18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

18$^{\text{th}}$ INTERNATIONAL SHIP AND
OFFSHORE STRUCTURES CONGRESS

09-13 SEPTEMBER 2012
ROSTOCK, GERMANY

VOLUME 3

COMMITTEE V.1

DAMAGE ASSESSMENT FOLLOWING ACCIDENTS

COMMITTEE MANDATE

Concern for the structural integrity of offshore structures exposed to hazards. Assessment of risk associated with damage, range of repair required and the effects of temporary repairs and mitigating actions following the damage. The hazards to be considered include hydrocarbon explosions and fires, wave impact, water-in-deck, dropped objects, ship impacts, earthquakes, abnormal environmental actions and possible illegal activities like the use of explosives and projectiles.

CONTRIBUTORS

Official Discusser: Preben Terndrup Pedersen
Floor Discussers: James Underwood
Marek Kaminski
Kristjan Tabri
Erkan Oterkus
Enrico Rizzuto

REPLY BY COMMITTEE MEMBERS

Chairman: Jurek Czujko
Natacha Buannic
Sören Ehlers
Chen-Far Hung
Frank Klæbo
Spyros J. Pahos
Mark Riley
Wenyong Tang
Alex Vredeveldt
John Wægter

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

CONTENTS

© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

1 DISCUSSION

1.1 Official Discussion by Preben Terndrup Pedersen

1.1.1 Introduction

It is apleasure to have been given the opportunity to serve as official discusser of the report of Committee V.1. As a long time member ISSC, I have been paying great interest into the efforts of ISSC committees in digesting new research results and presenting future directions for research and development of our fields of interest to the benefit of the maritime industry.

According to the mandate Committee V.1 should deal with assessment of risk associated with damage, range of repair required and the effects of temporary repairs and mitigating actions following the damage.

The report covers a wide range of hazards which can lead to structural damage, i.e. hydrocarbon explosions and fires, wave impact, water-in-deck, dropped objects, ship impacts, earthquakes, abnormal environmental actions and possible illegal activities like the use of explosives and projectiles.

With the mandate as background the committee decided that the focus of the report should be on:

1. Safety measures to be taken during the design phase and in case of accidents.
2. Assessment of the level of damage and of the residual strength of the structure.

To give a complete review of the advancements within these areas is a tremendous task and since this is the first ISSC committee to deal with these topics the committee has been forced to prioritise the topics to be included. As the committee will see there are only a few points where I disagree with the committee but there are a number of items where I would like to see further work to be done.

In addition to the review of published work the committee must be commended for carrying out a benchmark study concerning the response of stiffened plates subjected to hydrocarbon explosions.

1.1.2 General Remarks

Safety Measures to be Taken during the Design Phase

Risk analysis is a tool that is increasingly applied during the design phase in the marine and offshore industries to manage safety, health and environmental protection. For rational design of safety measures it is important to apply a comprehensive risk analysis, i.e. to estimate accident frequencies and to determine the probabilistic distributions of accidental loads given a specific hazard in order to perform rational consequence analyses.

Probability of Occurrence All the accidental damages considered by the committee are low probability, high consequence events. For this reason it is a challenge to develop procedures to estimate frequencies for the hazards such as those presented in the committee report.

From Table 1 it is seen that most of the structural analysis tools presented in the report can be considered as elements of comprehensive risk analysis procedures.

Except for the section on hydrocarbon explosions and fires the report gives very limited information on procedures for estimation of the probability of the different hazards and the load distributions given a hazard takes place. If this reflects the scarcity of research work in this area there are good reasons to recommend such work in the future.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

Table 1: Approaches for determining incident occurrence frequencies (from OMAE 2007-29760)

Approach	Main Advantages	Main Disadvantages
Statistics of incidents	Long been regarded as the only reliable sources	Limitation with incident reports, difficulty in application to the future
Expert opinions	Long been used when limited by data	Subjective
Predictive calculations	Predict unfavorable conditions, inexpensive	Targets known scenarios, limits choice of software/programs, restricted to occurrence probability
Comprehensive risk analysis	Rational, includes consequences	Relies on accident data for benchmarking

Risk Control Options The consequences of the hazards considered by Committee V.1 can be measured in terms of structural damage, the number of fatalities and injuries, the amount of material released to sea, the immediate impact on environmental resources, and the subsequent costs of restoration. An important part of a safety design procedures is to reduce these consequences by considering risk minimising measures or Risk Control Options (RCOs). That is, to include a combination of actions that reduces the frequency and consequences of accidents. Those assessing the risk normally prioritise Risk Control Options that are adopted to reduce the number of hazardous situations that may cause an accident. On the other hand, because the consequences of incidents are so serious for offshore structures, we must develop damage tolerant structural designs and develop consequence reducing arrangements, regulations and requirements.

