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WP 10

IMPACT OF FREAK WAVES ON SHIP DESIGN PRACTICE

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ABSTRACT

Recently significant interest has been paid to abnormal waves, often called *rogue* waves or *freak* waves. These waves represent operational risks to ship and offshore structures, and are likely to be responsible for a number of accidents. This study summarizes findings of MaxWave WP 10 and discusses these extreme severe wave conditions in perspective to the existing design and operational criteria. It is primarily concentrated on ships, however, some aspects of offshore structures' design are also presented. Requirements for future research are formulated in order to use extreme/freak waves in response analyses and secondly to consider the use of freak waves in design procedures. Socio-economic consequences of possible revision of current practice are discussed and illustrated by some examples.

INTRODUCTION

The shipping as well as the offshore community is concerned with continuous improvement of accuracy of environmental databases and models for design and operational conditions. The rules, standards and guidelines are under continuous development and incorporate high-quality research. In the last two decades probabilistic analysis has contributed significantly to improvement of several environmental models and quantification of the data and model uncertainty. Further, ocean wave measurements from satellites combined with global wave and atmospheric numerical models have dramatically increased the accuracy and coverage of ocean wave information.

A close co-operation between the industry and academia through international organizations, EC projects and network, national research projects, and international conferences is important. It gives opportunity for exchange of the recent research results as well as for flagging problems the industry is faced with when applying them.

Over the last decades several studies have been reported concerning unexpectedly large and/or steep waves. Such waves have been denoted freak waves or rogue waves, giant waves, abnormal waves, the "one from nowhere". These waves are expected to represent design and operational risks to ship and offshore structures. Even though the existence of freak waves themselves has been generally not questioned, neither the occurrence of these waves nor their physical structure has been well understood. Particularly the ongoing EU research project: "Rogue waves – forecast and impact on marine structures" or "MaxWave" has made significant contributions to the understanding of such waves. An interesting question is to what extent these waves affect extreme loads on marine structures.

This study summarizes Work Package 10 of the MaxWave project aiming at monitoring and assessing the possible impacts of the project findings on the relevant sector of science (design and oceanographic academia) and industry (shipping and offshore). Extreme severe wave conditions are discussed herein in perspective to the existing design and operational criteria. The study is primarily concentrated on ships, however, some aspects of offshore structures' design are also presented. Requirements for future research are formulated in order to use freak waves in response analyses and secondly to consider these waves in design procedures. Socio-economic consequences of possible revision of current practice are discussed and illustrated by some examples.

NOMENCLATURE

Hs: significant wave height

P_F: probability of failure

β: reliability index

ULS: Ultimate Limit State

FLS: Fatigue Limit State

SLS: Serviceability Limit State

ALS: Accidental Limit State

SRA: Structure Reliability Analysis

GCAF: Gross Cost of Averting a Fatality

NCAF: Net Cost of Averting a Fatality

CEA: Cost Effectiveness Analysis

CBA: Cost Benefit Analysis

IACS: International Association of Classification Societies

CURRENT DESIGN PRACTICE

When discussing impact of severe extreme waves on the marine structures a distinction needs to be made between ship structures and offshore structures. Even though the same basic principles prevail for hydrodynamic loads on ships and offshore structures, actual problems and methods for assessing these loads in the design stage are quite different. Further, different wave data and to some extend different wave models are used for defining design and operational conditions for these two types of structures. The state-of-the art review on wave knowledge in current design practice is given in the MaxWave report, Bitner-Gregersen and Hagen (2002).

Sailing ships exclude vessels that operate at a fixed locations (e.g. FPSO's). A salient feature of ship hydrodynamics is the nonzero forward speed. Further, as ships are sailing they are exposed to varying wave environment. This fact need to be taken into consideration when specifying design and operational criteria. Recently the shipping industry has started to apply risk based methods for the design and safety assessment of ship structures. These methods are based on modern reliability approaches and quantify in a probabilistic way the uncertainties in the different parameters that govern the structural design and combine them consistently in order to derive the safety factors.

Unlike ship structures, offshore structures normally operate at fixed locations and often represent a unique design. Therefore site specific environmental data are usually required. The risk based procedures based on the modern reliability methods are widely spread within the offshore sector.

