Managing Ship Structural Development

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ABSTRACT

The paper begins by considering the traditional methods of deriving ship structures before critically reviewing the use of the prescriptive approach. Possible alternative approaches are discussed and the basis of the safety case approach for developing ship structures is outlined. The application of this approach is illustrated for a European coaster vessel which has to meet IMO's probability damaged stability requirements. The main conclusions are that the enhanced safety case concept offers a method of focusing on areas of structures requiring attention and all the stakeholders should share responsibility for the development of effective structures.

Presentation

INTRODUCTION

Traditionally the structural arrangements of a ship have been derived empirically, with the hull providing both strength and water-tightness. In general, the structure of a ship is designed conservatively with wide margins to cater for unexpected loads. As experience is gained in the operation of a given type, similar future designs will use less steel. For example, the first batch of supertankers, built in the 1950's with a deadweight of over 100,000 tonnes were around thirty percent heavier than similar designs built in the 1960's.

This approach is quite understandable because these vessels were significantly larger than any previous ships and designers were extrapolating into uncharted regions. However, as computer technology advanced simultaneously with the development of software for ship structural analysis using finite element methods, it became possible to produce more "optimised" designs with few high stress areas and less weight.

An increased understanding of the effects of corrosion coupled with the occurrence of a number of high profile accidents, see for example [1], [2], has led to an emphasis on the need to have ship structures capable of withstanding higher external loads. It is interesting to note that in such situations naval architects, with their strongly technical background, are biased towards improving the design of the ship structure rather than exploring alternative solutions. To take ship collision as an example, designs are constantly being revised to withstand higher and higher dynamic loads that would be experienced on impact, see [3]. This approach, however, needs to be questioned for one key reason. It is true that the consequences of a two-ship collision can be extremely serious: for example, an outbreak of fire, one or both vessels sinking, pollution of the sea. The *risk* of a collision, however, is a function of both its consequences and the probability of the accident occurring. If the likelihood of a collision were reduced to a negligible level the present emphasis on minimising its consequences would not be justified.

A number of methods are available for reducing the probability of a ship collision, such as more effective training of the crew on ship handing, stricter adherence to shipping lanes, the installation of sensitive warning systems on board vessels, and the development of a positive safety culture. Furthermore, it is likely that these solutions would be less expensive than reducing the consequence of the possible collision. It should be noted, that cars are not designed to withstand side impact from another vehicle. Instead traffic lights are used to prevent that type of accident at road junctions.

In this paper the methods of developing ship structures are highlighted before a critical review of the prescriptive and goal-setting approaches to ship structural design. An example is then used to show how a managed approach can be used to drive ship structures when designers, prescribing organisations such as classification societies and intending users share responsibility for developing the structural design.

DEVELOPING SHIP STRUCTURES

In theory there are two possible ways of developing a ship structure so that it will fulfil its service requirements, and these are as follows:

a) To start from first principles using available information concerning the likely loads to be encountered by the ship during its operational life.

b) To use the information available from one of the classification societies, such as the American Bureau of Shipping (ABS), Lloyd's Register of Shipping (LR) or Det Norske Veritas (DNV). See [4] to [6] respectively.

In practice only the latter method would be appropriate, for the following key reasons:

- Time and effort required: For a shipbuilder to develop a design from scratch would take too long and cost too much. It would, therefore, not be sensible to adopt this approach unless there were exceptional reasons for doing so, e.g., the lack of information about a special type of ship.
- Lack of appropriate experience: Individuals or even a single organisations usually lack the data and the operational experience to be able to produce an efficient design.
- The amount of responsibility involved: If an organisation did decide to use this approach and had the expertise and resources to do its own structural design, it would be taking on sole responsibility for the structure's performance, and this would not be satisfactory to the ship operator/owner.

It should be noted that in using the rules of construction provided by a classification society, there is scope for selecting specific structural components in order to minimise, for example, weight, or building cost. In the case of a design which is not directly covered by published classification society rules, an organisation can call on the assistance of one of the societies in developing the structure for this particular design. Adopting this approach means that responsibility for the performance of a ship's structure is vested in the selected classification society. It is therefore useful to make a critical review of the merits and drawbacks of the approach.

