15th INTERNATIONAL SHIP AND
OFFSHORE STRUCTURES CONGRESS 2003
AUGUST 11-15, 2003
SAN DIEGO, USA

VOLUME 3

**DISCUSSION ON THE REPORT OF
SPECIALIST COMMITTEE V.3**

COLLISION AND GROUNDING

MANDATE

Concern for structural arrangements on ships and floating structures with regard to their integrity and adequacy in the event of collisions and groundings, taking into account the probabilistic and physical nature of such accidents. Consideration shall be given to the effectiveness of structural arrangements for reducing or avoiding pollution due to leakage, and to residual strength of damaged structures.

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1 DISCUSSION

1.1 Official Discussion by Prof. Alan Brown (USA)

1.1.1 Introduction

It is an honor and my great pleasure to have the opportunity to serve as the official discusser on the report of Committee V.3. I would like to congratulate the committee on an excellent report. All contributors deserve our recognition and gratitude. Generally, I agree with their summaries and conclusions. I hope to provide discussion that will generate more discussion. I may pose more questions than I answer. I will organize my discussion to be consistent with the subheadings of their report.

1.1.2 Discussion

1.1.2.1 Overview

The International Maritime Organization (IMO) is responsible for regulating the design of oil tankers and other ships to provide for ship safety and environmental protection. Their ongoing transition to probabilistic performance-based standards requires the ability to predict the environmental performance and safety of specific ship designs using probabilistic and risk-based methods.

IMO's current oil outflow and damage stability calculations use probability density functions (pdfs) to describe the location, extent and penetration of side and bottom damage. These pdfs are derived from limited historical damage statistics (IMO 1991), and applied identically to all ships without consideration of their structural design. A major shortcoming in these methodologies is that they do not consider the effect of structural design or crashworthiness on damage extent (Rawson *et al.* 1998, Sirkar *et al.* 1997). The primary reason for this exclusion is that no definitive theory or data exists to define this relationship. Providing this theory is our responsibility!

A method that considers crashworthiness must be sensitive to at least the basic parameters defining unique structural designs while maintaining sufficient generality and simplicity to be applied by working engineers in a regulatory context for a ship in worldwide operation. It should not require detailed finite element analysis or be limited to a single accident scenario. It is best implemented in classification society structural design rules. The use of an Accidental Limit State (ALS) approach together with serviceability, ultimate and fatigue limits states is an excellent way to organize structural design criteria for this application.

1.1.2.2 Collision and Grounding Data

It is generally agreed that a probabilistic approach to predicting collision and grounding damage is the only rational methodology for assessing the crashworthiness of a ship design. Accident data has become increasingly important to support this probabilistic approach. The HARDER project has greatly improved the quantity, quality and understanding of available accident data (Laubenstein et al. 2001, Lützen & Clausen 2001), but the use of damage data for predicting damage extents in collision and grounding must be considered only an interim measure! Our ultimate goal must be to predict accident damage for a specific structural design in a specific ship using probabilistic damage prediction tools. Past accident data, except for (external) collision and grounding scenario data, should be used only for damage-prediction-model validation. For this reason, most of my comments in this section are directed to scenario data required for damage prediction, which were somewhat, overshadowed by the damage data in the Committee V.3 report.

Probabilistic collision scenario data includes: description of the striking ship; struck and striking ship collision speeds; collision angle; and impact location. Figure 2 in the Committee V.3 report indicates that struck and striking ship characteristics are relatively independent, which contradicts the common view that like ships strike like ships. For ships operating in worldwide trade, it is best and sufficient to assume striking ship characteristics consistent with worldwide ship data, possibly with the exclusion of smaller striking ships (< 5000 MT), as collected by the HARDER Project or Brown (2002a, 2002b). For ships operating in a specific trade or on a specific route, a subset of the worldwide data may be used. Specific trade routes may also be used in collision and grounding simulations to predict ship speeds and collision angles (Pedersen 1995), but when two ships are maneuvering to avoid a collision (in-extremis) this prediction becomes very tenuous. It is preferable to use historical data for ship speed, collision angle and strike location pdfs. It is reasonable to assume that these pdfs are less sensitive to specific ship design characteristics and more general in their applicability, although parameters such as striking ship speed may change (increase?) gradually over time.