To have a clear and consistent approach for determining design loads, we need to define the limit states categories and the scenarios we design for. In the offshore industry the following well proven terminology is applied which is starting to be accepted also within the shipping industry:

Ultimate Limit State (ULS) corresponding to the maximum load carrying resistance.

Fatigue Limit State (FLS) corresponding to the possibility of failure due to the effect of cyclic loading.

Serviceability Limit State (SLS) corresponding to the criteria applicable to normal use or durability.

Accidental Limit State (ALS) corresponding to the ability of the structure to resist accidental loads and to maintain integrity and performance due to local damage or flooding.

The design practice is moving towards a more consistent probabilistic approach, for example: extremes are determined for a given return period (e.g. expected lifetime of the structure).

Offshore structures are designed for a specific location and for the 100-year wave load with appropriate safety factors in ULS. Alternatively in a reliability base design a target annual failure probability is defined dependent on safety class. In addition to adequate structural strength there must be enough room for the wave's crest to pass beneath the deck where vulnerable and safety critical processing equipment is installed. But even if bottom-mounted platforms are designed with a safe deck clearance, this maybe reduced with time due to platform settlement. Norwegian standards require a sufficient air gap to ensure that a 10 000-year wave does not endanger the structure integrity (ALS), see NORSOK Standard (1999). Thus rare wave events occurring with the annual probability of 10^{-4} are taken into account in ALS.

The majority of ocean-going ships are designed to the North Atlantic wave environment, which is regarded as the most severe. Classification Societies' (CS's) Rules, in fact, permit the design of ships for restricted service, in which case reduced design loads apply. While in principle open to all ship types, the use of such restricted service is in practice mainly confined to high speed vessels. Ship structures are designed today for a 20-year return period (ULS). The long-term distribution of the wave climate is considered based on which the corresponding distribution of ship loads and responses are derived. Freak waves are not explicitly checked in current design procedures.

Attention to abnormal wave conditions has been signalized by Buckley (1978). Later Faulkner with support from Buckley (Faulkner and Buckley (1997)), has suggested the use of survivability design. The profession at large has put more attention to rogues waves in the last decade when more observations have become available. So far freak wave conditions are not explicitly taken into account in CS's Rules for design, due to insufficient knowledge about the freak waves and ship response to them as well as to lacking knowledge about the probability of ships encountering such waves. Some answers will be given by the ongoing EU MaxWave project, where International Association of Classification Societies (IACS) is member of the Senior Advisory Panel (SAP). The question is whether these answers will be sufficiently accurate to adequately account for freak waves in design practice? ALS against abnormal waves is generally less critical for ship structures than offshore structures as ships may choose an optimal route in order to avoid bad weather conditions. Software and services exist to support ships with determining a route in accordance with SLS. One of these is Global Maritime Distress and Safety System (GMDSS) operating by the International Maritime Organisation (IMO).

IMPACT OF FREAK WAVES

Herein particular attention is given to design loads for ULS, SLS and ALS. FLS is not included in the present discussion as it is not expected to be significantly affected by freak waves.

ULS

The design basis in IACS Unified Requirements is a sea state with 20-year return period in the North Atlantic in which the expected maximum response is calculated. In a long-term approach this approximately corresponds to 10^{-8} probability level of the response to be exceeded during a single long term response cycle, calculated with an equal probability on all headings.

To increase the clarity with respect to what is considered during the design phase, scenario thinking would be beneficial. E.g. one of the following three scenarios will be governing for the design of a vessel depending on what part of the structure is being designed:

Scenario 1:

The ship is experiencing a 20-year sea state. In such a sea state the shipmaster will steer the ship up against the wave, and the ship will experience head waves in a severe sea condition.

Scenario 2:

The ship is operating in quartering/beam/stern seas according to an operational profile with at limiting wave height in the different wave headings. For more slender ships, the speed effect will have to be considered as well as wave headings.

Scenario 3:

Loss of steering and/or propulsion results in a beam sea condition, depending on the wave condition the loads in such a scenario will be governing for the design. This may alternative be considered as ALS depending on probability of occurrence of this situation.

