Evaluation of the Environmental Risk of Aframax Tankers

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The European Commission funded project, Pollution Prevention and Control (POP&C), investigated historical causes and rates of Aframax tanker shipping accidents leading to oil pollution. Key results from the project included; an updated database of tanker accidents, an integrated methodology to measure the oil spill risk of tanker designs extending the existing IMO methodology, a quantitative method to evaluate structural performance in the accidental condition, risk control and pollution control options, plus the development of an ALARP (As Low As Reasonably Practical) risk region for oil spills from transportation by tankers. This paper concentrates on expanding the IMO's Formal Safety Assessment to include oil spill risks, the development of the ALARP region, identification of groundings as the highest risk accident type, and the evaluation of a current state of Aframax tanker design compared to a more risk adverse design developed using concepts and methodologies developed in the POP&C project.

KEY WORDS: Risk-based Design; ALARP; Tankers; Environmental risk; Grounding; Oil Outflow.

INTRODUCTION

During the 1990's, the IMO's Formal Safety Assessment [MSC/Circ.1023] became the agreed method for identifying cost effective measures (or Risk Control Options) for reducing the loss of life in the maritime industry. FSA uses five steps:

- Hazard identification
- Risk analysis
- Identification of risk control options
- Cost-benefit analysis
- Recommendations for new regulations

These steps were developed by the Marine Safety Committee under IMO's remit to improve safety, and so were primarily directed at the reduction of loss of life and, to a lesser extent, the loss of assets. An example severity index typically used in the HAZID step of a FSA is shown in Table 1.

It can be seen from Table 1 that the effects on both humans and the ship (the asset) are considered. However, risk comes in three forms: Risk to Humans, Risk to Assets and Risk to the Environment. As yet, FSA has failed to incorporate environmental risks into the process, although all parties agree that it should be included. One of the main reasons for this is that environmental risk is a very broad catch-all phrase that can describe risks such as the impact of operational emissions to the effects of dismantling and, of course, it also includes the effect of accidental oil spills. The IMO has now decided to focus on incorporating the risks associated with oil pollution into the FSA process as a first step to incorporating all environmental risks in to FSA. This is being done via a correspondence group.

Table 1. Severity Index [MSC/Circ.1023]

SI	Severity	Effects on Human Safety	Effects on Ship	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe ship damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Having said this, even without an environmental FSA process, tanker design and operations have seen significant changes since the early 90s with the introduction of stricter international regulations resulting in considerable improvements in the safety record of the tanker industry. However, despite these improvements, two accidents Erika (1999) and Prestige (2002) in European waters, with their heavy oil cargoes, caused extensive pollution and have consequently resulted in the accelerated phase-out of single hull tankers; initially introduced by the European Union (2002) and later adopted by the IMO. At the same time, the Condition Assessment Scheme (CAS) for single hull tankers was introduced as a means of verifying that their structural integrity is maintained to the required standards for the remainder of their reduced life.

However, when these measures were introduced there was limited means for checking their effectiveness. If the industry can agree on a way of incorporating oil pollution risk into the FSA process then these and future rules will be better tuned to provide the most cost effective regulatory framework for tankers as possible. This paper aims to suggest a way for the IMO to move forward that would allow these cost effective measures to be identified.

The work this paper is based on research that was part funded through the European Union supported project POP&C. POP&C selected the Aframax class of tankers for analysis as a demonstration of the application of the methodology. Reasons behind this selection were the relatively large market segment of the Aframax tankers, past spectacular catastrophic Aframax tanker accidents and relatively high number of single hull Aframax tankers which were operational and expected to continue operating until they reached the recently amended (accelerated) phase-out date. Therefore, this paper will also be based on the AFRAMAX fleet.

CONSEQUENCES OF OIL SPILLS

The cost benefit metric known as ***Cost of averting a ton spilt (CATS)*** was proposed by another EU funded project, SAFEDOR, (Skjong et al 2005). This is a relatively new term, although the principle has been fairly well established for at least a decade. Essentially CATS is the same as ICAF (Implied Cost of Averting a Fatality) but for spilt oil. It is the net costs divided by the amount of oil not spilt as a result of a new design feature or operational measure.

However, there are a couple of problems with the CATS criterion. The first is that it is not clear when to use it. For risk to humans there is an As Low As Reasonable Practicable (ALARP) region defined, if you are above it (i.e. in the intolerable region) you do not need to use the cost calculation as you must act, no matter what the cost. If you are below it (i.e. in the negligible region) you need not act at all. It is only when you are in the ALARP region that the cost criterion comes into its own.