USING THE PRESCRIPTIVE APPROACH

The basis of the existing method of developing a ship's structure is the prescriptive approach, i.e., one party prescribes the way in which a structure should be designed and the other party complies with this. If a ship is to be classified with one particular classification society, for example, the structure must be designed in such a way as to meet that society's rules.

The prescriptive concept is universally understood. In childhood, parents prescribe the code of behaviour, later the school teacher has a similar role, at college the rules of the institution must be kept if the course is to be successfully completed, and the majority of adults recognise that the laws of the land have to be kept. It could be said, in fact, that the prescriptive concept is ingrained in our thinking.

There are merits to this approach for deriving a ship structure, and the key ones are:

- Reference standards: A set of prescriptive rules provides a reference standard for a shipbuilder setting out to design and construct a new ship.
- Incorporation of experience: The rules for ship structural design have been formulated out of practical experience and reflect the state of the art at a given point in time. Ships, unlike aircraft, are built in very small numbers. The first ship of a particular design can be regarded as a "prototype" while the ocean acts as the test-laboratory, and the experience gained from its operation is fed back to refine the rules for future designs.
- Help for the inexperienced: Classification society rules are particularly helpful to young and inexperienced naval architects who are just starting on the design of ship structures. They may not, in the early stages, be able to derive an optimised structural arrangement from the points of view of weight or cost, but at least they can be assured that their design will produce a sound structure capable of doing the job it is designed to do.

There are, however, a number of drawbacks to the prescriptive approach, and the key ones are:

- Devolved responsibility: Responsibility for the derived structure is vested in the prescriber, i.e., the organisation that formulated the rules, and the designer simply has to comply with the requirements. If a failure occurs in operation the prescriber will introduce more stringent requirements. It must, however, be recognised that ships are operated by human beings, and it is impossible to anticipate in advance everything that could happen during their operation.
- The assumed "correctness" of the regulations: It is usual to assume that once a rule is published and implemented it must be correct, and any questioning of its correctness would be looked upon with disfavour.
- The emphasis on compliance: The emphasis of the prescriptive concept is on compliance. Once the rules have been correctly applied that is the end of the matter unless some kind of failure occurs. There is a tendency, therefore, to restrict efforts at improvement to the minimum and to review very carefully the results obtained from these.
- Keeping up-to-date: The rules tend to lag quite far behind advances in technology and it takes time to amass sufficient data to verify any proposed changes.
- Scope for innovative treatment: The prescriptive approach tends to stifle innovative solutions to structural design problems, and the existence of rules can deter designers from proposing novel solutions in order to meet clients' requirements.
- The impact of accidents: Rules are strong influenced by high profile accidents and significant changes

and increased stringency can be expected after any major marine accident. For example the oil spillage from the *Exxon Valdez* [1] led to the Oil Pollution Act 90 [7] which insists that oil tankers trading with the USA are constructed with double hulls.

POSSIBLE WAYS FORWARD

Taking into consideration the merits and drawbacks of the prescriptive approach to ship structural development, it would be sensible to ask whether there are might be alternative ways forward. Two possible ways forward are suggested and these are now considered under separate headings, as follows.

Giving Operators Guidance and Information.

In this approach booklets would be prepared to provide guidance to those whose work directly affects a given type of ship. This approach has been adopted by the International Association of Classification Societies (IACS). It has produced a series of carefully prepared booklets for various types of ship, such as the one entitled *Bulk Carriers – Guidance and Information on Bulk Cargo Loading and Discharging to Reduce the Likelihood of Over-Stressing the Hull Structures*, see [8]. This type of booklet is produced by a sub-committee of IACS member societies and is a step in the right direction. However their contribution in practice may be limited for the following reasons:

- Need for an organised approach: There is a need to devise ways by which the information can be channeled to those on the job and give them "tools" for putting the guidelines into practice.
- Effectiveness of communication: Naval architects tend to write such booklets for fellow-professionals, and to pay insufficient attention to the background knowledge of users and readers. For such booklets to be helpful to a range of users it is essential to present relevant information in the most comprehensive manner to specific sectors of the industry. For example, the implications of bulk cargo loading and discharge operations need to be explained simply and clearly to those responsible for such activity. They can be given in summary form to designers of bulk carriers.
- Involvement of all stakeholders: For important issues such as over-stressing the hull structure of a bulk carrier, it is crucial to involve all stakeholders so that the responsibility for decisions can be shared.

