ISSC'2003 - Vol III, 2005

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2 REPLY BY COMMITTEE

2.1 *Reply to Official Discusser*

Committee III.1 would like to thank Dr. Eivind Steen for the discussion and for adding two references to the work. As Dr. Steen's discussion goes into depth with the benchmark study we have also divided our reply into a section about the general aspects and a section about the benchmark study.

2.1.1 *General*

Dr. Steen supports the views of the Committee that analytical, empirical and experimental methods remain to be important regardless of the available numerical methods and computational power. This viewpoint is not as trivial as it immediately seems because there is a tendency in research and teaching institutions and among practicing engineers to move away from the simplified methods and towards streamlined, integrated, colourful computer models. Such computer modelling tools hold a tremendous potential for very accurate analyses where the coupled, non-linear load and response can be predicted, and further development should definitely be encouraged in this area. However, quality assurance is a key issue here. The results of the full-blown computerised methods tend to be difficult to check. And in the end, the reliability of the ship is not only a function of loads and strength but also of the reliability of the various analyses of the ship. Therefore, parallel with the impressive advances in computerized methods it is important to develop and maintain a good basic understanding of the physics in the form of simplified, alternative prediction methods.

Along the same lines the Committee appreciates the work done by Dr. Steen and colleagues at DNV to develop the computer program PULS for estimation of the ultimate strength of stiffened panels. Such a tool, which could eventually be further developed to cover the ultimate strength of the hull girder, is helpful in building up a good understanding and simplified modelling capabilities in a systematic manner.

As also confirmed by Dr. Steen it is a general problem that good experimental data is lacking. Today very detailed numerical analyses often replace large-scale testing due to cost constraints. Certainly, computational mechanics can be very valuable and provide insight into complex problems. However, several structural problems are still too complex for pure numerical studies. Examples of such problems are: effect of imperfections (generated during production or operation) on ultimate strength, fatigue cracking, ductile fracture in collision and grounding, compression strength of composite structures. For example, while hundreds of papers have been published about the micromechanics of ductile fracture over the past 3 decades there is still no accurate, validated method available for practical engineering analyses. However, studies which combine detailed numerical analysis, experiments and analytical analysis could potentially provide the necessary insight into complex phenomena as mentioned above and provide prediction tools for the practicing engineering community.

Dr. Steen draws attention to the fact that slender structures may experience local buckling during normal operation. This leads to stress redistribution, as load is shifted to the stiffeners and will thus affect the fatigue damage in a rather complex manner. Stiffeners (and hot spots) will be loaded harder in compression, which will tend to reduce the residual stresses due to local plasticity (plastic shakedown), and then upon subsequent tension the hot spot has experienced a higher stress range than if the buckling and load shedding had not occurred. For typical ship structures where the plates are designed to buckle and yield at approximately the same longitudinal stress, the above effect is expected to be negligible. The Committee agrees that for new structural configurations it should always be assessed whether the typical division into Fatigue Limit State (FLS) and Ultimate Limit State (ULS) is still ideal and whether the FLS can be assessed by linear elastic models, as is common practice today.

2.1.2 *Benchmark study (by Dr. P. Rigo)*

Some data and results are missing in the ISSC report, as pointed out by the discusser. This is mainly due to severe space limitations. To compensate for this, a more comprehensive treatment of the benchmark study will be published in the *Marine Structures* journal, Ref. [1]. The Committee mainly agrees with all the reviewer's comments on the benchmark as described in the ISSC report. Some further discussion is given below, and reference is made to the upcoming paper, Ref. [1], when appropriate.

Important issues discussed by the reviewers concern the "boundary conditions", the "initial defections" and the "failure modes". In general, we agree with his comments, however, some additional discussion is provided below. Short replies to specific comments:

- *Load application mode*: the reviewer is right, the loaded ends were restrained from rotation and an axial displacement was prescribed.
- *Material curve with and without HAZ*: the curves by Aalberg were used and will be included in [1]. The statement "50-60 % reduction of the yield stress" means that the ratio between the two curves varies between 50 and 60 % for a given plastic strain.
- *Table 6 on plate thickness*: the upper row refers to cases without residual stresses and the lower row to cases with residual stresses, as suggested by the discusser.