The second problem with the CATS criterion is that it has a linear relationship with oil spill size. It is a fixed value of $60,000 per ton. This does not vary with size, even though it would seem intuitive that a one ton spill costs more per ton than a 2000 ton spill with all other variables remain constant. Several member states (MEPC 56/18/1 and MEPC 57/17) argue that spill size, amongst other variables, has a dramatic effect on the cost of cleaning up a ton of the oil spill in question.

One of the obstacles to progress is that there is no agreement on what the severity measure should be. At the moment there are two main views put forward: spill volume; or length of time for the environment to recover from a spill (MSC81/18). A third view, the cost of the environmental damage has not yet received wide support. The authors and several member states at IMO, feel that time to recover is not a feasible solution.

The correspondence group at IMO has started to discuss the issue of environmental risk acceptance criteria. The difficulty in defining such criteria comes also from the complexity in defining and assessing environmental risk. Risk is the product of frequency and consequence but at the moment there is no universally accepted way of calculating the environmental consequence of an accidental release. Environmental consequences may be classified in different ways but it is generally accepted that a rigorous assessment should include at least the following considerations (U.S. Marine Board 2001; White 2002):

- Direct economic consequences of the site pollution: this category covers the cleaning cost and restoration of the affected area.
- Indirect economic consequences: this category covers the impact of oil spill on market consideration i.e. fishing industry and reduced tourism.
- Long-term effects on environment: this category covers the ecological consequences of an oil spill which may be quantified in terms of population reductions of species and recovery time for habitats and population.

The assessment of environmental damage in economic terms remains a developing science. Cost estimates have been based on clean-up and legal liability expenses. Less obvious costs related to restoration of natural resources, replacement of species, ecological damage, socioeconomic and other effects remain difficult to measure. Investigations following past accidents have not yet given the definitive answer.

IMO document MSC81/18 proposed that the consequences could be defined based on how long it took for an area to recover from the spill. However this is an incredibly difficult for a naval architect to comprehend let alone take into account during the design and place a value onto it. Hence POP&C, as reported by Gibbons et al 2006, decided to use the consequence function as proposed by the U.S. Marine Board (2001).

The US Marine Board's consequence function for environmental risk from tankers

The U.S. Marine Board's consequence functions are shown in Table 2, where "x" is the non-dimensional spill amount. The spill is made dimensionless by use of a reference spill of 500,000 US gallons (1,892,705 litres).

These values were derived by running simulations that examined the effect of various input parameters on the consequence of a spill, these being spill location, weather condition at the time of the spill and following the spill, oil type, and the spill volume.

The total number of spill scenarios for investigation was 11,200 spills. This is from four locations, 200 weather events, two oil types and seven spill volumes. In the end, the Marine Board

Committee was only able to run 9,800 spills, as only one oil type was run for one of the locations investigated.

Four metrics were then used to examine the severity of the consequence:

- Area of slick
- Length of oiled shoreline
- Area of oiled shoreline
- Toxicity in the water column

These metrics were then combined in to an equivalence ratio by comparing the simulated spills to a reference spill of 500,000 gallons (1,892,705 litres). These equivalency ratios were then combined into the consequence functions presented in Table 2.

Table 2 US Marine board's Consequence Functions

U.S. Marine Board – Full Data	$0.9885\ x^{0.356}$
U.S. Marine Board - < 25m gallons	$x^{0.425}$

Table 3 Consequence function (< 25m gallons) stated in oil outflow

Consequence function	Oil outflow (Tons)	Proposed qualitative classification
0.01	0.035	Minor
0.1	7.5	Significant
1	1655.3	Catastrophic
10	379000	

The POP&C project repeated some of these calculations to verify the functions applicability to European waters (Gibbons 2006).

All subsequent analysis use the Marine Board's consequence function for spills less than 25 million gallons, this equates to 94.625m litres or 82,797 tons using a density of 0.875 tons/m^3.

The authors of this paper believe that the consequence function would make a good severity measure as it is a mix between the simplicity of oil outflow and the complexity of a full environmental assessment.

DEFINING A SEVERITY INDEX

Table 3 presents how the consequence function could be turned into a Severity index. In reality there is probably little requirement to state a qualitative classification for a consequence function of 10 as society would generally class a spill of 1655 as catastrophic event. Having three classifications is obviously different from that of the four traditionally used for humans. However there is no reason why four should be used for oil, as 3 seems sufficient.

DEFINING A VARIABLE CATS

We could now equate this to the implied cost of averting a fatality to generate variable CATS. In other words, we could say that a minor oil spill is equal in cost to a minor injury. Scientifically there is no reason why the cost of averting a minor oil spill should be the same as the cost of averting a minor human injury. However, IMO has historically done this when comparing damage to the ship and injuries to humans (Table 1). It also seems a good practical solution.