Use the Enhanced Safety Case Concept

In this approach use is made of the safety case concept together with the introduction of the idea of sharing responsibility among all the stakeholders. The basis of the concept will be outlined in the section before an illustrative example is used to demonstrate its application with enhancement to developing the structures of a coaster.

OPTING FOR THE SAFETY CASE CONCEPT

The alternative to the prescriptive approach is to use classification society rules as the starting point and to apply the "goal-setting" concept in order to examine specific areas, e.g., the structural design of hatches subject to high loading.. This approach is based on the application of the safety case concept, see [9] for a detailed description. The method, based on systems engineering, is used in connection with assessing the safety of a system or project for which there is little or no previous experience. In the context of ship structures the concept can be regarded as seeking answers to the five questions below once an outline design has been proposed.

Q1: What aspect of the structure could fail?
Q2: What are the chances/effects of them failing?
Q3: How can these chances/effects be reduced?
Q4: What should be done if a failure does occur?
Q5: How should structural integrity be managed?

These five questions can be translated into scientific terms as the following elements:

E1: Hazard identification
E2: Risk assessment
E3: Risk reduction
E4: Emergency preparedness
E5: Structural Integrity Management System (SIMS).

The relationship between these elements is illustrated in Figure 1, but it would be useful to highlight briefly the main features of each one.

Hazard Identification: The term *hazard* is defined here as "something that can lead to an undesirable outcome in the process of meeting the objective". In the context of ship structures "something" can range from large deformations and fractures to fatigue damage and the effects of corrosion. The task of identifying the hazards can be done with the help of methods such as "What If?", "Brainstorming", and "Failure Mode Effect Analysis" ("FMEA").

Risk Assessment: The task within this element is to determine the significance of the various hazards identified so that they can be placed on a scale which normally comprises intolerable, tolerable and negligible regions. The boundaries of these regions are not fixed but are determined by responding to what is "acceptable" to society at a given point in time. For example, from the environmental point of view, what was regarded as an adequate thickness for hull plating thirty years ago many not be acceptable in the 21st century. Risk assessment may be done in a number of different ways, ranging from qualitative methods drawing on ship designers' experience and making use of risk matrices, to quantitative ones involving the modelling of consequences and the analysis of probabilities of occurrence by means of techniques such as event and fault trees.