To what extent the ULS category will be affected by introduction of freak waves in design will depend on the probability of occurrence of these waves. At present there is a discussion about increase of return period on design loads for ships from 20-year return period to 25-year return period. That means increase of design Hs by only 1.4% from ca. 16.0m used today. It should be noticed that an increase of the environmental criteria does not necessary imply design for freak waves. Freak waves may occur in lower sea states than the design ones. Both the Draupner and the Ekofisk events, discussed e.g. by Bitner-Gregersen (2003), Gunson and Magnusson (2003), represent a freak wave according to the criteria suggested in the literature (see Haver and Andersen (2000), $C_{max}/H_s>1.2$ within a 20-minute sea elevation time series (C_{max}=maximum crest)). None of these freak events were observed during the design sea state. A 100-year Hs for both the Draupner and the Ekofisk offshore field is aproximately 14m while the freak event at Draupner was registered when the significant wave height Hmo=11.92m while at Ekofisk Hmo=9.17m.

As indicated by Toffoli et al. (2003) cross, opposing or following seas may play a role when freak waves are generated. Further, rapidly changing metocean conditions (wind direction) can create dangerous situations. This could have impact on specification of ULS criteria for the scenario 2 as well as SLS. Again , the results of the MaxWave study do not allow to draw firm conclusions. More research is called for.

SLS

A proper specification of operational criteria is essential both for ship and offshore structures. Ships need to determine an optimal route in accordance with SLS. The MaxWave project, Savina et al.(2003) in cooperation with the Joint Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Maritime Safety Services have suggested to include sea-state (total sea, if possible information about swell) as a mandatory parameter and dangerous sea-state/rogue waves as a potential criterion for warning. This will be presented for formal adoption by the next JCOMM plenary session taking place in Halifax in June 2005. Wave criteria have not been proposed yet for the provision of Marine Safety Information (MSI) within GMDSS as operational methods, tools, and practices should exist before the provision of such information as mandatory and on a global basis. Warning criteria against rogue waves will remain a high priority topic within JCOMM. As the MaxWave partner Meteo-France will implement a warning system against rogue waves on a pre-operational basis by the end of 2003. The warning system includes two parameters: a cross sea index (combination of directional spreading and significant wave height) and the steepness index (average wave steepness), see Savina et al.(2003). The proposed system is under evaluation by end-users.

The shipping industry welcomes the system on ship boards when it is validated.

ALS

Impact loads due to rogue waves maybe severe events both for local and global analyses. For offshore structures the most serious risks related to freak waves seems to be wave crest impact and platform pushover overloads. Local wave loads like green water on deck, wave runup and deck slamming will be particularly affected by freak waves. ALS against severe extreme waves is included in the Norwegian offshore standards. A question is to what extent the existing wave models are able to capture freak events and to predict the 10 000-year return period wave satisfactory? The Draupner platform even though designed for ALS experienced damage of the deck equipment when the January 1, 1995 freak wave hit the platform. On the other hand analyses of the seakeeping behaviour of a semi-submersible in the Draupner New Year Wave carried by Clauss et al. (2002) showed that the standard ULS procedures for predicting maximum response from frequency-domain analysis are quite reliable and coincide well with the time domain simulations.

As shown by Prevosto and Bouffandeau (2002) and Hagen (2002) the probability that the maximum predicted crest at Draupner within a 20-minute period exceeds the actually measured maximum of 18.5m, is low when the commonly used second order wave models are applied. This was confirmed later also by Bitner-Gregersen (2003) who demonstrated that even though the 2nd order models do not capture extreme freak events like the Draupner one they predict satisfactory less severe freak waves (e.g. the Ekofisk freak wave) when 6-hour sea state duration is applied. It was stated also that the sea state duration represents an important characteristic for prediction of freak waves. Further, several laboratory investigations (e.g. the University of Oslo) have demonstrated that kinematics associated with a freak wave is significantly different from the traditional 2nd order kinematics. The wave particle velocities are much higher, yielding increased structural loads.

Consensus is needed to be reached within the offshore industry on wave models for prediction of freak waves, critical freak wave parameters (e.g. maximum crest, wave steepness, wave asymmetry, wave spectrum,) and design scenarios to be included in ALS.

The operational risks for ships due to freak waves would be primary structural overload, loss of watertight integrity and capsizing. The following wave loads on ship structures are particularly affected by freak waves:

- Green water on deck
- Bow slamming
- Bottom slamming
- Impact on superstructure and bow.