Table 4 Calculating a variable CATS related to human FSA

Severity	Consequence function (Oil)	Severity Index (Human)	Equivalent tons spilt	Equivalent cost per incident using $3m per fatality	Scaled CATS value
Minor	0,01	0,01	0.03 - 7.3	$30,000	$920,245
Significant	0,1	0,1	7.3 – 1655.3	$300,000	$40,844
Catastrophic	1	10	>1655.3	$30,000,000	$18,123

Therefore it is suggested that the CATS values are Spill size dependant:

Table 5 Spill Size Dependant CATS Values

Spill Size (tons)	Proposed CATS values
0 - 7	$900,000
7 – 1655	$40,000
>1655	$18,000

Using a cumulative costing method, these new values would give the following costs for oil spills:

Table 6 Approximate Costs of an Oil Spill

Oil spill size (tons)	Approximate cost of oil spill
5	$4,500,000
500	$26,000,000
1000	$46,000,000
10,000	$222,000,000
80,000	$1,500,000,000

These figures may not be derived in the most technically accurate way but they seem reasonable; it is easy to understand where they come from; and they are easily updateable in the future. Therefore the authors recommend that the new variable CATS values are used.

RISK ACCEPTANCE CRITERIA

Risk acceptance criteria are an important part of safety management as they reflect the targeted safety level. Acceptance criteria are based on the established safety goals and quantification of these. They enable the determination of whether the risk is acceptable or not. If the estimated risk is too high compared to acceptance criteria, risk reducing measures need to be identified and implemented.

Without such criteria, it is necessary to introduce the equivalency principle. This means that the designer has to develop a prescriptive design in order to demonstrate that the new/innovative design is as safe as or safer than a design that would be approved according to the prescriptive rules, using the same model, same scenarios and same assumptions. This also means that the time required (and the cost) to perform the study is a lot higher.

A very comprehensive and detailed review of existing criteria and current situation at IMO was carried out within the context of SAFEDOR (Skjong et al 2005). It is concluded that the risk evaluation criteria for safety have been used extensively over the last few years, and a lot of experience with their use now exists. However, from an environmental point of view no such experience exists in the marine industry.

Development of a Frequency – Consequence curve for oil pollution

The authors started to look at the oil pollution by initially looking at Frequency – Consequence curves. These are similar to Frequency – Number of fatalities curves (FN Curves) but use the consequence function instead of number of fatalities.

A good description of what FN curves are, and how to construct them, can be found in Evans (2001). However, a simple description is: an FN, or in this case FC, curve is a cumulative frequency plot starting with the worst incident (the right hand side of the graph) and finishing with the least bad incident (the left hand side) with frequency on the y axis and consequence on the x axis.

The benefit of these types of graph is that it allows the viewer to analyze what incidents are contributing the most to the global risk of the item being investigated. The F-C curve generated for AFRAMAX tankers' oil spills during the period 1991-2003 is presented in Fig. 1.

If the gradient is -1 then the risk, in strict mathematical terms, is equal. So what we can say by considering Fig. 1 is that: up to a consequence of approximately 2, as the size of the accident increases the risk also increases because the frequencies of the accidents do not reduce enough to keep the risk levels equal. After a consequence of 2 the risk level initially levels out and then decreases.

Therefore, the highest contribution to the risk level of the AFRAMAX fleet comes from spills with a consequence between approximately 2 and 5 as seen in Table 7. This roughly equates to spills in the region of 8,500 to 73,000 tons. This is probably a fair reflection of public concerns. Of course, the upper limit is due to the upper size limit of what is defined as an AFRAMAX tanker.

Table 7 AFRAMAX accidents with oil spills (1991-2003)

Accident category	Year of accident	Oil Spill	Consequence	Reverse cumulative frequency
Structural Failure	1996	0.05	0.01200	0.003979
Structural Failure	2002	0.1	0.01611	0.003826
Structural Failure	1997	0.5	0.03192	0.003673
Contact	1992	0.99	0.04267	0.00352
Collision	1992	1	0.04285	0.003366
Contact	1999	1	0.04285	0.003213
Structural Failure	1995	3	0.06835	0.00306
Contact	1991	3.22	0.07044	0.002907
Structural Failure	1993	5	0.08493	0.002754
Structural Failure	1994	5	0.08493	0.002601
Structural Failure	2000	20	0.15308	0.002448
Structural Failure	1994	40.5	0.20661	0.002295
Contact	2000	73	0.26539	0.002142
Contact	1997	102	0.30594	0.001989
Contact	2001	116	0.32313	0.001836
Collision	1999	144	0.35423	0.001683
Collision	1992	280	0.46992	0.00153
Grounding	1993	325.12	0.50072	0.001377
Grounding	2000	540.56	0.62149	0.001224
Explosion	2000	1770	1.02888	0.001071
Grounding	2000	7000	1.84563	0.000918
Grounding	1997	8571	2.01148	0.000765
Structural Failure	1991	17983	2.75610	0.000612
Grounding	2003	29000	3.37674	0.000459
Structural Failure	2002	77000	5.11372	0.000306
Grounding	1993	88214	5.41791	0.000153

Note: No accidents were deemed to have been caused by a fire. There was a total of 6535 ship years for the AFRAMAX fleet in this time frame.