Impact location must often be inferred from the damage description because a reliable record of the precise location is not available. The current IMO pdf for longitudinal impact location specifies a constant value over the entire length of the stuck ship (IMO 1991). Sandia (1998) data indicates a somewhat higher probability of midship and forward strikes compared to the IMO data. HARDER project data indicates a gradual and slight bias towards the bow when uncertain bow striking cases are removed as shown in Figure 1. This is probably the best collection of data for impact location available at this time.

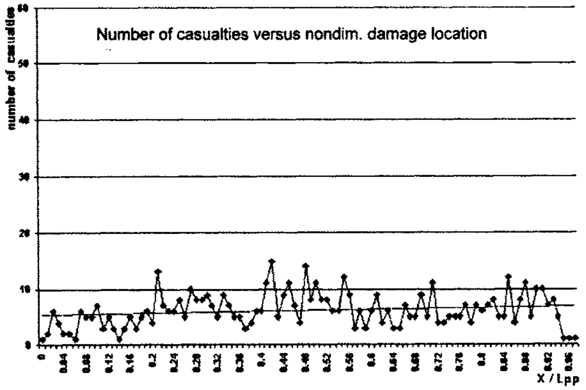


Figure 1: Collision Impact Location (Laubenstein *et al.* 2001)

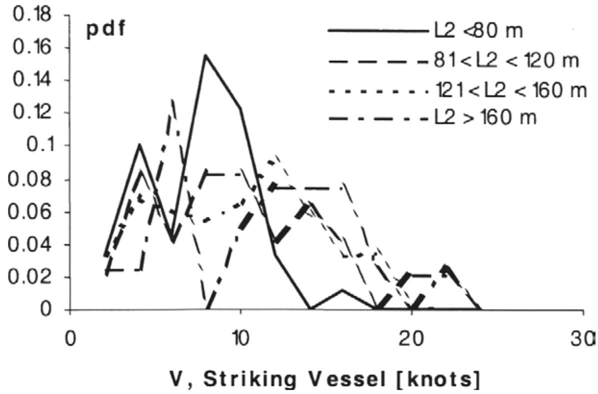


Figure 2: Striking Vessel Speed (Lutzen & Clausen 2001)

Ship heading and speed prior to a collision are often included in accident reports, but collision angle and ship speed at the moment of collision are frequently not included or only estimated and described imprecisely. These parameters, particularly striking ship speed, are extremely important in determining absorbed energy. The striking ship speed, at the moment of collision, is not strongly related to service speed, or even ship speed prior to the collision event. It depends primarily on actions taken just prior to the collision. Striking ship speeds reported by the Harder Project as shown in Figure 2 are somewhat higher than speeds reported by Brown (2002a, 2002b) as shown in Figure 3, and this difference is significant. Additional data is required for this parameter and the data should be updated over time.

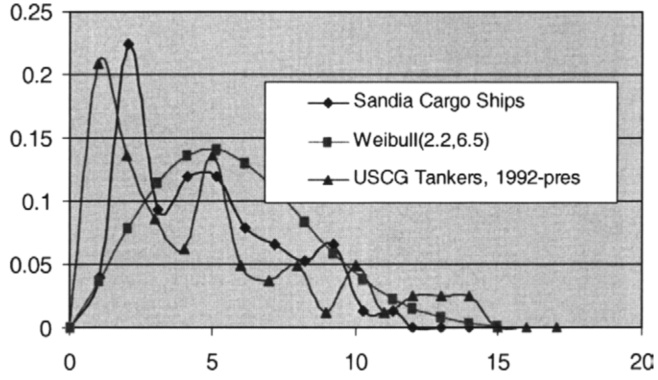


Figure 3: Striking Ship Speed (knots) (ORI 1980, USCG 1991)

The struck-ship collision speed pdf is also very different from service speed. Struck ships are frequently moored or at anchor, and this greatly skews their pdfs towards zero speed. Again, the HARDER data as shown in Figure 4 represents somewhat higher speeds than the data collected by Brown (2002a, 2002b) as shown in Figure 5, but the trends are consistent.