Indeed, the boundary conditions and a 3 spans FE model (instead of a ½ + 1 + ½ span model) with restrained rotation at the two ends ($W_{,x} = 0$) were selected as they are clear and easy to implement with (in principle) little risk of misunderstanding.

The committee thanks the reviewer for performing comparative analysis with the PULS code. His results are slightly different as his model differs from the committee model.

For the plates along the two edges, the Committee considered a half width and not a full width. As the standard width between stiffeners is 252.5 mm, our model is 1262.5mm wide (1/2+1+1+1+1+1/2=5x252.5) but Dr. Steen's model seems to be 1515mm wide (1+1+1+1+1+1=6x 252.5). This explains why the shape of the local buckling mode is slightly different.

The next figures present failure modes obtained by the Committee which can be compared to Figure A of the reviewer. Figure 2a can be compared with Figure A(a) of the reviewer. When the max load occurs Figure 2b has to be compared with Figure A(c). In both cases the results are similar.

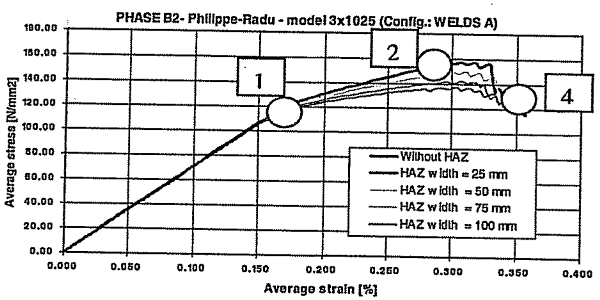

Figure 1: Influence of the HAZ width on the ultimate strength.

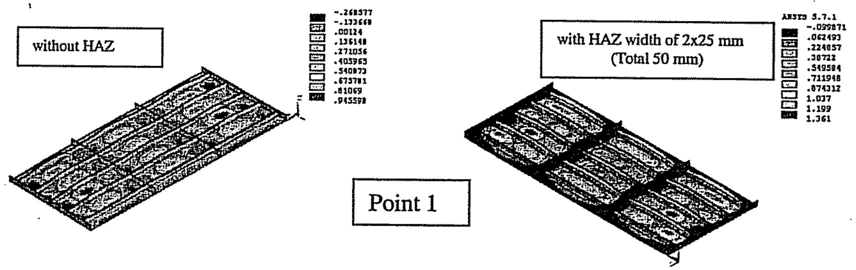

Figure 2(a): Collapse modes of 3 x 1025 mm model (Point 1: first plates buckle).

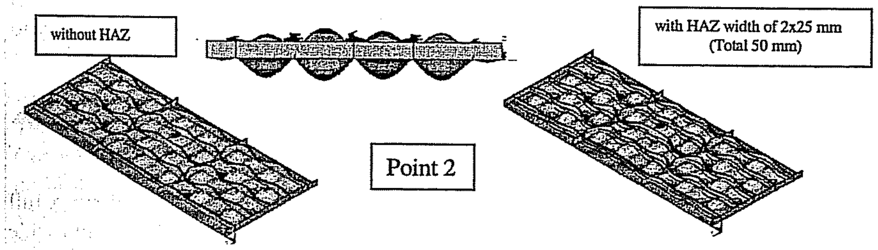

Figure 2(b): Collapse modes of 3 x 1025 mm model (Point 2: local failure mode).

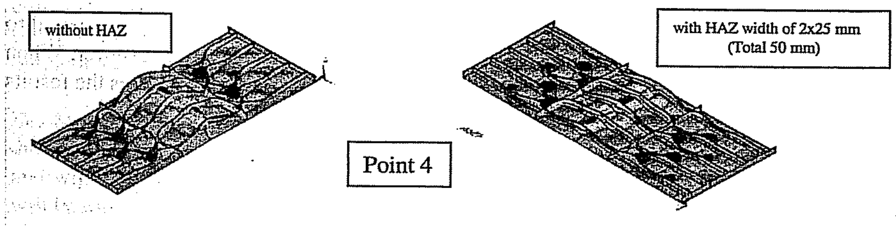

Figure 2(c): Collapse modes of 3 x 1025 mm model (Point 4: global failure).