The tools presented in the report are essential elements for analysis of damage tolerant structures. Future committee work could preferably also give attention to consequence reduction, i.e. possible RCOs for the different hazards.

Rules and Regulations Most design codes reflect a number of distinctive risk assessment steps in the design process. For instance API Recommended Practice 2A-WSD specifies the following assessment tasks for evaluating the events (fire, blast, and accidental loading) that could occur to a platform over its intended service life and service function(s):

- Task 1, assign a platform exposure category for the platform
- Task 2, assign risk levels to the probability of the event
- Task 3, determine the appropriate level of risk for the selected platform and event
- Task 4, conduct further study or analyses to better define the risk, consequence and cost of mitigation
- Task 5, reassign a platform exposure category and/or mitigate the risk or the consequence of the event
- Task 6, assess structural integrity if the platform is considered high-risk

In Section 15 “Design and Assessment Process” the committee has a section on Codes and Standards. For designers this is an important subject. A number of codes are mentioned. But no systematic listing of relevant codes is presented. For instance the above mentioned API code is not included in section 15.2 even if this code is often used in the industry.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

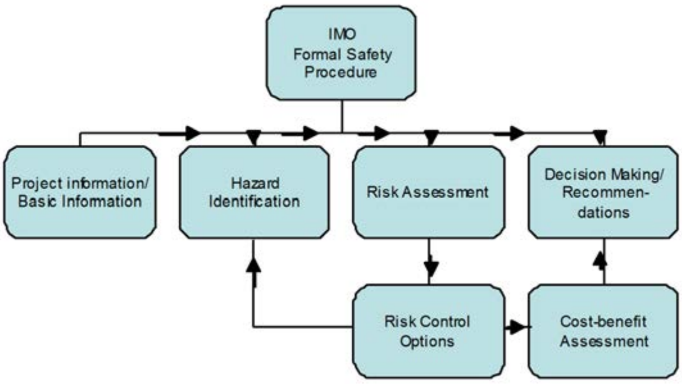

Figure 1: IMO's Procedure for Formal Safety Assessment

Perhaps the report could have summarised relevant codes in a tabular form to the benefit of designers.

It is my experience that for a consistent design process for safety it is of considerable value in a formal way to go through steps such as those from API presented above in order to document the procedure and to make a risk summary. A similar approach has been taken by IMO's Formal Safety Assessment procedure for evaluation of proposed new regulations. See Figure 1.

Assessment of the Level of Damage and of the Residual Strength of the Structure

When an emergency has happened on a platform the crew is often overwhelmed by tasks. There is little time and not often the expertise available to produce a residual strength assessment and safety evaluation onboard the platform.

For commercial vessels the concept of "Emergency Response Service" has been established to provide fact based assistance to a vessel in distress immediately after an incident.

Has Committee V.1 any thoughts about the use of the tools and procedures presented in the committee report to be applied as integral parts of a similar Response Emergency Service for offshore platforms to assess the level of damage and the residual strength of structures given an incident has happened?

After these more general remarks some comments will be offered to the sections on the specific hazards considered by Committee V.1.

1.1.3 Hydrocarbon Explosions and Hydrocarbon Fires

These two sections of the committee report focus on hazards involving sudden loss of containment, fires, explosions, or combinations thereof. Even though the theoretical foundation for the physical and chemical processes involved is reasonably well established, then the complexity of realistic offshore problems limits direct use of basic theory for predicting the outcome of potential accidents. Practical engineering solutions rely on empirical correlations or phenomenological models. The current up to date procedures are based on the use of computational methods for evaluating the relevant partial differential equations in the form of algebraic equations. However, caution should be exercised whenever computational (CFD) models are used outside their validation range. There are not many large-scale experiments suitable for model

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)

© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

validation, and the quality of the available measurements varies significantly. Furthermore, the repeatability of large-scale experiments is rarely investigated. There is a need for further research within this important area.