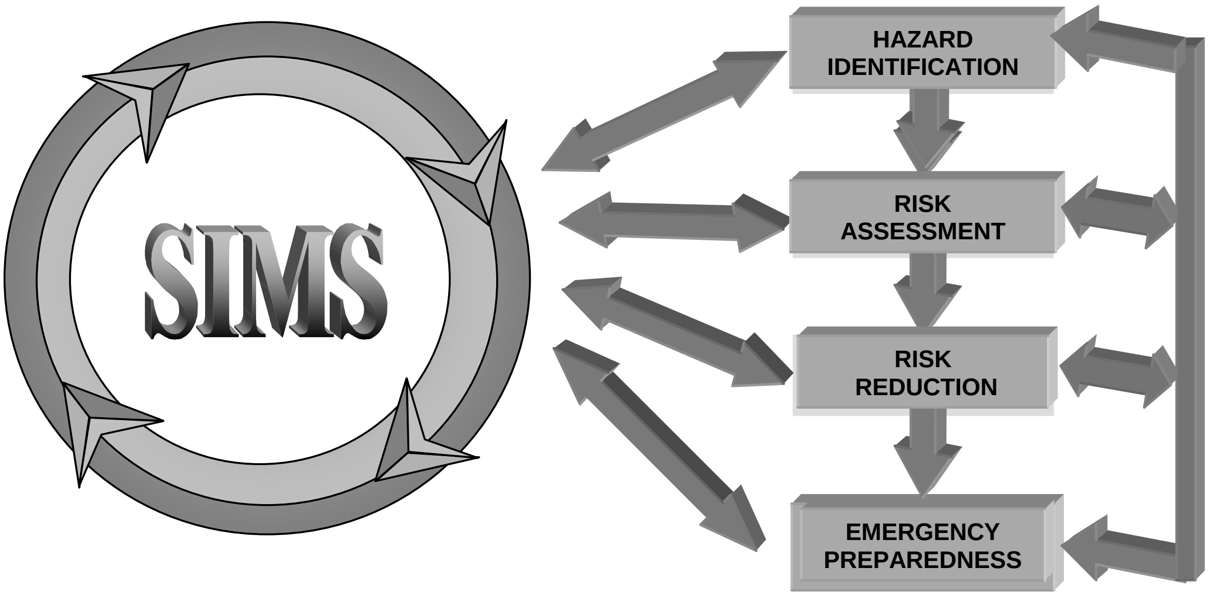

Figure 1

Risk Reduction: In practice, hazards associated with ship structures will follow similar lines to those associated with other systems, i.e., there may be some in the intolerable risk region and some in the negligible risk region but the majority will be in the tolerable risk region. It is essential to reduce hazards in the intolerable region because they could endanger the structural integrity of the ship. Those with an engineering background tend to use engineering methods to achieve reduction of a risk or at least of the *consequence* of the given hazard, although this is often the most expensive solution, and may offer no guarantee of success. There is reluctance to use appropriate methods to reduce the *probability of occurrence* because this is less "absolute" and involves human actions and decisions. However, methods available for reducing probability of occurrence include management, operational, commercial, political and environmental methods.

Emergency Preparedness: Despite the care and attention given to structural design, it has to be recognised that ships are operated by human beings and in an ever-changing ocean environment. In fact there are many variables that can affect the performance of a ship's structure, and it is necessary to be prepared for emergencies. This will involve studying likely emergency scenarios and setting up appropriate arrangements to deal with situations as they occur.

Structural Integrity Management System (SIMS): SIMS is the core element which ensures that the other four are being correctly implemented. SIMS has five components, as follows:

- Define the structural standard
- Organise resources to meet the requirement
- Implement the process for addressing hazard identification, assessing the risk levels of hazards, risk reduction and emergency preparedness
- Measure in-service performance to check how far the standards are being satisfied.
- Review the performance of the structure and feed back the experience gained for future designs.

For further details on the safety case concept as applied to ship safety management, see [9].

The key merits of the approach are as follows.

- The main focus is on significant hazards and methods for reducing their significance.
- There is a management system which ensures that the process is continuously improved.
- The method is ideal for handling new structural designs for ships.

There are three main drawbacks to this approach, as follows:

- Responsibility for structural integrity tends to be vested in the user.
- It may be difficult to compare the resulting structure with other similar designs because there may not be any common basis.
- The concept makes use of *risk methodology*, and there is a danger that the method will be misused because of the present poor understanding of the concept of *risk*.

AN ILLUSTRATIVE EXAMPLE

Background

This example is concerned with the "crashworthiness" of the sides of coasters operating in

European waters, and the suggested safety case concept, with incorporation of a responsibility-sharing concept, is offered as an alternative to or enhancement of the work done by Pinkster *et al* [10]. Theoretically it is the major companies operating large ships that would apply this concept to their fleets as this could be justified on economic grounds. However the principles can be illustrated by the coaster, and it has to be recognised that the capsize of one of these vessels could have serious consequences if it were carrying a dangerous cargo.

Essentially, Resolution A.684(17) of the International Maritime Organization (IMO) requires new ships with a length between 80m and 100m to satisfy the probabilistic damage stability requirements, see [11]. Coasters currently in service would not be able to comply with these requirements in the event of damage to their holds, because these hulls are designed with a single ship box-type structure. One solution by Pinkster *et al* was to propose the use of a double skin structure for these ships and consider ways of improving their *crashworthiness* - defined by them as "The ability to withstand violent impact due to collision". The work covered a number of issues and use was made of an explicit finite element calculation method. Amongst the authors' conclusions and recommendations, the following were noted:

- A double skin hull structure would be able to meet IMO requirement.
- There is a need to seek practical measures to increase "crashworthiness" of coaster hulls..
- The actual cost and the practical implications of achieving full compliance with IMO requirements need to be studied.

