainties in strength models for design shall be highlighted.

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Official Discusser: Paul A. Frieze
Floor Discussers: Andrea Ungaro
Shengming Zhang
Daisuke Yanagihara
Weicheng Cui
Philippe Rigo

REPLY BY COMMITTEE MEMBERS

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1.2 Floor Discussions

1.2.1 Andrea Ungaro

Regarding chapter 5.1.3, and specifically the overview of current design practices for submarine pressure hulls, it is pointed out that the accuracy of conventional Submarine Design Formulae (SDF) for predicting pressure hull collapse is close to that obtained by nonlinear numerical models, which implies that the latter are not strictly necessary in the design phase unless a better representation of the geometric imperfections is used.

However, typical SDF do not take into account the effect of internal structures (tanks, decks, foundations, etc.) which, while having a mostly local (but potentially very significant) effect on stresses, can influence the failure behaviour of the whole compartment by significantly changing its deformed shape and instability mode shape.

At the same time, even computationally simple axial-symmetric numerical models can offer interesting information on the local stress and deformation close to transition areas (cone/cylinder, cylinder/end-cap), where a different scantling is often necessary and where SDF typically offer lower precision.

Therein, in its inherent flexibility, and in the possibility of accounting for a damaged structure, lie the main advantages of FE techniques in the design of pressure hulls.

Among the list of the non-linear factors in chapter 2.2, the "follower force" effect, that is the change of direction of the applied loads and pressure forces due to large structural displacements, is not listed. This effect can be considered implicit in the geometric non-linearities, however it would be proper to mention it separately in point d), loads.

1.2.2 Shengming Zhang

Regarding hull girder ultimate strength, the current mostly used methods included in the CSR, only longitudinal stress is considered. How important are other stress components such as transverse stress, shear stress and lateral pressure? Should we include all components in design assessment? Should the residual stress effects on ultimate strength assessment be included? Why?

1.2.3 Daisuke Yanagihara

In the benchmark of the unstiffened and stiffened plates, the comparison with CSR is only a few cases. Particularly, there is no comparison with the CSR-B which is the rule for bulk carriers. Does the committee have a clear reason for this?

In the benchmark, the FE analyses were almost performed applying the initial deflection of the buckling mode with $0.1ß^2t$ amplitude. I think that this deflection is very large and not realistic. But these FEA results are used as the reference values to verify the prediction method. Of course, I understand that the lower limit is necessary to provide the safety of the prediction. However, I think that the investigation on the model uncertainty of the prediction method is also the purpose of the benchmark. From this point of view, the average condition of the initial deflection should be considered, and the FEA results under the average condition should be used as the reference value for the comparison. Could you show the committee's view about this problem, that is, what should be used as the reference value in the benchmark?

1.2.4 Weicheng Cui

I like the way of Committee's representation of the ultimate strength problem as a function of several important parameters, in this case, eight aspects of factors (a – h), first I wish the committee chairman to confirm whether I can optimistically say that when eight aspects of factors are clearly described for a particular situation, then the current state-of-the-art method can predict the ultimate strength within 10% of error?

If that is the case, the future emphasis of this committee should be directed to the descriptions of these damage states such as fatigue cracking, corrosion, residual stresses, etc. and in particular the determination of human factors are extremely difficult to quantify their effect on ultimate strength. Do you have any suggestion on how to treat those problems, especially the human factors?

If the 10% of error cannot cover some of the problems, can you give some examples where the ultimate strength of the given structure cannot be predicted within that accuracy requirement?

1.2.5 Philippe Rigo

Let me first thanks the ISSC committee III.1 and his chairman Jeom K. Paik for their brilliant report and attractive presentation in Rostock.

My comments concern the need to integrate the assessment of ultimate strength (specifically the hull girder bending moments) within the optimisation procedure of ship structure (scantling).

In Rostock, the chairman of committee III.1 concluded his excellent presentation saying that, to his knowledge, ultimate strength has not yet been integrated, at industrial level, in the ship structure optimisation loop.

So it is my pleasure to highlight the fact that the LBR5 software (see references below) is an ship structure optimisation package, dedicated to early design, which target least weight and least cost optimisation (multi objective approach), and which is used since 2005 at industrial level by STX France (St Nazaire shipyard) for the design of their large cruise vessels and previously by ALSTOM for gas carriers. LBR5 considers as active constraints of the optimisation process the ultimate strength of each stiffened panel (bottom, decks, side shells, ..) and also the hull girder ultimate bending moments (using the simplified analytical method of JK Paik within the optimisation loop, and a progressive collapse module (PROCOL) as post-analysis (for validation)).