It is obvious that design explosion loads derived from the worst credible event is far too large to be accommodated by any structure. Thus the focus of these sections has been on comprehensive risk based approaches as mentioned in the last lines of Table 1. Nearly all elements are touched upon. Quantitative risk assessments of the risk associated with hydrocarbon explosions and fire are still in its infancy and as the committee points out different analysts will often come to quite different estimates. But a thorough and critical review of the latest literature as presented here will help to standardize risk analyses in this area.

These two sections of the committee report give excellent reviews of current knowledge and are of value for designers of offshore structures. They give a good introduction to the physics of the problems where the different structural load mechanisms are described. Based on an overview of recent research, a probabilistic explosion risk model is presented together with design exceedance curves for overpressure. In these two sections the committee has managed to give a lot of information in a limited number of pages.

The only topic I could miss is a description of possible risk control options. But this could be a good topic to be included in a future committee report.

1.1.4 Underwater Explosions, Illegal Activities Like Use of Explosions and Projectiles.

It is not clear to me why Section 5 “Underwater Explosions”and Section 14 “Illegal Activities like use of Explosives and Projectiles” have not been combined. From a structural point of view these subjects are closely related.

The source of underwater explosions is often the result of acts of terrorism. For this reason it is of course difficult to make any probabilistic predictions on frequencies and load distributions.

The committee has chosen to describe different procedures to determine the structural response associated with different given underwater explosions. Unfortunately, most of the research results within this field are probably not available in the open published literature.

Design against structural damage due to underwater explosions could be a subject for further work by the committee. The analysis procedures reviewed by the committee have in the past been used to improve the failure resistance of underwater structures. For instance, after the USS Cole incident, research was initiated to find structural configurations which can sustain higher underwater explosion loads. Some of this literature has been published and the results can probably be used to design more explosion resistant structures.

1.1.5 Wave Impact, Wave-in-Deck, Freak waves and Tsunamis

Wave impacts and slamming loads at the underside of superstructures is different from the other hazards treated by the committee. These loads and their effects are considered in the normal design process for fatigue limit loads as well as for serviceability load effects. They are not normally considered as accidental loads. I assume that one of the reasons why the ISSC standing committee has included these subjects in the mandate has been to look for procedures for assessment of the residual strength of

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

offshore structures subjected to damage from these loads and/or some guidance for emergence response for consequences of these load types.

Again it is not clear to me why Section 6 “Wave Impacts” and Section 11 “Abnormal Environmental Actions” have not been combined to one section.

1.1.6 Dropped Objects and Ship Impact on Offshore Structures

Together with hydrocarbon explosions and fire, ship collisions are among the most costly accidental loads. As stated in section 9.1 the offshore industry has a risk management concept for these accidental loads. For this reason it would be helpful for designers to get guidance for generation of an absorbed energy spectrum that shows the cumulative collision frequencies versus the impact energy generated by the collision. Such load and energy distributions are needed for rational consequence calculations. Again it does not seem reasonable to base the design against dropped objects and ship collisions on some deterministic worst case scenarios.

The probability of the occurrence of impacts due to dropped objects and collisions may be computed from historical data, expert opinions and predictive calculations as indicated in Table 1. Historical data provide realistic figures which nevertheless are difficult to use for future predictions since they are not relevant to offshore structures which may differ from those used today and they do not take into account the actual geographical location, the operational procedures, new navigational equipment, etc. For these reasons mathematical models for prediction of the frequency of hazard occurrence is an important first step for a rational risk assessment procedure for impact loads. Such probabilistic analyses must involve identification of a number of different impact scenarios, each one associated with a probability level. A number of frequency prediction models have been developed during recent years which together with external energy analyses can be used to determine probabilistic distributions of energy released for crushing of structures. The final step in that part of the risk analysis is then to determine the consequences given that an event takes place.

The focus of these two sections of the committee report is on analyses of consequences given that a well described impact incident has taken place.The Committee mainly concentrates on explicit FE-methods for consequence assessment of the large number of possible scenarios related to high energy impacts and structural configurations.

In addition the committee recommends basing the consequence calculations on an integrated approach where the external mechanics of the impacting ship (or dropped object) is solved together with the structural response analysis.