Clearly, Pinkster et al have taken the traditional approach of minimising the consequences of coaster collision. However, for the reasons discussed earlier, this is likely to be an expensive solution. In this example, the enhanced safety case concept is used to show an alternative solution.

The Enhanced Safety Case Concept

In this concept six components will be examined to assist in the explanation.

Component 1 : Define the Basic Goal

The goal in this example can be stated as "to evaluate the risk of a coaster capsizing when damaged in a ship-to-ship collision hazard". Defining this goal will help to focus the attention of structural designers.

Component 2 : Organise Effort to Meet the Goal

In order to meet the goal it is necessary to ensure adequate "effort" is available. This may be represented by funds, staff-time, etc. It is also necessary to devise a strategy to ensure that the endpoint can be reached.

Component 3 : COLLABORATION by Stakeholders

Everyone with a significant interest in the coast and its operation should be involved or contribute to this component. Those involved would include: ship operators, maritime regulators, those doing ship charter, coast guards and environmental organisations, the classification society by which the vessel is classed, and researchers. They would work together to carry out the following tasks:

Task 3.1 – <u>*Hazard Identification*</u>

The team would use brainstorming, "What if?", HAZOP (Hazard Operability) methods to identify hazards closely related to impact loads on the ship. Examples of such hazards would include:

- Adverse sea state
- Coastal fog
- Strong wind
- Malfunction of navigation equipment
- Crew fatigue
- Collision – bow to side
- Wave damage to hull
- Failure of steering gear.

Task 3.2 – <u>*Risk Assessment*</u>

Selecting the risk relation R (risk) = C (consequence) x P (probability of occurrence), it is possible to use both qualitative and quantitative methods in order to determine the risk level of each identified hazard. In this case, bow-to-side collision would be a hazard with an intolerable risk level, i.e., the consequence would be very serious, and there is also a distinct likelihood of the hazard being realised.

Task 3.3 – <u>*Risk Reduction*</u>

To reduce the risk level of collision it is possible to consider the following:

- <u>Reduce the consequence</u>: Using engineering methods, one would design coaster hulls with double skins in the manner given in [10]. This would be an expensive solution which could affect the operator's viability.
- <u>Reduce the probability of occurrence</u>: This can be achieved by a combination of risk reduction methods, such as introducing strict guidelines on sea lanes, giving crew members appropriate extra training, installing intelligent sensors linked the Global Positioning System (GPS) on board coasters and implementing safety sensitive operational procedures.
- <u>Combined approach</u>: This approach will aim at reducing both consequence and probability of occurrence, e.g., selective strengthening of the coaster's hull and the introduction of a positive coaster operational culture.

The final choice can be determined by using a decision analysis technique. For example, reduction methods can be grouped under the following headings:

- Increase "crashworthiness" by strengthening hull structures
- Giving crew members focused training on collision avoidance plus installing intelligent vessel sensors
- Developing a positive structural design culture.

The choice of a particular method will be made on the basis of the following three assessment criteria:

- Cost
- Effectiveness
- Feasibility.

Using the analytic hierarchy process suggested by Saaty, [12], the first step is to compare the relative importance of each parameter or cost with others so that a pairwise comparison matrix can be derived. Repeating the same process for effectiveness and feasibility allows a performance matrix [P] to be derived. A similar process applied to the criteria of cost, effectness and feasibility will lead to an assessment matrix [A]. The resulting weighting matrix [W], can then be derived from the product of performance and assessment matrices, i.e., [W] = [P][A].

An examination of values of the weighting matrix, [W]. will help to determine where effort should be applied to achieve the "best" solution for minimising coaster collision.

Task 3.4 – <u>*Emergency Preparedness*</u>

This would involve devising contingency plans to implement in the event of a collision, and ensure that the various aspects of the plan are regularly rehearsed by the crew.