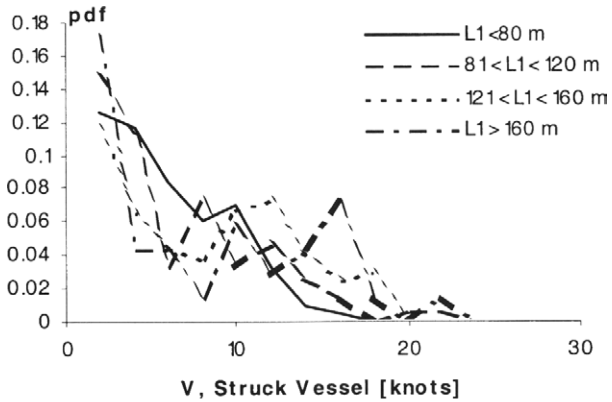
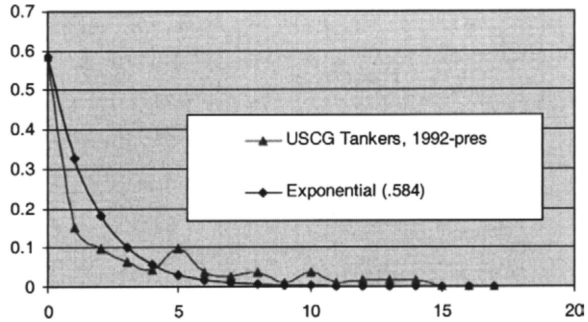


Figure 4: Struck Vessel Speed (Lutzen & Clausen 2001)

Figure 6 is a plot of collision angle data derived from the Sandia Report (1998). An approximate Normal distribution (μ = 90 degrees, σ = 28.97 degrees) is fit to this data. At more oblique angles, there is a higher probability of ships passing each other or only striking a glancing blow. These cases are frequently not reported. HARDER (Lützen & Clausen 2001) assumes a constant distribution for collision angle.



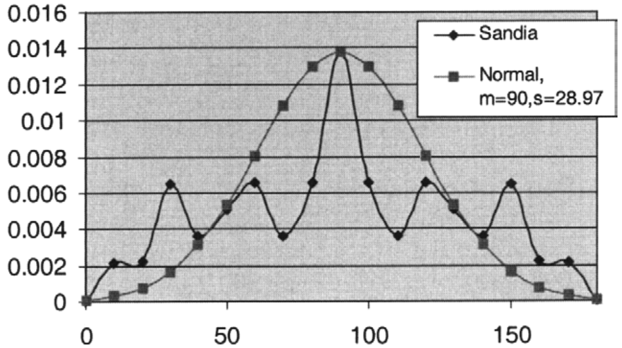


Figure 6: Collision Angle pdf (degrees) (Sandia 1998)

Probabilistic grounding scenario data includes: ship speed, ship loading, depth (or elevation) of the obstruction or bottom, and description of the obstruction or bottom. Except for ship speed, very little grounding scenario data has been collected or published. The 'standard rock' remains a submerged mystery. Tikka (2001) collected grounding data from four US high tanker-traffic locations. Data included ship speed, tidal conditions and obstruction depth. Rawson *et al.* (1998) proposed a set of grounding scenario pdfs developed using expert opinion, and these pdfs were used with MIT's DAMAGE program to calculate grounding damage pdfs. These pdfs showed reasonable agreement with the IMO grounding damage pdfs, but results are not conclusive.

1.1.2.3 Framework for Accidental Limit State Design

A rational Accidental Limit State design procedure must include or consider a probabilistic analysis as shown in Fig. 9 of the Committee report. Probabilistic analysis requires the calculation of many accident cases, usually thousands, using Monte Carlo simulations or similar methods. This requirement makes full non-linear FEA prohibitive due to lengthy set-up time and run time. Simplified non-linear FEA and analytical methods are most useful for a probabilistic analysis.