An unfavourable combination of pitch motion and steep incoming wave can lead to large impact forces in the bow area causing excessive local structural damage as for the *Michelangelo* and *Wilstar* ship incidences. As shown by Pastoor et al. (2003) for the simplified wave freak case analysed impacts occur on the ship superstructure and the bow when plunging into the freak wave as well as upon re-entrance in the water. Wave steepness, both the front and aft part and horizontal velocities are critical parameters.

Fonseca et al. (2001) and Pastoor et al. (2003) have demonstrated the importance for use of time domain codes to calculate wave-induced loads on ships in severe weather. Dynamic response, especially for floating structures, is the result both of the instantaneous wave action and the time history of both wave and body motions, see Pastoor et al. (2003). Two freak waves with equal amplitude but different shapes might give significant different responses. In order to improve hydrodynamic response prediction more information is required on the spatial description of freak waves in time and on the structures' behaviour in freak waves. The first is of paramount importance in order to simulate these waves with sufficient accuracy. Satellite data providing information on special profile of freak waves can contribute considerably to improving the present models. The MaxWave project has already made a large step forward to reach this goal, see Nieto Borge et al. (2003).

The following scenarios could be considered for ALS for ship structures due to extreme severe waves:

Scenario 1:

Structural overload due to freak wave

Scenario 2:

Flooding of vessel due to freak wave

A systematic investigation of hazards and consequences must be done prior to defining the relevant scenarios for ALS. In both scenarios the capacity is checked on intact structure. A capacity check of damaged structure may also be relevant for scenario 2.

FORMAL SAFETY ASSESSMENT

As already mentioned, there is still a lack of information regarding freak waves, their frequency of occurrence and physical behavior. In this and the following section, a framework for how to handle the freak wave phenomenon as more information becomes available is presented.

Structural failure of ships may result in risk to human life, severe environmental damage, and large economical consequences. Therefore ship structures must be designed with adequate safety and reliability, and their designs must be acceptable from an environmental and economical point of view. For ship structures in particular, the acceptable safety level is to a large extent ensured by complying with rule requirements developed and set forth by classification societies as agreed with other stakeholders.

According to the Lloyds "World Casualty Statistics" the yearly average rate of number of ships losses has an evident trend of decreasing while the yearly average rate of gross tonnage lost is much more stable in the last 55-years, see e.g. Guedes Soares et al. (2001). It is much to gain by improving design and safety of ships. Less pollution is also an obvious benefit of better design. As shown by Bitner-Gregersen et al. (1997) the risk due to environmental pollution maybe of the same order as the risk due to loss of crew and economic loss. The disasters like the tanker "Erika" and the tanker "Prestige" should not repeat.

The traditional format of Classification Societies' Rules is mainly prescriptive, without any transparent link to an overall safety objective. IMO (1997, 2001) has developed Guidelines for use of the Formal Safety Assessment (FSA) methodology in rule development which will provide risk-based goal–oriented regulations. FSA will be used when implementation of freak waves in design practice is considered. Principles of FSA illustrated by two examples are given below. Although freak waves are not explicitly analyzed the same methodology can be applied considering freak waves, where the associated uncertainties are taken into account in a consistent way.

Formal Safety Assessment consists of five inter-linked steps given in Table 1. When performing FSA for ship structures it is beneficial to apply Structural Reliability Analysis (SRA) in the risk assessment (step 2) and the cost-benefit assessment (step 4).

Use of the gradually adopted 1st principle approaches in design can provide by help of SRA failure probabilities not sufficiently given by ship accidental databases. Still sufficient information about physical and statistical freak wave models and uncertainties related is necessary. Lacking knowledge can be compensated by use of SRA Importance and Parametric Sensitivity Factors.

Table 1: Steps of Formal Safety Assessment (FSA).

