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Damage Assessment Following Accidents - Official Discussion

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1. ISSC COMMITTEE V.1: DAMAGE ASSESSMENT FOLLOWING ACCIDENTS

1.1 Official Discussion by Preben Terndrup Pedersen (DTU, Denmark)

1.1.1 Introduction

It is a pleasure 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 prioritize 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

1.1.2.1 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.

1.1.2.1.1 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.

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

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.

1.1.2.1.2 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 minimizing 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 prioritize 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.

1.1.2.1.3 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.

Perhaps the report could have summarized 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 Fig.1.

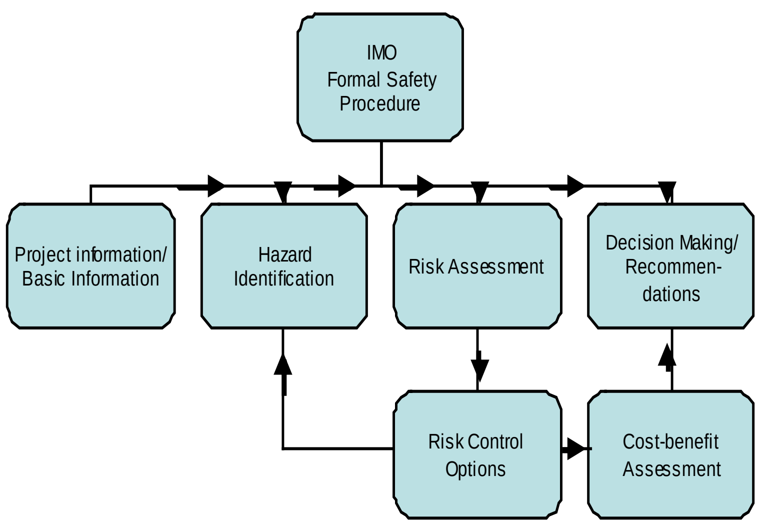

Fig.1. IMO’s Procedure for Formal Safety Assessment

1.1.2.2 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 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 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.

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 Fig. 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 modeling 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, aluminum, 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.

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.