A potential simplification of the probabilistic collision scenario definition solves the external ship dynamics problem uncoupled from the internal deformation problem. This allows multiple collision scenario random variable definitions to be replaced by pdfs for total, transverse and longitudinal absorbed energy, or even more simply, by a single total energy value as a function of struck ship displacement with a specified probability of not exceeding (Lützen & Clausen 2001, Pedersen & Zhang 1998). A single energy value could then be used in the limit state criterion, as described in Eq.(3) of the Committee report. Brown (2002a) compared absorbed energy derived using the Pedersen-Zhang method for 10000 collision cases to results obtained using a simplified analytical model (SIMCOL) that simultaneously solves internal and external mechanics in time steps. Total absorbed energy for the two methods was very similar, but the individual longitudinal and transverse components showed a larger difference, particularly in the longitudinal direction as shown in Figure 7. This may result from differences in structural resistance in the transverse and longitudinal directions, which in SIMCOL varies during the collision process. The difference in longitudinal absorbed energy is potentially significant because once the structure is penetrated; longitudinal damage extent determines the number of compartments that are opened to the sea. This has a significant effect on damage stability and oil outflow. Struck ship speed can also have a significant effect on longitudinal extent of damage, and should be considered explicitly.

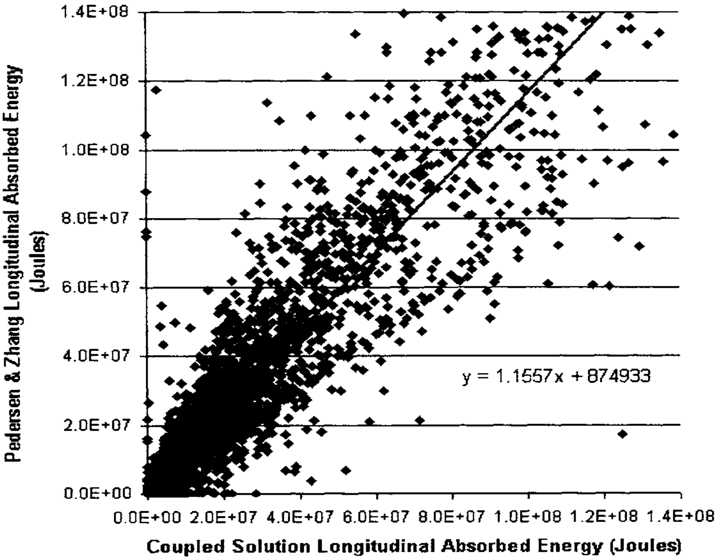


Figure 7: Longitudinal absorbed energy

1.1.2.4 Nonlinear FEA of Internal Mechanics

Simplified non-linear FEA offers the flexibility to consider a wider range of struck ship designs than simplified analytical methods while still maintaining computational efficiency. If full probabilistic grounding and collision scenarios are used with these models a pre-processor must also be used to expand the parametric description of a striking bow or obstruction into a physical geometry modeled in the FEA. Appropriate material properties such as failure strain must be selected to be consistent with element size and strain rate. Failure strain continues to be used as a 'calibration factor' in many analyses and should be selected in a more rigorous fashion based on material properties, but this becomes a challenging problem in real structures. We need some consensus and standards on how to deal with this.

1.1.2.5 Alternatives to Double Hull Design

The Marine Board (2001) study provides a methodology for assessing alternative tanker designs that includes significant documentation and details.

1.1.3 Conclusions and Recommendations

The committee has provided an excellent summary of grounding and collision models and design methodology. Our emphasis must be on models for probabilistic analysis. Although full FEA can provide useful insights about a particular design in a particular collision, the application of simplified methods (analytical or FEA) in a representative probabilistic analysis is essential for a meaningful assessment of crashworthiness. A simplified probabilistic approach using an absorbed energy distribution may not sufficiently discriminate between designs or properly predict longitudinal extent of damage, but would allow significant simplification of the methodology.

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1.2 Floor and Written Discussions

1.2.1 Mr. J. Sirkar and Mr. H.P. Cojeen (USA)

We would like to remind the readers that the concepts for structural performance of ships during (and after) accidents was first introduced in a paper by Astrup *et al.* (1995) presented at MARIENV Conference held in Japan. Significant developments in technology during the 1990s have yielded the promise of computational tools. The practical application of ALS would need to include properly developed and combined design criteria. The report does refer to the "objective functions" that would be needed in such criteria. We recommend future research appropriate criteria should be used for the development of performance standards. In other words, what we believe is that it may be possible to combine, comprehensively, oil outflow performance, stability characteristics, as well as structural integrity after damage, so that an integrated approach to performance after damage may be developed. We fully understand that the existence of such an integrated approach is not imminent. Nonetheless, we recommend that this Committee consider this matter in future work, possibly in coordination with one of the Design Philosophy Committees.