Steps	In layman terminology	Professional language
1	*What might go wrong?*	Hazard Identification
2a	*How often or how likely?*	Frequencies or probabilities
2b	*How bad?*	Consequences
2c		Risk = Probability× Consequence
3	*Can matters be improved?*	Identify risk management options
4	*What would it cost and how much better would it be?*	Cost Benefit Evaluation
5	*What actions are worthwhile to take?*	Recommendation
IMO	What action to take?	Decision

Frequencies of casualties associated with loss of vessels maybe derived from accident databases (e.g. LMIS). However, the existing databases do not include sufficient information to allow the identification of the areas in which accidents due to abnormal waves occurred. The category 'heavy weather' or 'bad weather' applies to the first event occurred, and does not record other consequences that may have occurred in the same accident. Further, the LMIS database regarded as the most reliable, includes ship larger than 100 gross registered tons, leaving out a major part of shipping vessels. In the period 1995-1999 only 2 cases were registered as freak events in the database. Locations of ship accidents due to severe weather extracted from the LMIS database are shown, e.g. by Guedes Soares et al. (2001), Toffoli et al. (2003).

It should be noticed that as the result of current design practice such an accident database would usually reflect an average world-wide trade and the number of casualties is then expected to be lower than the number for the North Atlantic being the basis for design. Here SRA is very useful.

Within modern reliability theory, Madsen et al. (1986), Skjong et a. (1995), the failure criterion is expressed in terms of a limit state function, g, which may have any form in general and is a function of N random variables $\mathbf{X}=(X_1,X_2,...X_N)^T$ that describe the failure set (g<0), the failure surface (g=0), and the safe set (g>0). Thus, the probability of failure is

$$P_F = P(g(X_1, X_2, ..X_N) \le 0) \tag{1}$$

with the corresponding reliability index β defined as

$$\beta = -\Phi^{-1}(P_F) \tag{2}$$

where Φ denotes the standardized cumulative normal distribution function (see Table 1).

Note that a reliability index obtained by a structural reliability analysis is a nominal value, dependent on the analysis models and uncertainties included, rather than an absolute reliability value, which may be given a frequency interpretation. This is a limitation, which implies that target reliability indices cannot, normally, be specified on a general basis, but only case by case for individual examples.

There are several ways of determining a target reliability. In cases where similar structures exist, one may execute structural reliability analysis and thereby determine the inherent reliability level, see Bitner-Gregersen et al.(2002). Under the assumption that designs carried out in the past are optimal with respect to safety, environment and economy, such a calibration to past practice may be used to establish what the target reliability level should be.

Alternatively, the target reliability may be based on accepted decision analysis techniques or taken in accordance with the tabulated values provided by the DNV Classification Note 30.6, DNV (1992), see Table 2, in which the target reliability depends on the consequence and nature of failure.

Table 2: Annual probabilities as recommended by DNV CN 30.6 (1992).

Class of failure	Consequence of failure	
	Less serious	Serious
Redundant	$P_F = 10^{-3}$ $\beta = 3.09$	$P_F = 10^{-4}$ $\beta = 3.72$
Significant warning before the occurrence of failure in a non-redundant structures	$P_F = 10^{-4}$ $\beta = 3.72$	$P_F = 10^{-5}$ $\beta = 4.27$
No warming before the occurrence of failure in a non-redundant structure	$P_F = 10^{-5}$ $\beta = 4.27$	$P_F = 10^{-6}$ $\beta = 4.77$

Both past practice reliability indices as well as tabulated values are expected to be applied when considering the use of freak waves in design procedures.

COST EFFECTIVENESS ANALYSIS

When the inherent reliability level in existing design codes is not acceptable from a safety, environmental and economical point of view an evaluation of life cycle costs and failure consequences might be required in order to set the target.

A Cost Effectiveness Assessment (CEA) is applied in an FSA to assess the marginal return of an additional Risk Control Options (RCO) by comparing the cost of implementation and the benefit of the RCO in terms of the risk that would be averted. A ratio called the Gross Cost of Averting a Fatality (GCAF)

$$GCAF = \frac{\text{Cost of RCO}}{\text{Reduction in PLL}} \qquad (3)$$

where PLL is the Potential Loss of Life (Expected Loss) can be used as a criterion. Alternatively, as shown by Skjong and Bitner-Gregersen (2002), the Net Cost of Averting a Fatality (NCAF) defined by subtracting eventual economic risk reduction from the cost of the RCO.

$$NCAF = \frac{\text{Cost of RCO - Reduced Economic Loss}}{\text{Reduction in PLL}} \qquad (4)$$

can be a satisfactory tool for comparison of different RCOs.

Note that both a net cost of measure and a reduction in fatality rate refer to annual values. A number of fatalities (loss of life) can be extracted from the ship accident data available in e.g. the LMIS database.