2.1.3 *Initial imperfections*

It is true that the initial imperfections used in the Committee models are generated by placing pure lateral pressure on the smooth plate side of the panel and then keeping the resulting displacement pattern as the stress-free imperfection. This unusual procedure is applied, firstly to produce uniform and comparable results between the members but also as this procedure has some advantages. The deflection produced in the panel by lateral pressure is different from the local buckling mode (standard procedure). This deflection is of a thin-horse mode and is composed of many deflection components including the local buckling mode. If only the buckling mode is given as initial deflection, the buckling mode gradually develops when the load approaches the buckling load. However, when a thin-horse mode is assumed as initial deflection, other components restrain the development of the buckling mode until the load exceeds the buckling load. As a result, a very clear buckling behaviour is observed as indicated in Figure 3. This buckling behaviour could be accompanied by a snap-through if the load at which buckling deflection appears is higher than the buckling load in a simply supported mode. Figure 3 gives the deflection history of the centre point of two adjacent plates. Due to the initial deflection shape, the deflections at the two points are initially identical. Later, for higher compressive loads, the two plates buckle but in opposite directions. As the initial deflection shape differs completely from the shape of the collapse mode, it induces a strengthening of the structure.

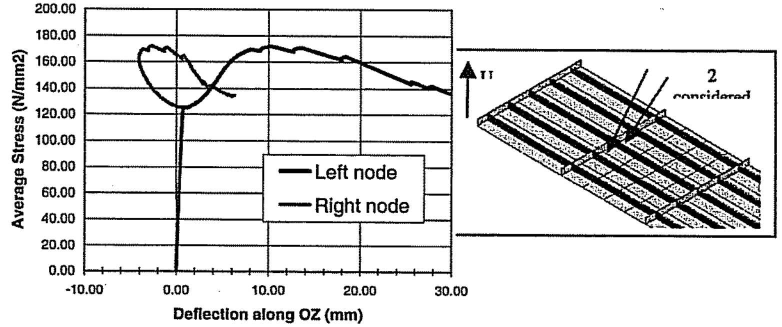

Figure 3: Shape of the plate collapse mode (3x1025 mm model, without HAZ)
- Stress-deflection curves at the centre of two consecutive plates.

2.1.4 *Finite Element Modelling*

The reviewer asks if the HAZ is sufficiently modelled with one element across the zone width of 25 mm, and if larger elements can be used across the rest of the plate width. This is an important issue. Unfortunately, the Committee has not studied the way to model the HAZ – it is left for future work.

Nevertheless, additional analyses with HAZ effects (Phase A and welds A) were completed using about 20 different mesh sizes. The model includes respectively 1866, 4242, 6042, 7150, 7842, 9642 and 12292 shell elements (see Figure 4). The results show that the convergence of the ultimate stress is quite good. However, the convergence rate slows down when the number of elements increases. For the present collapse analysis of stiffened aluminium panels, the optimal mesh size seems to require about 8000 elements. It seems that a 8000-element model, including 5x10 or 5x12 elements in the 'y' transverse direction and 3x40 elements in the 'x' longitudinal direction, is convenient to determine the maximum average stress (the ultimate strength). However, if the post-ultimate strength has to be considered, at least 5x16 elements in the 'y' direction and 3x50 elements in the 'x' direction (about 12000 elements in total) are needed.

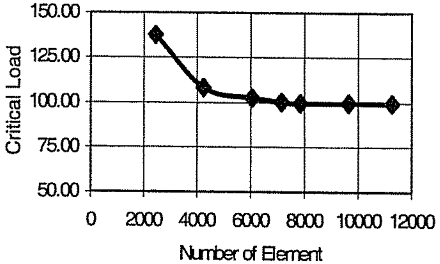

Figure 4: Sensitivity of the mesh size.