For comprehensive risk based analyses of damages to be expected due to ship impact I am not so sure that nonlinear explicit FEM simulations using coupled fluid dynamics always should be preferred. Even if significant progress in software and hardware has been made it seems to be an unattainable task to get the statistical consequence distributions needed for a risk based procedure by these coupled procedures. The loss of accuracy by separating collision problems into an external dynamic analysis and an internal analysis is normally quite small. The statement in Section 9.2 that in ship collisions mooring can give different external mechanics characteristics does not correspond to my experience.

Of course, for specific analyses of accidents that have taken place the proposed advanced analysis procedures are very relevant.

For future committee work within this area it is recommended that the committee reviews risk based assessment approaches which makes it possible also to evaluate risk control options in the form of increased crashworthiness of offshore structures.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

1.1.7 Flooding

The report includes a section on the effect of flooding on the structural integrity of a ship or a floating offshore structure.

Mitigation of the further consequences of ship-ship impacts is to day usually achieved by controlled flooding, i.e. through defining a certain distance between inner and outer watertight barriers, defining appropriate subdivisions for survival in case of flooding, appropriate arrangement of cargo and fuel tanks etc.

Two effects of flooding are considered in the committee report:

The first is the global effect on the hull girder. Here Figure 11 in the report shows the RAO for torsional moments of an intact and a damaged ship in beam waves. The choice to include this figure is somewhat surprising since hull girder torsional moments in FPSOs and other ship shaped offshore structures usually play a very small role for the overall stress level. It may have been of more interest to see similar curves for longitudinal bending moments and shear loads, even if analyses show that flooding does not normally increase the wave-induced hull girder sectional forces.

The second effect considered is sloshing loads in flooded compartments. This load type is similar to the sloshing loads from liquid cargoes. The latter may be of more concern due to the more frequent partial filling ratio conditions during normal operation.

1.1.8 Material Models for Structural Analysis

When Benchmark Testing and Joint Industry Projects involving advanced structural analyses are carried out then it is quite often found that the results deviate considerably and can fail to model the physical tests in a reasonable way. One reason for these poor results can be the material models used for the numerical calculations.

For this reason the committee must be congratulated for including a quite comprehensive section on material models.

The committee first gives a review of existing guidelines and standards. It is shown that these existing guidelines fail to provide clear guidance for material modelling to the analysts.

This section of the Committee Report is then followed up by a thorough discussion of properties for relevant materials such as steel, aluminium, foam, rubber, ice, air water, explosives, composites, soil, etc. The report even contains example input cards for the recommended material properties to a commonly used explicit finite element program. A section like this is new for ISSC, and I am sure that this will be used by structural analysts in the future.

1.1.9 Benchmark Study: Stiffened Panel Subjected to Explosion Loads

The committee has performed a valuable benchmark study where calculated structural response results are compared for a stiffened steel panel subjected to explosions loads using different numerical procedures. The benchmark is based on a full scale test experiment subjected to a hydrocarbon explosion load. The time variation of the deflections and the permanent plastic deformation of the panel are measured and numerically predicted by five different participants.

The benchmark study is very illustrative. It shows that even if the panel and the physical set-up is quite simple and the test conditions are such that fracture has been avoided there is a considerable scatter in the results.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

Adding to this spread in structural response results also the uncertainty in explosion load prediction in the current design process then it is obvious that much more work is needed before reliable procedures for damage assessment of offshore structures subjected to explosions hazards is a mature field.

1.1.10 Closure

Accidental loads on offshore structures cause loss of lives, economic losses, environmental damages and other unwanted events every year. It is indispensable that such hazards are considered to be so rare that the benefit of the operations to the owner and the public exceeds their sensitivity to risk. Therefore, one of the many performance goals during the design phase of offshore structures should be to ensure that serious accidents and service disruptions are low enough to be acceptable to all stakeholders, i.e. owners, the public and those responsible for public safety. On the other hand, the required risk levels should still allow construction and operation of these structures at feasible cost levels. To obtain this equilibrium structural damage assessment following accidents is an integral part of any risk assessment and serves to evaluate consequences of different hazards.

That is, the procedures and tools reviewed by Committee V.1 are essential tools for balanced design against hazards and for estimation of survivability after incidents have taken place.