The upward limiting value for NCAF (the optimum amount of money to spend to avoid a fatality) can be evaluated as shown by Skjong and Ronold (2002) by help of the Life Quality Index (LQI). The NCAF value used e.g. in the various bulk carrier studies (e.g. IACS, 2001) as an acceptance criteria is in the range \$1.5 to \$3 million as recommended by Norway (2000).). In these studies this corresponds relatively closely to 10^{-4} annual probability of failure, as recommended in DNV (1992).

Below examples of the use of Cost Effectiveness Analysis (CEA) and Cost Benefit Analysis (CBA) as a supporting tool for choice of the safety levels are presented. The first one is concerned with hull girder collapse (global loads) while the second one with bottom slamming (local loads), both central for assessment of freak wave impact on design practice. Note that increase of the calculated safety levels reflects increase of the wave criteria.

A cost effectiveness assessment of the safety in a design code for an long oil tanker has been carried out by Skjong and Bitner-Gregersen (2002). The hull girder collapse (ULS) in the North Atlantic wave climate has been considered. Herein some of the results are discussed. The reliability level inherent in the current rules, has been quoted to be β=2.4 ($P_F = 0.6 \cdot 10^{-3}$) for flat-bar-profiles and β=3.4 ($P_F = 2.7 \cdot 10^{-4}$) for L-profiles at approximately the same cost of the ship deck (L-profile slightly higher). For comparison the total loss of oil tankers due to foundering (not necessary the hull girder collapse) from the LMIS Data Base is $3 \cdot 10^{-4}$ (data from 1992-97).

The cost of average ship deck as a function of reliability index beta is given in Figure 1, indicating that the L-stiffeners are more beneficial to be used than flat bar profiles (see also Bitner-Gregersen et al. (2002)). A CEA analysis has been performed in order to establish the target reliability level under assumptions that

- a loss of an oil tanker with 50% of the entire crew occurs in case of the hull girder collapse
- a ship life cycle is 20 years, the loss of the ship is expected to occur after 15 years of operation with a ship value of $ 21 million
- the value of the cargo is estimated at $ 11 million.

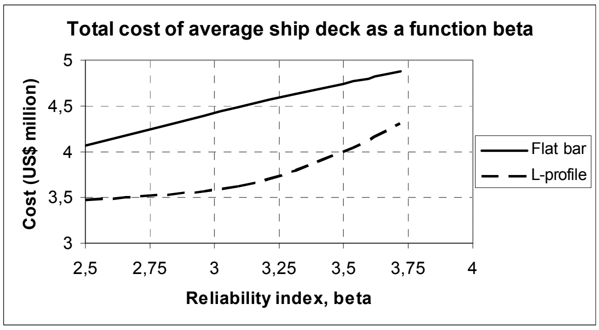

Figure 1 Total cost of average ship deck as a function of reliability index beta.

GCAF and NCAF values for increasing values of β are given in Figure 2. Note that the negative NCAF values implies that the economic risk reduction outweighing the cost of the RCO; i.e. the nominator of equation (4) is less than zero.

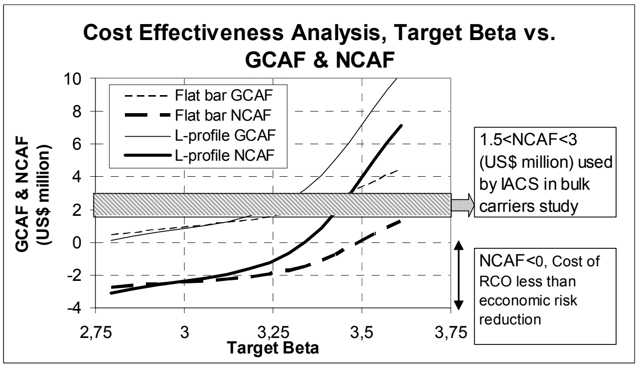

Figure 2 Cost Effectiveness Analysis, GCAF and NCAF versus target beta.

At first it may seem surprising that the target beta, based on CEA and a criterion of 1.5<NCAF<3 US$ million, is lower for L-stiffeners than for flat-bars; i.e. ~3.45 versus ~3.65. The reason for this is because the change in cost going from one reliability level to an increased level is higher for the L-profile solution (when beta is higher than ~3.1), see Figure 1. However, it should not be interpreted in the favour of flat-bar solution, since, as also shown in Figure 1, the total cost associated with this is significantly higher than the L-profile solution at any given reliability level.