It will not come as a surprise to the authors of this excellent Specialist Committee report that the commenters, working with the United States Coast Guard, will have very clear ideas and opinions of this topic. Though it may seem otherwise, we based our opinions on facts and peer reviewed studies and reports. The double hull though not the perfect solution, has numerous attributes, as compared to nearly all the alternatives that trade off one type of outflow with another – oil against the side shell which always results in a finite amount of spill.

Double hull tankers reduce the numbers of spills from groundings and collisions. No other alternative even comes close to the performance of double hull tankers when it comes to reducing the numbers of spills. This point is of utmost importance since small spills have a significantly disproportionately negative impact on the environment when compared to larger spills, per unit spill volume. These findings were tentatively reported in two papers, the previously noted Astrup *et al.* (1995) and the Sirkar *et al.* (1997) paper presented to the Society of Naval Architects annual meeting held in Ottawa. The commenters note that the Marine Board (2001) of the National Academy of Sciences validated these results in a recent study. The Marine Board's findings support an emphasis on preventing oil spills over minimizing larger spill volumes because of the relatively greater environmental impact.

Now, one asks what is the next step with regard to IMO regulations, or classification society rules. Our view is that we are not going to see the use of crashworthiness methods to justify reduced sizes of inner bottom or the side tanks. To reinforce this contention let us bring the readers up-to-date on the matter of "robust ships" which has been swirling around IMO these last few months.

In a paper by Greece and the Bahamas (IMO 2003a) they seem to be seeking IMO assistance in achieving 'goal-based standards' for construction. What they seem to have in mind are structural strength and robustness, and these are issues of which this Congress is very interested. Our view is that through the use of more powerful computational tools we have indeed evolved to the situation where our ships have become marvels in optimisation, but some types now possess the smallest of residual strength margins. In another paper to the Maritime Safety Committee on the same subject the OCIMF proposes a new build checklist. (IMO, 2003b) Two papers we are fully aware of -- and I am sure additional papers referenced by Committee III.1 (ultimate strength) -- Payer (2002) and Paik (2002) showed us calculations that indicate some ships with a mere 6 or 7% of strength margin in ultimate failure. The second standard that Bahamas and Greece was referring to, fatigue life, is also of a mature enough technology that IMO's setting a fatigue life minimum is possible.

We believe that this will be possible in part because of the recently initiated project to develop an ISO standard for ultimate strength. In contrast our view of the maturity of the crashworthiness is another matter. Although the technical community has made great advances – looking at the first ISSC report on collision and grounding in the 13th ISSC Congress (1997: Specialist Committee V.3) - we believe we still have some time before we as a technical community can claim that the technology is at a sufficient level of maturity to impact IMO standards.

Thus, we agree with, and endorse the proposals for further research suggested by the Committee in Chapter 6 of this report. In the interim period though, we believe that there may be some unique types of ships that can only be viable with a reduced inner dimension, and thus the need for Administrations to accept equivalences based on crashworthiness calculations. In this interim period though, the assumptions and computational methods will need to be very conservative developed and presented to the international regulatory community.

In closing, we believe that this specialist committee should be extended for another inter-congressional period of study. We also want to stress the fact that owners should consider opting for ships with additional class notations – such as GL's COL – that demonstrates to customers that their vessels are operating at a higher level of safety than their competitors.

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1.2.2 Prof. T. Yao (Japan)

First of all, I should say that the committee is congratulated for a good report on collision and grounding. The results of benchmark studies are very interesting. In relation to this, I have a comment on analysis of tensile coupon test of mild steel. The committee tried two models as true stress-strain relationships of the material, and the committee's recommendation is the Model II which shows the stress reduction in a large strain range. However, this behaviour is because of the occurrence of necking, and this relationship itself is not the true stress-true strain relationship as material characteristics. This is a particular behaviour which can be observed in a tensile test using a coupon specimen. The true stress-true strain relationship of the material is in general represented by Model I and the stress reduction can be automatically obtained using this relationship if a material instability criterion for a finite deformation problem and a structural instability (bifurcation) criterion are adequately incorporated in the analysis.