The committee must be commended for presentation of a very valuable overview of different hazards for fixed and floating platforms, an excellent review of design principles for hydrocarbon fires and explosions, a new and rather complete material model database, and a benchmark study of the response of a strength element subjected to explosion loads.

Hopefully the Standing Committee decides to continue this committee for another three year period. During a coming term the committee will have a chance to place more focus on procedures to estimate the probabilities for the different hazards, to probabilistic distributions of the associated accidental loads, to recommend Risk Control Options for the different hazards, to give a schematic overview of current regulations and recommendations, and to include a final section which gives advice on needed future research and development to improve safety.

1.2 Floor and Written Discussions

1.2.1 James Underwood

Section 5 refers to three incidents of either UNDEX or surface explosions. In fact all three are the result of surface explosions alongside or from within the vessel. The same events are used again later in section 14, where it is clearer that none were damaged by UNDEX. Section 5 is entitled “Underwater Explosions” and I believe it is misleading to include these examples here. The most obvious source for examples of UNDEX damage would be military conflict torpedo or mine strikes. Possible examples include sinking of merchant vessels attempting to reach the UK during WWI, strikes during the Pacific War post WWII; sinking of ARA GENERAL BELGRANO, 1982.

Section 11 refers to a Wikipedia reference for defining freak waves. More recognized references are listed below and may be more appropriate.

Kharif and Pelinovski (2003): The amplitude criterion of freak waves: its height should exceed the significant wave height in 2 – 2.2 times.

Clauss (2002) presents published wave data where $H_{max}/H_s > 2.15$.

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

Bennett *et al.* (2002) utilises the assumption that the freak wave height is at least twice the average wave height for experimental investigation of freak waves on ships.

In Section 13.1, it is noted that information on the effects of flood water on the loads seen by a vessel is not very extensive. Although not currently published, PhD research work being undertaken by Mr Daniel Fone at UCL (University College London, UK) under the supervision of Dr Kevin Drake may add to this area in the near future.

1.2.2 Mirek Kaminski

My question refers to Figure 28 of the report. It seems that in all cases, the frequency content is the same. This indicates that the stiffness and mass were modelled in the same way. A good practice is to carry out a non-linear, transient analysis step-by-step in order to understand the source of possible differences. My question is if the committee did a step-by-step analysis e.g. by carrying out first a quasi-static response. If so, was the difference already present at this level of analysis?

1.2.3 Kristjan Tabri

Figure 28 in the report presents significant difference between the simulations conducted by different parties even though often the same software is used. Is the difference due to the different application of loads or is it rather due to this response?

1.2.4 Erkan Oterkus

Finite element analysis is not a suitable tool for failure analysis and damage analysis, because of its mathematical structure. There are some available tools such as VCCT, cohesive zone model, X-FEM, etc. These techniques are either questionable or require very talented engineer. Even the Abaqus cohesive zone element implementation is not accurate. I personally recommend a new technique called "perdynamics" which is a natural way of doing failure analysis. Although it is a new technique, it has been used at Boeing, Sandra National Laboratories, etc.

1.2.5 Enrico Rizzuto

While complimenting the Committee Members for their work, I note that, in my view, they concentrated more on the phases of the damage generation (and the preceding ones) more than on those following the accident and generating consequences. The name of the committee is a bit misleading in that, but the text of the mandate covers also the phases following the accident, containing an explicit reference to risk assessment.

Prof. Tendrup Pedersen in his official discussion pointed out the need for a probabilistic characterization of loads at accident to assess risk. My point is that, to assess consequences (i.e. the other 'ingredient' of risk assessment) it is also needed to identify the scenarios in which the postaccident situation may evolve. This would imply to characterize, in addition to the damage, also other relevant parameters (and inherent probabilities). For example: duration and severity of the exposure to sea loads (after the accident), the wind and its direction, the residual capacity of operation of the unit, etc.

These scenarios are quite important from a design point of view and it is crucial that they are identified as those generating the larger risk contribution for the system under analysis. An inadequate selection may result into checking unrealistic situations (possibly with low probability of occurrence and therefore non-significant contribution to risk).

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

The definition of these design scenarios could be the result of an overall risk assessment, comparing different escalating situations and identifying those contributing more to the total risk for the system. May I ask if the Committee supports this viewpoint?