ALARP - Risk Acceptance Criteria

Risk acceptance criteria addressing loss of life have been widely developed and a number of publications present the progress made so far on the subject. The criteria in Table 8 are broadly used in other industries and have been also published in by the U.K. Health and Safety Executive (Evans 2001). They are widely accepted as standard risk acceptance criteria for loss of life that define the ALARP region.

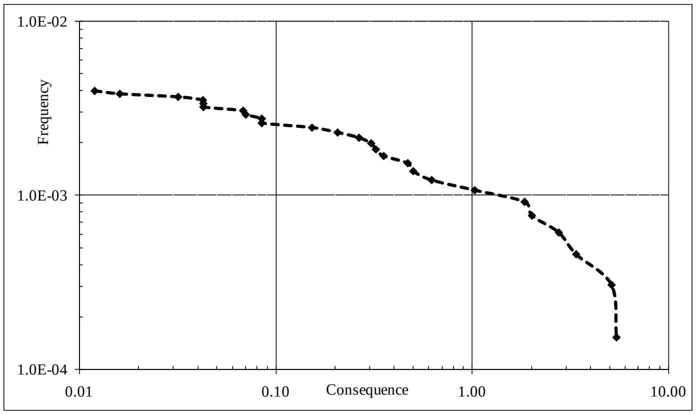

Fig. 1 F-C curve for AFRAMAX Tankers 1991-2003

Table 8. ALARP Frequencies for 1 Fatality

Maximum tolerable risk for crew members	10^{-3} annually
Maximum tolerable risk for passengers	10^{-4} annually
Maximum tolerable risk for public ashore	10^{-4} annually
Negligible risk	10^{-6} annually

These criteria have been derived from comparison with other hazards. The annual fatality rate is about 10^{-3} (OECD member countries). This value is used by many as the intolerable limit for crew. For passengers it is common to use a stricter criterion ($1x10^{-4}$ fatalities per individual per ship year) because they are exposed to risks over which they have little or no control. A risk of $1x10^{-6}$ fatalities per individual per ship year is seen as insignificant.

If a risk is larger than $1x10^{-3}$ fatalities per ship year for a crew member, then the risk is deemed intolerable and risk control options must be introduced no matter what the cost (however, the most cost effective risk control option can and should be chosen). Likewise, if a risk is less than 10^{-6} fatalities per ship year per individual, then the risk is deemed to be negligible and therefore no actions need to be taken.

However, if the risk falls inside the ALARP region a cost analysis must be done on the options to control the risk. Those that are deemed cost effective, if any, should be introduced.

Oil pollution ALARP

As stated above, ALARP regions can be defined by comparison with other generally accepted risks. For AFRAMAX tankers therefore, there are two possible risks from which comparisons can be made:

1. Oil pollution from an offshore installation
2. Oil pollution from a pipeline

Unfortunately, these industries have not defined a globally accepted ALARP region and have not stated specific risk acceptance criteria in an explicit manner that would allow such a globally accepted ALARP region to be easily drawn.

However, for pipelines in the U.S. (Pipeline and Hazardous Materials Safety Administration) there are several common threshold values used in various Federal laws.

- Spills over one barrel must be reported.
- Spills over 10 barrels must be reported instantly by telephone.
- Spills of more than 50 barrels must have additional information reported and there will be a formal investigation with possible sanctions.

It was considered that the most suitable value for the definition of an ALARP region is 50 barrels. This is for practical reasons, 50 barrels is not a very large spill in tanker terms, and also it would seem an upper limit of acceptability in the U.S. pipeline industry. The fact that there is an investigation and possible sanctions above this line, implies that spills of less than this are somewhat tolerated.

50 barrels is equivalent to 4.99 tons (using a density of 0.85 kg/l), which in turn gives a consequence of 0.085, which we will round up to 0.1. It should be noted at this point, that this was felt to be quite a relaxed limit, especially if compared to standards in the UK and other European states.

The POP&C investigators then had to identify a frequency at which this size of spill would be somewhat tolerated. This was significantly harder to acquire data for; however some FPSO's use target levels of safety for oil outflow that were $1x10^{-3}$ per FPSO year, for spills of more than 50 barrels.