Analyses were also done to assess the effect of the variation of yield stress in the HAZ on the ultimate strength. Plate and stiffener material properties and yield stress outside of the HAZ remain unchanged. These analyses concern the configuration with Welds A (model with 3 x 1025 mm spans) and with HAZ effect.

The initial material stress-strain curves in the HAZ are defined as "Sy(ref HAZ)". The modified curves considered to assess the effect of the yield stress in the HAZ are "Sy(ref HAZ)-10" up to "Sy(ref HAZ)+60", with increments in N/mm^2.

The ultimate strength is presented in Table 1. It is observed that a reduction of yield stress in the HAZ of 10% induces an ultimate strength reduction varying from 5% to 2%. The first reduction of yield stress has a larger effect than additional reductions.

TABLE 1: Variation of ultimate strength versus yield stress in the HAZ
WELDS A, MODEL 3 x 1025 mm spans

Philippe - Radu (shape 1)	Maximum average stress		Average strain
	[N/mm^2]	Difference to reference	[%]
Without HAZ	171.919		0.320
With HAZ - Welds A			
Sy (ref HAZ) - 10	148.37	-1.31%	0.313
Sy (ref HAZ)	150.34	ref	0.311
Sy (ref HAZ) + 10	152.38	1.36%	0.317
Sy (ref HAZ) + 20	154.35	2.67%	0.317
Sy (ref HAZ) + 40	159.98	6.41%	0.320
Sy (ref HAZ) + 60	167.70	11.55%	0.307

For the sensitivity analyses performed within the benchmark framework, the Committee tried to provide some quantitative assessment of the sensitivities. It is important to keep in mind that these values are only valid for the range of variation considered. More extensive analyses have to be performed to cover wider ranges of variation. As discussed by Dr. Steen, this is the case for the plate thickness (Phase B5) and for the amplitude of the initial deflection (Phase B3). Even if the discusser is surprised by our results, we confirm that each additional mm of initial deflection induces about 1.10 % of reduction of the ultimate strength (for the considered panel and range of variation, from 2 to 8 mm), see Figure 5.

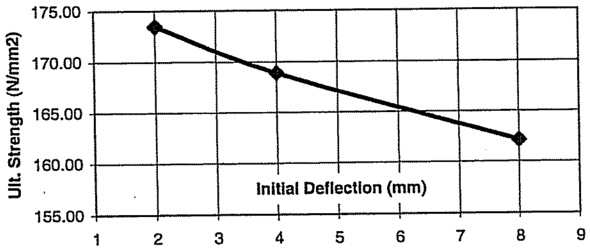

Figure 5: Effect of the amplitude of the initial deflection (B model, without HAZ)

2.1.5 *Concluding Remark*

In these few pages, the committee has tried to reply to the main comments discussed by the reviewer. Additional answers may be found in the extensive benchmark report to be published, Ref. [1].

References

[1] Rigo et al. (2003), Sensitivity analysis on ultimate strength of aluminium stiffened panels, *Marine Structures* (submitted for publication).

2.2 *Reply to Floor and Written Discussions*

2.2.1 *Reply to Prof. Claude Daley*

Prof. Daley is thanked for adding references and pointing out the ongoing work on strength of polar ships and the so-called robust or redistribution methods. It seems that investigation of these items would be very relevant for the new TC III.1.

We appreciate the suggestion for an alternative Figure 1 and the accompanying explanations. The comments on stress redistribution are general and important. It seems that for the general validity of the figure, the curve should have a different inclination after yield is initiated since few - if any - materials exhibit the same stiffness in elasticity and yield.

As regards Figure 1 in the report, the aim was to include a sketch that would be illustrative for all the materials, structures and loads considered in the report, and avoid discussions about a specific configuration. The sketch was not intended to describe comprehensively all the basics of ultimate strength for this wealth of considered configurations. Although such a treatise would be relevant our main points were limited to these three rather basic ones:

- The ultimate strength is the maximum on the load curve, regardless that the structure may be deformed permanently at this point (and even before this point is reached) and thus may need some kind of repair for continued operation. The definition of the

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VOLUME 3

DISCUSSION ON THE REPORT OF TECHNICAL COMMITTEE III.1

ULTIMATE STRENGTH

MANDATE

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

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