When these criteria are adequately incorporated in the computer code, the influence of necking is then doubly counted if you use Model II as a true stress-true strain relationship of the material. So, Model II should not be used. Model II is only representing a result of tensile test on a coupon specimen and can not be a true stress-true strain relationship as material characteristics.

1.2.3 Prof. K. Suzuki (Japan)

First I would like to congratulate the work done by the committee members. This report gives quite important review of the state-of-the-art research works on the collision and grounding area.

In Chapter 5 of the Committee report, varying double side width and varying double bottom height is discussed as well as alternative design to double hull tanker. My question is that did the committee reaches any kind of conclusion or any kind of proposal on the alternative design to double hull tanker?

I understand that is quite difficult task, since collision and grounding has quite variety of situation, such as in collision striking ship sizes, heights, speed and in grounding many kinds of sea bed, and you have to consider them properly. If no conclusion has been reaches yet, what kind of research work needs to be carried out in the future?

1.2.4 Prof. S.R. Cho (Korea)

The report of this Committee is enjoyable to read due to the great efforts provided by Chairman, Prof. J. K. Paik and other Committee members. I would like to add four comments:

Offshore Collisions; As we all know, this congress is not only for ship structures but for offshore and offshore collisions is also included in the mandate of this committee. Thus, many of participants may expect to obtain some information regarding offshore collisions from the committee report. But, unfortunately, it was difficult to do so.

Collisions of Aluminium Alloy and Composite Materials; As many of us know, the major materials of high speed vessels are aluminium alloy and composite materials. Collisions of high speed vessels, especially passenger ships, are also concerns of marine structural designers. Collision responses of aluminium alloy and composite structures are not covered in the report. Even the committee report of V.4 Structural Design of High Speed Vessels covers on this topic with only a couple of lines.

Scale Effects of Impacted Structures; Experimental results of any collision and grounding tests on scaled models may show scale effects. It is necessary to mention these in the committee report at least in the recommendations for future works.

Convergence Study of Numerical Techniques; In the report on pages 96 and 97 of vol. II of the proceedings, two types of meshed models are shown for FEM calculations. The coarsely meshed one is named as for ultimate strength analysis and the more finely meshed one as for grounding analysis. As far as I am aware, the number of elements or mesh size can be determined based upon the convergence test results of the numerical method. I wonder whether any convergence tests have been performed before determining the number of elements.

1.2.5 Mr. B. Boon and Mr. G. Janssen (The Netherlands)

The Committee did a wonderful job in reporting on the present state regarding collision and grounding. Unfortunately the committee member Hans Ludolphy deceased suddenly a year ago. We feel that we comment to the official discusser on Hans' behalf.

Professor Brown stated that official rules and authorities do not take into account crashworthiness of a ship and thus the benefits of such property are not fully to be reaped.

Hans Ludolphy developed the Schelde collision resistant side shell, or, as we now might term it, the crashworthy side shell. This shell structure is used in two push barges used for inland transportation on river Rhine. Because of the crashworthy side shell larger gas tanks have been accepted by the authorities. Four instead of six tanks mean a significant gain in new-building and operational costs. Moreover, it was found that the crashworthy side shell actually was cheaper to fabricate than the traditional side shell structure. We think that this is a good example of the benefits of crashworthiness and the acceptance by authorities. A few preliminary reports on the system were published, but, no doubt, more publications will follow. We expect that the new collision committee will report more in detail on these developments.

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1.2.6 Mr. B.L. Hutchison (USA)

The Committee is to be commended for an excellent report that extends the work and contributions of this valued Committee.

One mode of damage not addressed by the Committee is the side raking form of collision and grounding. In some operating areas of the world side raking on rock ledges or pinnacle rocks is as common, or more so, than bottom grounding. It would be a benefit if the next Collision and Grounding Committee could extend their work to include side raking.

A previous discusser, Prof. S.R. Cho, mentioned high speed vessels. During discussion of the Committee V.4 Structural Design of High Speed Vessels, questions were raised regarding the requirement for double bottoms in high speed craft, as introduced by IMO in HSC 2000 following the tragic *Sleipner* accident. I would like to suggest that the next Collision and Grounding Committee should include consideration of grounding of high speed vessels.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discusser

The Committee thanks Prof. Brown for a through and constructive official discussion.