With these two values and our knowledge that frequency and severity scales are logarithmic we can define an ALARP region; this is presented in Fig. 2.

For the intolerable region this equates to a spill of 1892 m^3 occurring not more than every 10,000 ship years, or with the current fleet size, not more than every 20 years.

It can be seen from Fig. 2, that the AFRAMAX tanker fleet performs disappointingly when compared to these criteria. In fact, the fleet performs so badly that even if there were no more accidents and there were ten times as many ships, the frequencies would still not be reduced enough for the curve to fit completely into to either the ALARP or negligible regions.

Given the above result, two things need to be considered: the AFRAMAX fleet's role in the world economy; and whether it is possible for an existing fleet to be intolerably risky.

The AFRAMAX fleet, and for that matter the world tanker fleet, provide the world economy with the fuel it requires to function. Quite literally the world would stop if tankers were banned, as there is no feasible way to transport oil across vast oceans from the production site to the consumer.

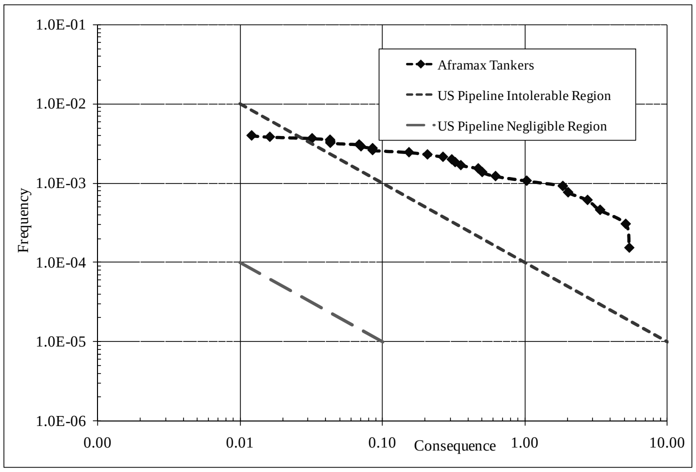

Fig. 2 AFRAMAX F-C curve 1991-2003 compared with ALARP region derived from U.S. pipeline requirements

Pipelines are being built all the time but they have a limit to what they can do. So ships will be required for some time to perform this duty. This benefit should be taken into account when deciding on an ALARP region.

Secondly, is it possible for an existing fleet to be intolerable? Within POP&C there was some debate about whether a ship that is considered acceptable by current rules could actually be considered intolerable by an ALARP region. The two arguments are quite simple: If it is allowed, it is tolerable and if it is tolerable it cannot be intolerable.

The counter argument is that if and when there is a large oil spill, the public and politicians will demand more research, such as POP&C, more regulations and less chance of it ever happening again. Therefore, it can be considered that the public and politicians do not think the fleet, which is perfectly capable of having a large spill, is tolerable, they just do not realize it yet.

The authors considered that it is possible for aspects of an existing ship to be intolerable. In this case it is possible that large spills, that can still occur, are not acceptable to the population and they will demand that action is taken, as and when another large spill occurs. Therefore it is realistic for these larger spills to be in an intolerable region of an ALARP region as this is, in actual fact, the case in reality.

With this in mind, the authors decided that a new ALARP region should be drawn (see Table 9 and Fig. 3):

Table 9. Proposed ALARP region consequences and frequencies

Severity (Consequence Function)	Intolerable Frequency (per ship year)	Negligible Frequency (per ship year)
0.01	$1x10^{-1}$	$1x10^{-3}$
0.1	$1x10^{-2}$	$1x10^{-4}$
1	$1x10^{-3}$	$1x10^{-5}$
10	$1x10^{-4}$	$1x10^{-6}$

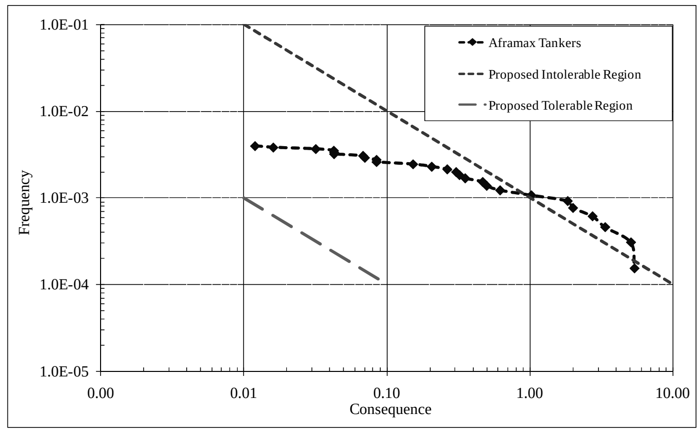

Fig. 3 F-C Curve for AFRAMAX Tankers 1991-2003 with proposed ALARP region

As can be seen from Fig. 3, this puts the AFRAMAX tanker fleet much nearer the ALARP region and in fact puts the world tanker fleet firmly in the ALARP region; it is therefore proposed to use these values for the ALARP region.