Results from a Cost Benefit Analysis (CBA) for bottom slamming are shown in Figure 3. The more detail study is documented in Hørte et al. (2003). In this CBA the acceptance criteria is simply that the reduced economic loss is greater than the cost of RCO; i.e the nominator of equation (4) less than zero. Base on review of historical data bottom slamming incidents seem not be associated with loss of life. Hence, the losses are purely related to cost of damage in terms of direct cost of repair and opportunity cost (delay to ship).

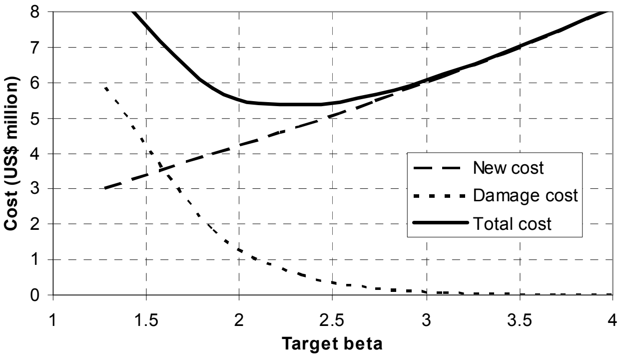

Figure 3 Cost benefit analysis results concerning damage due to bottom slamming.

Figure 3 shows how the total new construction costs of the forward bottom structure of altogether 20 vessels (mainly bulk carriers) increase in order to obtain a reduced annual probability of damage. It also shows the costs related to damage, i.e. the cost of damage multiplied by the annual probability of damage accumulated over the lifetime set to 25 years for all the ships, and how these costs decrease with reduced probability of damage. From a pure economic point of view, the optimum target level is when the total cost has its minimum; i.e. corresponding to a nominator of zero in equation 6. It is seen that this corresponds to a target beta around 2.3; i.e. an annual probability of damage of 10^{-2}.The owner may have additional considerations that are not accounted for in the model; e.g. appearance aspects and consideration regarding loss of reputation, which would tend to increase the target level.

The present example concerning bottom slamming includes a type of loading that is very relevant concerning freak wave design. However, at present the information related to frequency of occurrence of freak waves , wave shape and its effect on the ship response is associated with very much uncertainty. Studies can be performed conditional on such assumptions, but the lack of data is likely to make firm recommendations difficult to reach at the present time.

DISCUSSION AND RECOMMENDATIONS

The Norwegian offshore standards are taking into account extreme severe wave conditions by requiring that a 10 000-year wave do not endanger the structure integrity (Accidental Limit State, ALS). So far rogue waves are not explicitly account for in CS's Rules for design of ships, due to insufficient knowledge about these waves as well as due to lack of information about the probability of ships encountering such waves.

The study demonstrates that even though the EU research project: "Rogue waves – forecast and impact on marine structures" or "MaxWave" has made significant contributions to the understanding of freak waves more research is still called for before these waves can be introduced in ship design practice. Particularly, consensus should be reached about the probability of occurrence of freak waves.

It is shown that lacking information about freak waves in the existing accidental databases can, to some extent, be compensated by the use of the modern Structural Reliability Analysis (SRA). Formal Safety Assessment (FSA) methodology can provide regulations which are well balanced with respect to acceptable risk levels and economical considerations. Still improved knowledge about physical and statistical freak wave models and related uncertainties is necessary. Several research studies carried out recently by the industry (e.g. in regime of IACS) will be of great support when decision about accounting for freak wave in design practice is considered.

Although the existing safety level for global loads seems to be satisfactory some revision of the Ultimate Limit State (ULS) maybe considered depending on the probability of occurrence of freak waves.

Based on the current knowledge it is suggested to introduce ALS for ships accounting for rogue waves with two scenarios: structural overload and flooding of holds

Warning criteria against freak waves are welcome by the shipping industry to be introduced in ship weather routing services (Serviceability Limit State (SLS)). A large step towards reaching this goal is already made by the MaxWave project.

The issues presented in the present paper are currently discussed by the DNV operative units and DNV IACS and IMO representatives.

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