Running structural optimisation (ship scantling) is only meaningful at the conceptual design stage or at initial design stage. Later, there is no more room for significant changes in the structure. So, the challenge to include ultimate strength assessment of hull girder and its components (stiffened panels) within the optimisation process relates to the lack of detailed data to perform advanced ultimate strength analysis (as non linear FEA). The scantling details of the structure are not yet fixed; it is therefore challenging to make a FE model (too high uncertainties on the real geometry). In addition there is also a high uncertainty concerning the imperfection levels (deformation, residual stress) as details about the welding technology and assembling scheme are unknown.

So, there is an urgent need for researches to develop structural optimisation tools including ultimate strength capabilities that are integrated with design and production tools used at initial design stage (CAD, scantling tool, block splitting, ...).

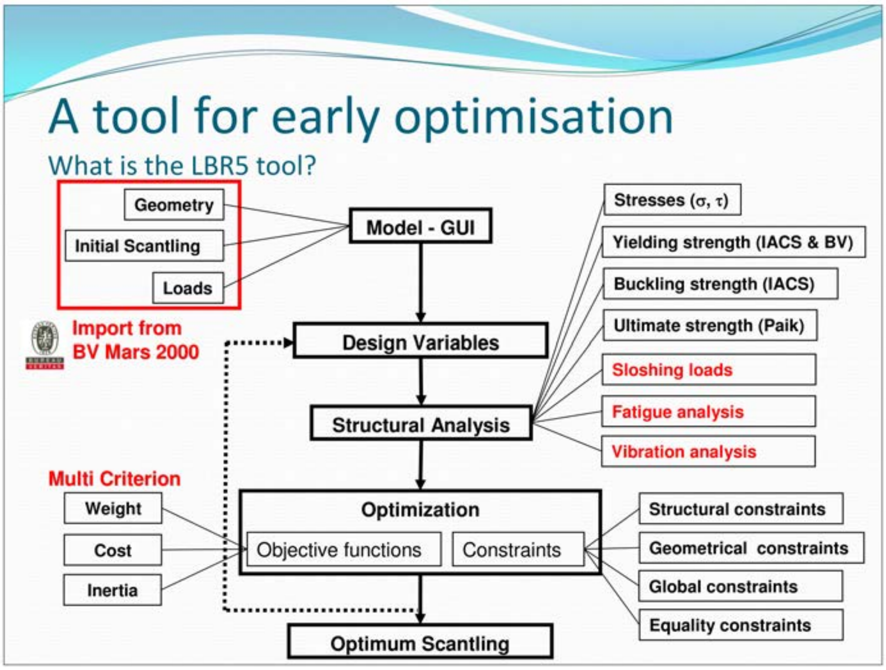

Figure 12: LBR5 Integration in Optimisation Process

1.2.6 References

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2 REPLY BY THE COMMITTEE

The Committee thanks official and floor discussers for their valuable comments and discussions related to our report. In the following, we respond to their remarks.

2.1 Reply to Official Discussion

Accidents are the result of a long chain of human error which is due to a lack of knowledge and engineering disciplines at various stages, including engineering and

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design, construction and operation. To prevent accidents, human error should be eliminated. Human error can be reduced by taking advantage of engineering disciplines in accordance with human factors engineering principles.

Our Committee deals with a key engineering and design disciplines for ships and offshore structures, and it is hoped that the uncertainty characterization of influencing parameters and the development of more refined ULS methods will help to reduce catastrophic failures of ships and offshore structures.

Two types of design format are usually applied in ensuring that a structure has an adequate degree of safety and reliability against ULS, namely partial safety factor design format and probabilistic design format in which the uncertainties are characterized.

In the offshore industry, substantial efforts have been devoted to the development of international standard guidelines associated with limit state assessment of offshore structures, and to extensive applications of such standards and guidelines to industry practices.

Residual strength of ships after significant yielding or buckling is treated by classification societies, e.g., Bureau Veritas (BV 2010), providing a service ERS-S which is an emergency response service corresponding to damage longitudinal strength and damage stability analyses. The structural model is generally very simplified, just removing damaged area from initial or intact model. The main investigations are focused on the additional load due to unexpected flooding. The aim is to determine the allowable still water bending moment and the allowable sea states. A more refined structural analysis would require a good knowledge on the actual state of the structure. Just to obtain accurate information on the actual structural integrity in emergency condition is a primary issue.