Of course, this does not mean that either AFRAMAX tankers or the world fleet are ALARP, as there has been no cost effectiveness calculation done. Studies into cost effectiveness of different risk control options are presented in Moore et al (2007).

COMPARISON OF PROPOSED ALARP REGION TO THAT EXTRAPOLATED FOR OIL OUTFLOW

As previously stated, it was decided to use the U.S. Marine Board consequence function to represent the environmental consequences of an oil spill. An alternative method is to use oil outflow, i.e. the quantity of oil that escapes from the ship during an accident.

It was therefore decided to compare the proposed ALARP region against oil outflow and also to consider an ALARP region that had been extrapolated from the U.S. pipeline data with outflow as the consequence. The two ALARP regions are described below in Table 10, Table 11 and Fig. 4.

Table 10. Proposed ALARP region expressed with oil outflow consequence

Oil Outflow (Tons)	Frequency for Negligible (per ship year)	Frequency for Intolerable (per ship year)
0.035	1x10^{-3}	1x10^{-1}
7.5	1x10^{-4}	1x10^{-2}
1655.3	1x10^{-5}	1x10^{-3}
379000	1x10^{-6}	1x10^{-4}

Table 11. Alternate ALARP region based on oil outflow

Oil Outflow (Tons)	Frequency for Negligible (per ship year)	Frequency for Intolerable (per ship year)
1.6553	1x10^{-2}	1x10^{-00}
16.553	1x10^{-3}	1x10^{-1}
165.53	1x10^{-4}	1x10^{-2}
1655.3	1x10^{-5}	1x10^{-3}
16553	1x10^{-6}	1x10^{-4}
165530	1x10^{-7}	1x10^{-5}

It can be seen from Fig. 4 that the proposed ALARP region has a significantly gentler gradient than the oil outflow based ALARP region. This is because the consequence function used in this paper considers the size of spill as, relatively less important for bigger spills. This gives the impression that the permissible risk associated with larger spills is higher than that of lower spills. However as the U.S. Marine Board (2001) discussed, oil outflow alone is not a good indicator of environmental consequence.

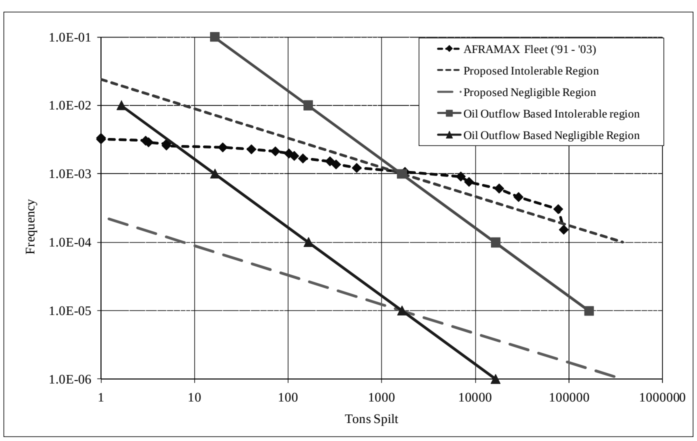

Fig. 4 Comparison of the proposed ALARP region against an oil outflow extrapolated ALARP region

ALARP for Oil pollution by Accident Type

Accepting that the proposed ALARP region is appropriate, the authors set about analyzing which category of accidents was contributing the most to the AFRAMAX fleet creeping into the intolerable region.

It can be seen from Fig. 5, that grounding incidents are the primary contributor to the AFRAMAX fleet creeping into the intolerable region. As explosion is a single point (there was only one explosion accident that resulted in an oil spill in all of the historical data analyzed) it should be ignored. There is also some contribution from structural failure. Perhaps this result is to be expected as grounding accidents cause large damage to the hull and may continue for days or even weeks, before the ship is finally freed.