The Committee thinks that one of the focus areas for future research related to ship collisions and grounding is to establish accident scenarios on which assessment of a ship's performance in accidents can be based. We are pleased that Prof. Brown also shares the same opinion with the committee.

The probability density functions (pdfs) that IMO specifies for oil outflow and damage stability calculations do not consider the effects of structural design (or structural crashworthiness) on the damage extents. This is primarily due to the fact that there is virtually no historical accident data that can fully describe the relationship between damage characteristics (e.g., extents, locations) and structural designs. We agree that definitive theory which can predict accident damage is essential in this regard.

Often, historical accident data is used for establishing the accident scenarios. Prof. Brown provides valuable information on historical data for estimating ship speed, collision angles, and longitudinal strike location pdfs. We appreciate this.

When historical accident data is not sufficient enough, as is the case we are in now, numerical simulation provides an alternative means to generate additional 'artificial' information. Promising simulation procedures include SIMCOL (Brown 2002a, 2002b), GRACAT (Friis-Hansen & Simonsen 2002), and others introduced in the Committee report.

It is important to realize that historical accident data often shows quite different trends depending on the condition of accident or even the institutions which record the data. Therefore, a standard format is required to systematically record necessary parameters from past accident data. For instance, the database of ship collisions under way in open water must be distinguished from that in ports under maneuvering operations. This is because in the former condition damage and pollution risks are high, while in the latter they are more modest since the collision speed is so slow.

We agree that simplified nonlinear FEA and simplified analytical methods are most useful for probabilistic analyses. However, it is noted that full nonlinear FEA as well as large scale experiments are also important to verify the simplified methods and to investigate the detailed characteristics of structural crashworthiness.

Prof. Brown compared SIMCOL simplified analytical model simulations with the Pedersen-Zhang method calculations as shown in Fig. 7 of his discussions. A large difference is shown in the longitudinal absorbed energy, while total absorbed energy predicted by the two methods is very similar. This may be because the primary concern of the two methods is different: SIMCOL is concerned with both longitudinal and transverse damage extents, while the Pedersen-Zhang method primarily focuses on the transverse extent of damage.

We agree with Prof. Brown's view that at present the fracture strain remains a calibration factor. However, we also noted in the Committee report that there are some promising important research progress. For example, the rupture criteria can be based on stress using the continuum mechanics theory (Gurson 1977, Lemaitre 1986). This provides a better alternative to the common strain rupture criteria of material (Yu 1996). A stress-based criterion does not depend on element-size, and therefore is more flexible and easy to be included in predicting the failure behaviour of material in regions of welding joints. Different investigations have shown a certain influence of the rupture of welding joints on the failure of relevant parts of structural members. Depending on the type of failure mode of member it has been found (Peschmann 2000) that the basic material and the welding material in regions of joints contribute also to the energy dissipation.

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2.2 *Reply to Floor and Written Discussions*

2.2.1 Reply to Mr. J. Sirkar and Mr. H.P.Cojeen

First of all, the Committee likes to thank all of the discussers for their interests, time and valuable discussions or comments. The discussion begins by Mr. J. Sirkar and Mr. H.P. Cojeen.

Design criteria for accidents are required to establish for approval or acceptance of a design. As the discussers pointed out, design criteria for accidents should be developed considering not only structural integrity after damage but also oil outflow performance and stability characteristics. Accordingly, the probability of loss of lives, economic loss and environmental damage after the accidents should be kept under a certain level. The form of design criteria may be deterministic, probabilistic or semi-probabilistic.

As the discussers mentioned, the double hull is a very effective design for mitigating and preventing oil pollution during collision and grounding accidents of oil tankers. However, there are other design alternatives that improve the structural performance of ships against collision and grounding.

The discussers suggest several ideas which are very valuable for validating better designs in the future, designs which may prove to be not only efficient for environmental damage prevention but also perhaps less costly to build and operate.

The Committee agrees that more effort is needed to establish international standards for ALS design. Vessels complying with these standards will also add values to the owners, because the vessels are operating at a higher level of safety than their competitors.

2.2.2 Reply to Prof. T. Yao

Prof. Yao raises a question regarding finite element modelling for the tensile coupon test: if the finite element models used for the benchmark study of the Committee doubly take into account the necking effect.