In the last decade, the shipbuilding industry has also tended to implement ultimate limit states principles into rules by IACS or classes, but such an effort is far from the level of the offshore industry. For example, 'critical buckling strength' of structural components determined by elastic buckling strength with a simple plasticity correction is regarded as an ultimate limit state, but this technique is not always true and is irrelevant in some cases.

Furthermore, neither international standards nor standard guidelines for limit state assessment of ship structures do exist. Large scale or full scale experimental studies are very lacking, especially in the sense highlighted by the Official Discusser that the limited available experimental data are not shared among involved parties. Moreover, often testing procedures and measurements are not comprehensively documented. Comparison and merging of such data, indeed very expensive to obtain, will be very beneficial and fruitful. The Committee agrees with the official discusser that there are still a lot of technical issues to be resolved.

2.2 Reply to Floor and Written Discussions

2.2.1 Andrea Ungaro

It is challenging to take into account the effects of all influencing parameters such as geometric imperfections and internal structures, among others, within a set of submarine design formulae. In this case, nonlinear finite element methods will be useful as far as their modeling techniques are adequate. Chapter 2.2 lists up the factors affecting the structural nonlinearities. The order or pattern of applied loading, e.g., lateral pressure or out-of-plane loading followed by in-plane loading, can cause different responses as well, and this issue can be classified into the quasi-static load case.

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2.2.2 Shengming Zhang

Ship hull girders are subject to combined hull girder loads which include not only vertical bending but also horizontal bending, shearing forces and torsional moments. Even though vertical bending moments are predominant component of hull girder loads, the effect of other load components on ultimate strength cannot be disregarded.

Welding causes geometric imperfections and residual stresses. In welded steel ship structures, it is known that the welding residual stresses can be released by cyclic applications of hull girder actions, i.e., hogging and sagging. In this case, remaining amount of welding induced residual stresses may be small and thus its effect on ultimate strength may also be small. However, this aspect is still uncertain and further studies are recommended to characterize the release of welding residual stresses by cyclic hull girder actions. It is important to realize that the welding residual stresses can reduce the ultimate strength and that its characteristics should be identified for robust design of ships and offshore structures.

2.2.3 Daisuke Yanagihara

The benchmark studies of the Committee have included stiffened panels of both tankers and bulk carriers with class rules, CSR, ULSAP, PULS and nonlinear FEA. Because of the page limits of the Committee Report, only the summary of the results was included. The conclusions of the studies obtained from the stiffened panels of tankers or bulkers are similar.

The geometrical imperfections in stiffened panels induced by welding include plate initial deflection, column type initial distortion of stiffeners and sideways initial distortion of stiffeners. We agree with Dr. Yanagihara that it will be better to consider an average level of initial imperfections in the benchmark studies. In this regard, we adopted the average level of plate initial deflection as $w_0 = 0.1\beta^2 t$, where β = plate slenderness ratio and t = plate thickness. According to Smith et al. (1988), it is noted that the maximum amplitude of the initial deflection of steel ship plates may be given as follows:

$$w_0 = \begin{cases} 0.025\beta^2 t & \text{for slight level} \\ 0.1\beta^2 t & \text{for average level} \\ 0.3\beta^2 t & \text{for severe level} \end{cases}$$

The effect of the initial deflection shape is also significant. The maximum initial deflection indicated in the above equation may actually not be the buckling mode of the plate, but rather it must be equivalent to a “hungry horse’s back shape”. We agree with Dr. Yanagihara that the uncertainties due to the shape of initial distortions needs to be further investigated.

2.2.4 Weicheng Cui

The Committee believes with a certainty that the clear characterization of all the eight aspects is very challenging and further studies are required. For some specific cases, however, we have various refined methods that are able to predict the ultimate strength within 10% error. As previously discussed in Section 3.1, human error is due to a lack of knowledge with uncertainties. Although it is theoretically impossible to totally eliminate human error, we could reduce human error to some extent by taking advantage of advanced engineering disciplines.

2.2.5 Philippe Rigo

The Committee thanks Prof. Rigo for sharing with us on the effort for developing full optimization of merchant ship hull structures. We absolutely agree with him that we will have to urgently develop structural optimisation tools including ultimate strength capabilities that are integrated with design and production tools used at initial design stage. This effort will eventually help to save design times, adjust structural scantlings for too strong and/or too weak members, improve structural safety, reduce structural weight and building cost, improve operational efficiency, and reduce CO_2 emission.

2.3 Reference

BV (2010). Emergency Response Service (ERS), Rule Note NR 556 DT R00 E, January 2010.