Component 4 : IMPLMENT the Result Obtained

There are various possible options for implementing the results of Component 3. These include:

- Formulating a fresh set of prescriptive regulations which would have to be compiled.
- Prescribing a basic standard and asking operators to demonstrate how they could manage the risk level of the collision hazard so that it would always be in the tolerable or negligible risk regions.
- Providing guidelines to be followed by operators with strict monitoring of their practical implementation.

Clearly, the choice in any given case would depend on the areas of operation, the track record of operators, the role of the stakeholders, society's views on coaster accidents, etc.

Component 5 : MEASURE Performance

Once the results are implemented, there is a need to use "independent" methods to measure how effective they prove to be. Alternatively, it is possible to employ people not directly involved in coaster operations to appraise the performance of the implemented solution.

Component 6 : REVIEW : the Results and Experience

On the basis of the results obtained and experience gained, there should be a thorough review so that lessons can be dawn from the implementation of the solution and relevant information can be fed back to enhance any aspect of the other five components.

Merits of the Approach

It will be noted that the suggested approach has a number of merits, and the key ones are:

- It offers an extra option, in addition to placing all the emphasis on reducing the consequence of the hazard.
- It involves all the stakeholders and thereby gives them a share of responsibility.
- The solution is likely to be a more effective method of expending valuable resources, both human and financial.

DISCUSSION

On the basis of the work presented in this paper, three issues deserve brief discussion, as follows.

Direction of the Ship Structural Research Effort

This paper may have given the impression that effort should not be devoted to advancing ship structural research because sufficient knowledge is already available. In fact, what we are promoting is a more cost-effective focusing of ship structural research effort. It is a well established fact that researchers are generally motivated by a wish to seek the "complete" answer to a problem, but this cannot always be justified on either scientific or funding grounds. Because research studies are affected by the Pareto or "80-20" rule, one has to question whether it is justifiable to devote, for example, twenty-five percent of effort to achieve three percent of improved accuracy. To put it in another way, "Should funds be devoted to the pursuit of 'perfection' in a relatively small area when there are many other bigger problems requiring research attention?"

The Consequence of Failure versus its Likelihood

Technical education tends to encourage students to seek technological solutions to a problem - for example to introduce double-hull tanker designs in response to a grounding incident caused by a human error of navigation, see O'Neil [13]. This is understandable because it provides "physical" evidence that "something" has been done. However, ships are operated and designed by human beings and technical solutions alone will not prevent failures. For the reasons given in the previous section, naval architects must begin to explore actively alternative ways of dealing with failures, in parallel with reducing their consequences. It is suggested that attention should be given to reducing the likelihood of failure. In the ship structural context, examples of this would include seeking ways of minimising the over-stressing of structures by providing information to enable better decisions to be made, giving appropriate training to crew members, and developing a positive ship operational culture.

The Role of Effective Communication

Experience has shown that those involved in technical activities are generally good at communicating on technological matters with fellow professionals, but they are less effective at interacting on technical issues with those from other backgrounds. This stems from three main factors:

- Difficulty in explaining complex technical matters to those who have less specialised knowledge of the subject.
- The fact that the system of technological education places strong emphasis on obtaining solutions but little on explaining how they are derived.
- A lack of communication skill.

In the area of technology transfer, statistics have shown that about ten to fifteen percent of effort is needed to solve a problem, and eighty-five to ninety percent of the effort must be spent on implementing the transfer. This result may not correlate directly with what happens in ship structural research but there is considerable scope for improving the communication of design outcomes to those who are chartering, operating and managing ships.

CONCLUSIONS

Based on the content of this paper, the following conclusions can be drawn:

- The existing prescriptive methods of developing ship structures have made significant contributions to ship design, but there is scope for exploring the use of methods that address both the consequence of structural failure and its likelihood of occurrence.
- The goal setting safety case concept is an effective method for helping to place emphasis on structural areas needing attention, and it is essential to involve ship operators, ship managers and other stakeholders in the process of devising appropriate ship structures for meeting specific requirements.
- Ship structural designers should devote attention to understanding users' needs and how specific ships are operated in practice before focusing on producing optimum designs.

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Discussion