1.2.6 References

Bennett S, Hudson D, Temarel P. (2012). A comparison of abnormal wave generation techniques for experimental modelling of abnormal wave-vessel interactions. *Ocean Engineering*, Vol. 51; pp. 34-48.

Clauss G. (2002). Dramas of the sea: episodic waves and their impact on offshore structures. *Applied Ocean Research*, Vol. 24; pp. 147-161.

Kharif C, Pelinovsky E. (2003). Physical mechanisms of the rogue wave phenomenon. *European Journal of Mechanics - B/Fluids*, Vol. 22, Issue 6; pp. 603-634.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

2.1.1 Introduction

The Committee members wish to thank Prof. Pedersen for his efforts reviewing the report, his helpful comments and his kind remarks.

The report covers a wide range of hazards which can lead to structural damage. To give a complete review of the advancements within these areas is a tremendous task. The Committee has been forced to prioritise the topics to be included and its members agree that there is a lot of further work to be done.

2.1.2 Safety Measures to be Taken During the Design Phase

In the last two decades risk analysis has become an advanced engineering tool. In offshore development projects it plays a key role in joining identification of hazards and guidelines for design against these hazards.

2.1.3 Probability of Occurrence

The Committee members agree that except for the section on hydrocarbon explosions and fires the report gives very limited information on procedures for estimation of the probability of the different hazards and distributions of the loads involved. Only very limited information on the determination of probabilities for other hazards than hydrocarbon explosions and fires currently is available. Therefore, Prof. Pedersen's recommendation to focus on such work in the future is supported and welcomed. This committee's focus was on damage assessment following accidents rather than on the estimation of probabilities of different hazards.

2.1.4 Risk Control Options

The problems associated with risk control options raised by Prof. Pedersen are an important observation. These issues should be included in a next committee mandate in the future.

2.1.5 Rules and Regulations

As for design codes specifying assessment tasks for evaluating accidental events, it is agreed that the risk assessment steps mentioned by Prof. Pedersen are useful for the designer, and they are also part of the ISO 19902 standard which is thoroughly reviewed in the Committee's report.

Recent international development is to use semi probabilistic design standards such as ISO 19902 and Norsok N-004, while the use of WSD standards is discouraged. This is

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

also reflected by API which now uses the ISO 19902 standard with additional national information as their API LRFD standard in an API wrapper, and further by their decision to discontinue the API WSD design standards.

Recommending certain design standards over others will always be somewhat subjective. However, the committee has carefully reviewed and commented on the Norsok N-004, and in particular ISO 19902. These are the committee's recommended design standards for fixed steel offshore structures. Generally, the recommendation is to use the ISO 19900 series of offshore standards whenever relevant.

It is agreed that the IMO procedure for formal safety assessment presented by Prof. Petersen can be a useful tool for the designer. It is interesting to notice that quite a similar procedure is recommended in ISO 19902 but in a somewhat different context (Clause 23 In-service inspection and structural integrity management).

Additionally, the fact that the suggested risk assessment steps are an integrated part of risk assessment and are based on national laws and regulations irrespective of design standards cannot be overlooked.

2.1.6 Assessment of the Level of Damage and of the Residual Strength of the Structure

Residual strength assessment and safety evaluation is not carried out by the crew onboard platform because, as Prof. Pedersen remarked, there is no time for it in case of accident. It is the platform operator who assesses the damage based on the engineering resources from the design phase. It needs to be verified if the accident has been covered by the design hazard report. In case of larger accidents the structure is probably damaged and the crew evacuated, and the focus must be on the possibility of saving it or the necessary repairs.

2.1.7 Hydrocarbon Explosions and Hydrocarbon Fires

The Committee agrees with Prof. Pedersen about the need for large-scale experimental sites providing computation model validation.

As for the problem of discrepancy between the contractor dependent estimates that different analysts come to, more benchmarking needs to be done to verify differences and standardize quantitative risk assessments of the risk associated with hydrocarbon explosions and fires.

2.1.8 Underwater Explosions, Illegal Activities Like Use of Explosions and Projectiles

It was the Committee's opinion that Section 5 "Underwater Explosions" and Section 14 "Illegal Activities like use of Explosives and Projectiles" should remain separate due to the added load possibilities from terrorist events. It would be highly unlikely that an UNDEX event would be used in a terrorist attack. The more likely attack would be in the way of an air blast or a surface blast, as was used on the USS Cole.