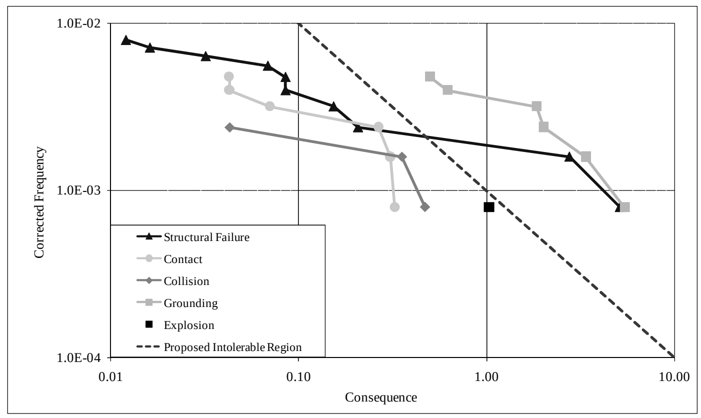

Fig. 5 Comparison of risk contributors

One conclusion that can be drawn from this analysis is that designers and regulators should spend time concentrating on controlling the frequency and consequences of grounding events as a priority for increasing the tolerability of AFRAMAX tankers.

FREQUENCY – CONSEQUENCE EVALUATION OF AFRAMAX TANKERS IN GROUNDING

The historical performance of Aframax tankers in groundings in comparison to the ALARP region is shown in Fig. 5. Using the methodology developed in this paper, it can be seen that it is possible to evaluate existing and new designs in terms of the F-C diagram and the ALARP region.

The methodology combines incident rates, damage extent statistics, tides, oil outflow analysis and consequence modeling to develop the F-C diagram for Aframax tankers. The methodology considers only the consequence due to the damage associated with the initial grounding. It does not include subsequent events such as structural breakup or fire that can significantly increase the consequence of the event. The basic methodology is described in Moore et al, 2005 and for groundings represents a small extension of the IMO methodology for evaluating alternative tanker designs (IMO…).

The methodology has been applied to the historical Aframax fleet for the period 1991-2003 taking into account historical incident rates and observed oil outflow amounts.

Incident Rates and LOWI

Much work into the identification of scenarios and the probability of occurrence of incidents has been undertaken for Aframax Tankers by Papanikolaou *et al* (2005) within the POP&C project, by developing a database of historical incident data from which incident statistics could be developed. In combination with relevant "fleet at risk" data, the incident rates per ship year were calculated. These rates are specific to Aframax tankers but similar information could be developed for other vessel sizes and types. For evaluation of the historical Aframax vessels the rate 5.53×10^{-03} per shipyear for the period 1991-2003 is most relevant.

The damage extent statistics assume rupture of hull structure and thus the incident rates need to be adjusted for the probability of loss of watertight integrity (LOWI) given the basic event. The POP&C project provides the rate of LOWI (for Aframax tankers) for the various accident types. For groundings the LOWI percentage is 18.6%.

Finally, the frequency development assumes a 13 year period during which the Aframax tanker is at full load one-half the time. It is assumed that most of the risk is due to fully loaded tankers.

Historical Fleet Makeup

In POP&C the historical division of the Aframax fleet was developed as shown in Fig. 7 (Del Castillo, 2005) for the period 1990-2004. The fleet makeup for the period was 56% single hulls and 44% double hulls. For purposes of grounding, double sided vessels are considered single hulls and double bottomed vessels as double hulls. This breakdown of vessel types has been applied as a reasonable approximation for the 1991-2003 period.

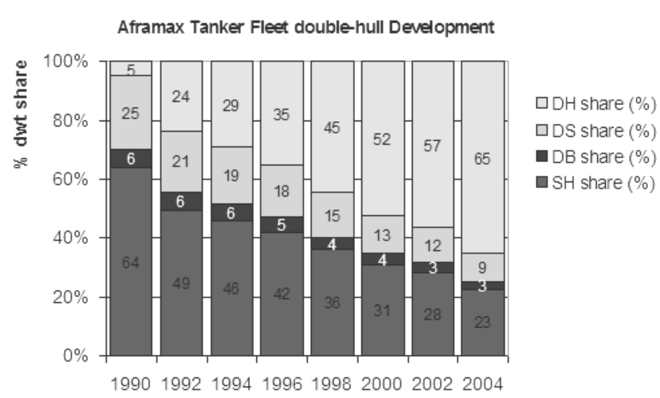

Fig. 7 Aframax Tanker Fleet Makeup

Calculated F-C Curves for Aframax Fleet

The methodology was calibrated against the historical data for oil spills. Fig. 8 includes the ALARP boundaries, the historical data F-C curve and F-C curves for single and double hull tankers and for a weighted average of the Aframax fleet. As the figure demonstrates the combined curve closely approximates the historical data for lower consequence values. As noted previously the methodology does not account for subsequent events that can lead to higher consequences.

Further these curves demonstrate that the double hull design by itself dramatically reduces the risk and moves it into the upper edge of ALARP region, although this does not mean they are ALARP.