We would say that the necking effect was correctly dealt with in the finite element modelling. Some additional explanation may be needed. The real 'true stress-strain curve' is not straightforward to obtain because it is difficult to measure the reduced cross-sectional area of test specimen during tensile coupon test, even though it is not impossible. In this regard, the true stress-strain curve is normally estimated from the nominal stress-strain curve using Eq.(5) of the Committee report as long as the latter is known. However, it is important to realize that upon using Eq.(5) most usual approaches employ only the tensile coupon test data points between yield point and ultimate tensile strength point, but do not use the data points in the post-ultimate tensile strength regime including necking.

As a result, the estimated 'true stress-strain curve' does not accommodate necking behaviour properly. This approach may be valid for the ultimate strength analysis of structures, but it is not relevant for the analysis of rupture behaviour which is a primary failure pattern in collision and grounding. In our Committee report, therefore, we suggested to use tensile coupon test data points covering all regimes including necking as well as strain-hardening, so that more realistic stress-strain curve can be obtained. It is evident from Fig.16 of the Committee report that the proposed approach improved the computational accuracy compared to the test results.

2.2.3 Reply to Prof. K. Suzuki

Prof. Suzuki asks if the Committee reached any kind of conclusion or any kind of proposal on the alternative design to the double hull tanker. During the last decade, a number of useful proposals have been made as reviewed in the Committee report. For instance, it is reported that the collision performance of side structures can be significantly increased by arranging 'framed panels'. However, it is considered to be premature to reach any permanent conclusion, while double hull design concept still remains as the structural standard for oil tankers.

We think that application of direct ALS design method can produce the robust ships that are not only effective for oil pollution prevention but also be not costly to build and operate.

2.2.4 Reply to Prof. S.R. Cho

The first comment of Prof. Cho is about offshore collisions. As mentioned in the Committee mandate, the prime concern of the Committee is with structural crashworthiness and potential consequences of ships and floating structures in the event of collisions and grounding. Here, floating structures may include FPSOs or some types of floating offshore structures such as semi-submersibles for instance. The structural characteristics of FPSOs are quite similar to those of ocean-going ships. In terms of oil pollution after collision accident, FPSOs might be more concerned. Also, collisions on other types of floating offshore structures are of course important in terms of structural integrity after damage.

The use of aluminium alloys and composite materials is increasing for building high-speed vessels. We would agree that more studies are necessary to investigate their structural performance characteristics. Such effort is important not only for ALS design but also for ULS (ultimate limit state) design (Paik & Thayamballi 2003).

Prof. Cho discusses about the scaling effects on experimental results. To resolve the scaling effect-related problems, the size of the test structures must be similar to those of the real structures. But in reality this may not be possible. For example, real-scale collision or grounding experiments are prohibitively expensive. Real-scale tests may not be necessary when refined numerical methods are available. Once verified, theoretical or numerical methods can be applied to structures with different sizes. When empirical formulae based on experimental results obtained using scaled models are used, however, the scaling effect will play a significant role. For more elaborate description on the scaling effect, Jones (1997) may be referred to.

Finally, Prof. Cho gives a comment on convergence test in conjunction with finite element modelling considered in the Committee report. It is usually very time-consuming to iterate many times in order to perform a convergence test for a collision or grounding analysis because of the obvious very fine meshes. In this regard, our Committee recommends 'fine enough' mesh sizes. It is apparent from the benchmark study results that the guidelines for determining the relevant mesh sizes presented in the Committee report is very useful.

REFERENCES

Jones, N. (1997). Structural impact, Cambridge University Press, Cambridge.

Paik, J.K. and Thayamballi, A.K. (2003). Ultimate limit state design of steel-plated structures, John Wiley & Sons.

2.2.5 Reply to Mr. B. Boon and G. Janssen

We would agree that by applying ALS design approach which involves structural crashworthiness in collisions and grounding better designs can be obtained in terms of higher accident performance. We thank you for Prof. Boon's introduction about 'crashworthy side shell design concept', which was developed by Mr. H. Ludolphy and his colleagues.

2.2.6 Reply to Mr. B.L. Hutchison

We would agree that the topics on side raking damage and collisions of high-speed vessels are of importance, while the Committee is more concerned with structural crashworthiness and oil pollution of oil tankers after collisions and grounding. We would therefore recommend these topics to be included in the next Committee report.