Frequencies of underwater explosions are very difficult, if not impossible, to accurately predict. However, the load distributions could be determined from a series of analyses with various charges and standoffs. It is true, though, that the sources of an underwater explosion could be numerous especially in offshore oil platforms, as was seen with the Deepwater Horizon. It is very unusual that a terrorist attack would include an UNDEX event, surface would be the most probable with fast crafts or air blast.

Describing procedures to determine the structural response associated with different given underwater explosions is challenging due to limited literature, but not impossible. It is a concern that the experimental results are fairly limited. However there are

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
`http://www.stg-online.org`

several sources, such as DRDC which will, and has, openly published experimental results in journal papers and reports. There has been very few UNDEX experiments pertaining to definite structures, such as ships or offshore platforms, and they are generally performed with plate and panel specimens. This is mainly due to cost and environmental considerations.

The Committee supports Prof. Pedersen's view that design against structural damage due to underwater explosions could be a subject for further work by the committee. There is a move toward looking at stiffened panels in different configurations. Stiffeners can actually reduce the UNDEX resistance of a panel and this is an area which could be further developed.

2.1.9 Wave Impact, Wave-in-Deck, Freak waves and Tsunamis

The Committee has not seen it as a central matter to decide whether the wave impact (mainly floaters), wave-in-deck, freak waves and actions from tsunamis should be presented in one or two sections. The thinking behind using two sections in the Committee's report has been that freak waves and actions from tsunamis represent a special group of potential hazards characterized by the most immature understanding. However, the Committee may consider merging the two sections in future work.

2.1.10 Dropped Objects and Ship Impact on Offshore Structures

The load assessment follows a case-by-case risk analysis, which certainly includes a probabilistic assessment. However, due to the page limit of the chapter only the overall procedure and the available tools are presented, as well as conservative measures to treat such events.

Concerning the ship impact only the analysis relevant steps are presented as well as a discussion on the complexity of the event and the need to analysis all phenomena involved unless it is known that certain aspects can be neglected. The chapter does however not claim that the worst case scenario needs to be analysis, moreover this is typically not know and therefore it shall be identified in order to design the structure against the most probable actions.

The focus of this section lies with the as accurate as possible assessment of the incurred consequences considering the relevant effects. Hence, an integrated approach should be favoured over the uncoupled simulation, especially because a fully coupled dynamic collision simulation can be run using LS-DYNA in a couple of hours today. However, simplified procedures will be needed for a while to limit the amount of high-fidelity assessments as much as needed. Consequently, this will allow the identification of the highest energy scenario and thereby allow designing the structure for the most probable actions, which must not necessarily be the highest energy case.

The Committee supports Prof. Pedersen's suggestion that for future committee work within this area it is recommended that the committee reviews risk based assessment approaches which makes it possible also to evaluate risk control options in the form of increased crashworthiness of offshore structures.

2.1.11 Flooding

The Committee reports the RAO for torsional moments of an intact and a damaged ship in beam waves and torsional loads, according to Prof. Pedersen, usually play a very small role for the overall stress level on hull girder. However, a reference was found which reported a significant change of the hull girder load especially with respect to the torsional moment. The Committee would also like to state that in case of a

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

severely damaged structure the cross section of the hull girder, in way of the damage, loses its 'closed cell' properties and may therefore become more vulnerable to torsional loads.

Another effect of flooding considered in the report is sloshing loads in flooded compartments. The Committee considered it interesting to report on these as in some flooding cases it may be beneficial to deliberately flood an additional compartment in order to improve the hydrostatic stability of the ship or reduce the still water hull girder loads. When this involves a relatively large compartment, e.g. an engine room, apart from the water head on bulkheads the dynamic effect due to sloshing is worth considering because it may significantly increase the momentary load on such bulkheads. The importance of sloshing in partially filled cargo tanks, marked as worth consideration by Prof. Pedersen, is acknowledged in the report.

2.1.12 Material Models for Structural Analysis

The Committee thanks Prof. Pedersen to clearly outline the potential of using material models in numerical simulations. The intended purpose of this section was to provide structural analysts with example input cards for the recommended material properties to a commonly used explicit finite element program and the Committee hopes that it will find its users.