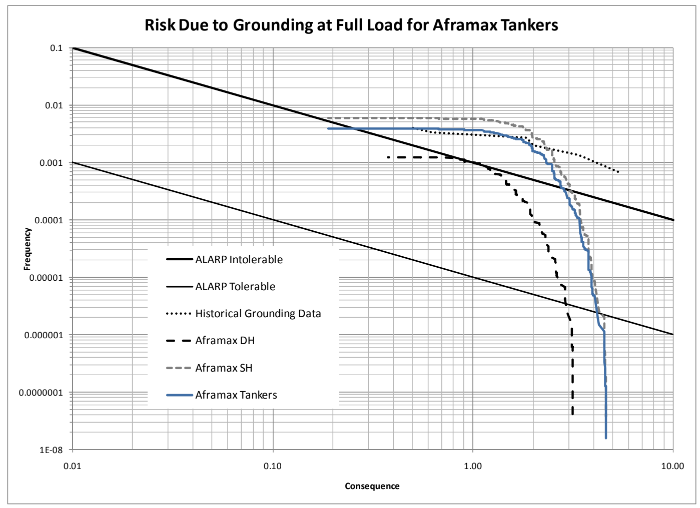

Fig. 8 Calculated F-C curves for the Aframax Fleet 1991-2003

This methodology can be used to illustrate the gains in risk reduction for more environmentally friendly designs as shown in Fig. 9 where the F-C curve is developed for an Aframax tanker developed as a case study in POP&C (Moore et al, 2007). The improvements included a larger double hull envelope, a 6x3 cargo tank arrangement and machinery redundancy.

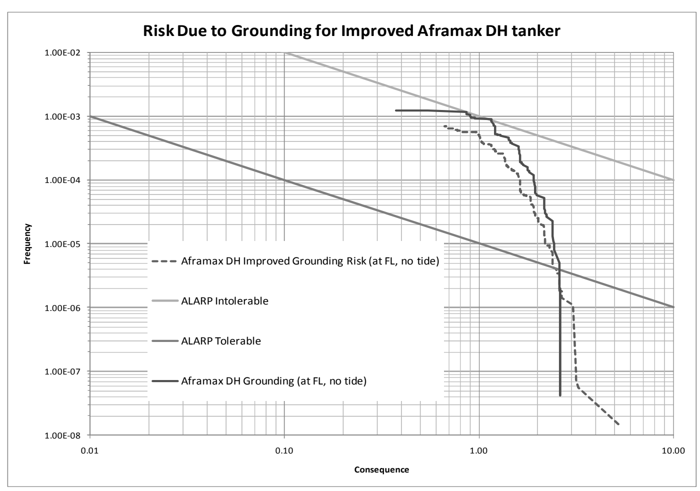

Fig. 9 F-C curves for Aframax DH and Improved Aframax DH, no tidal effects included.

The proposed improved design improves the performance by reducing the frequency of accidents that lead to relatively small spills and reducing the consequences of smaller hull damages while keeping higher consequence accidents within the tolerable frequency region.

CONCLUSIONS

The paper suggests that the consequence function developed by the US Marine Board (2001) would be well suited for use as a consequence measure for oil spill pollution in FSA. The authors argue that it is a good compromise between the over simplistic use of oil outflow and the over complicated full environmental analysis.

The authors use the consequence function to develop a severity index (Table 3) and related variable CATS (Table 4). This cumulative costing method allows for fixed ‘start up’ costs and then a variable clean up cost. Therefore small spills are significantly more expensive than larger ones.

The paper goes on to show how F-C curves can be drawn (Fig. 1) and develop an ALARP region based on comparison to the offshore and pipeline industries (Fig. 2). This ALARP region was considered to harsh for the marine industry, so the authors argued that an order of magnitude reduction in the requirement could be explained by considering tankers’ unique role in the world economy. This allowed the authors to present a proposed ALARP region (Table 9).

As a check of the proposed ALARP region, the paper goes on to compare the ALARP region against a second ALARP region developed using oil outflow as the consequence measure (Fig. 4). It is shown that the proposed ALARP region fits the fleet’s performance better than an ALARP region developed with oil outflow and with a gradient -1. This implies that the ALARP region proposed would be less stringent on larger spills than smaller spills.

Following on from this, the paper examines the types of accidents that most contribute to the risk. It is shown that grounding is by far the biggest contributor to risk (Fig. 5).

With this in mind the authors present an overview of their work on predicting future risks for tankers, in particular that related to tanker groundings. This prediction closely fits the historical data for small and medium sized spills (Fig. 8). The prediction method at present does not take into account ‘secondary’ events that can lead to total loss of the oil onboard.

The paper goes on to show how new design features can be included in the risk calculations and new FC curves drawn (Fig. 9).

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