2.1.13 Benchmark Study: Stiffened Panel Subjected to Explosion Loads

Recently a significant amount of time and money has been spent on risk assessment and a number of studies document explosion and fire loads. The knowledge in this field today is complete and precise. In the same time design processes are very much underdeveloped and in most cases use rough and imprecise techniques – linear tools. The Committee observe that the gap between accuracy of predicting loads and predicting structural consequences of these loads.

The Committee concludes that work needs to be done to control consequences of accidental loads in design process and improvement of design tools.

2.1.14 Closure

The Committee fully supports Prof. Pedersen's view that the work needs to be continued, with the mandate shift from the assessment of damage after accidents to damage prevention by the implementation of risk analysis results into structural design. There is still a lot of work to be done in the field of hazard engineering.

2.2 Reply to Floor and Written Discussions

2.2.1 James Underwood

The examples of USS Cole, Superferry 14 and Limburg are mentioned clearly as surface explosions in the first sentence. The Committee do not suggest that these attacks were underwater detonations, they are solely mentioned in order to stress the extent of capability on behalf of the perpetrators; their modus operandi. The remaining part of the first sentence says: "...very likely to predict similar attacks on offshore structures and platforms" in order to bridge the introductory sentence with Par. 5.1 where the reader embarks on the specifics of UNDEX. Detonations at the waterline and below the waterline (at close proximity only) share similar characteristics, like cavitation, brisance, and focusing, hence the aforementioned examples in the introduction. If perpetrators can get close enough to the target to detonate at the waterline, it is fair to say that UNDEX is well within their capability although it is much more

18th International Ship and Offshore Structures Congress (ISSC 2012) - W. Fricke, R. Bronsart (Eds.)
© 2014 Schiffbautechnische Gesellschaft, Hamburg, Germany
http://www.stg-online.org

complicated to deploy hardware underwater. It is believed that this scenario would likely include SCUBA divers who would attach the explosive charge to the hull/leg. It is difficult to imagine perpetrators towing a mine as these are bulky and difficult to transport. Failed attacks where the dingy sank under the weight of its own explosive charge have been reported.

Examples where naval vessels were hit and sunk by limpet mines or torpedoes are numerous, but they were not included here as the focus of Committee V1 is on damage assessment following accidents. Acts of war are not accidents. Some may even argue that the attack on USS Cole was not a terrorist attack as explosive loads are among the design loads of warships.

The Committee wishes to thank Mr. Underwood for additional references regarding the freak waves and flooding.

2.2.2 Mirek Kaminski

Finite Element models used in the study (developed by all members separately) were based on the same 3D CAD model ensuring the same stiffness and mass of the models. The step-by-step approach/benchmark study performed is presented in the report. Static analysis was carried out to document sensitivity to different FE sizes. This was not reported in the benchmark study presentation.

2.2.3 Kristjan Tabri

For the same solvers used in the benchmark study, the differences in transient and final deformations are mainly due to different approximation of pressure load and slight differences in the boundary conditions applied.

2.2.4 Erkan Oterkus

The Committee wishes to thank Dr Oterkus for his comments. Establishing specialised committees to further investigate advantages of this new method and report results to the ISSC will be suggested.

2.2.5 Enrico Rizzuto

The Committee wishes to thank Prof. Rizutto for his comments. All the comments and suggestions are supported by the Committee.

Indeed, Committee on Damage Assessment Following Accidents was mainly concerned with damage that can be controlled during design phase. In order to assess and quantify the effects of different hazards a Quantitative Risk Analysis is carried out that delivers Design Accidental Loads. These loads form basis for damage control and ensuring required residual strength. During accidents loads are rather undefined and the extent of damage is normally assessed by accident investigation. The requirements and scenario to be considered for the post-damage strength such as duration and severity of the exposure to sea loads (after the accident), the wind and its direction or the residual capacity of operation of the unit have recently been defined by design standards like ISO, Norsok or DnV.

We support the view that the post accidental loads scenarios could be assessed within the total risk analysis of structures. This concept has been successfully implemented into the design process of offshore installations. However, for the ship structures we still need international consensus for implementing these methods into design.

The Committee wishes to thank Prof. Rizutto for additional references for the subject.