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Review of Tanker Safety after the Introduction of OPA 90

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Abstract

The present study focuses on a comprehensive analysis of recorded accidents of medium and large oil tankers (deadweight over 20,000 tonnes), which occurred after the introduction of OPA 90 and until today. Raw casualty data was reviewed and re-analysed in order to produce appropriate statistics useful for the implementation of risk-based assessment methodologies. The main outcome of the presented study is the identification of significant historical trends and of quantitative characteristics of individual categories of tanker accidents, like overall accidental frequencies per ship year, frequencies of each major accident category and per tanker ship size, ship type/design and age, the degree of accidents' severity and the oil spill tonne rates per ship year. Therefore this study is a valuable source of information for the assessment of the effectiveness of current IMO regulations, classification society rules and tanker industry's practice.

JEL Classification: L9.
Keywords: Tanker casualties; Marine oil pollution; Risk analysis and assessment; Tanker hull design.

Glossary

Collision includes cases of striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking wreck.

Contact events contain cases where the vessel is striking any fixed or floating object other than in collision cases.

Grounding events include cases where the ship is going aground or hitting/touching shore, sea bottom or underwater objects (wrecks, etc.).

Fire, and Explosion events are defined in the way that the event in question is the *first initiative event* reported.

Non-Accidental Structural Failure (NASF) contains cases of hull damage in view of non-accidental structural failure, such as cracks and fractures, affecting ship's seaworthiness or efficiency. Damage to a vessel's rudder, or rudder-adjoining parts are also considered as structural damage.

Machinery Failure: cases in which a technical failure of machinery or of related system affects vessel's seaworthiness.

Failure of Hull Fittings: cases of damage to ship's hull-fitting equipment/outfitting, affecting ship's seaworthiness or efficiency, like deck equipment, vessel's propeller, propeller portion or propeller adjoining parts.

1. Introduction

A prime concern of the maritime industry and of relevant regulatory authorities is the enhancement of ship safety and the reduction of marine pollution related to ship incidents/accidents. Since an elimination of marine accidents is practically unrealistic, a reasonable target is the mitigation of accidents in terms of a reduction of the occurrence's probability and of associated consequences of accidents, both taking into consideration economic constraints. Starting point of such mitigation measures is a critical assessment of the current safety status, i.e. the determination of accident frequencies and of societal risks.

The main objective of the present study is the identification and quantification of the main high level hazards that may lead to a tanker's loss of watertight integrity and consequently cause environmental damage.

The particular investigation started within the framework of the EU funded project POP&C (POP&C, 2007, Delautre, 2005) and was enhanced and continued through another EU funded project, namely SAFEDOR (SAFEDOR, 2009, Papanikolaou *et al.*, 2007, Eliopoulou and Papanikolaou, 2007). These studies led to a rational evaluation of risk of *large tanker* safety and ultimately to a submission to IMO in 2008 (Denmark-IMO, 2008).

Further studies were performed subsequently for the *medium size* crude oil tankers by the Ship Design Laboratory of NTUA in collaboration with Germanischer Lloyd, Hamburg (TANKOPT, 2011), aiming to identify the effect of tanker size on maritime pollution accidents (possible differences to the pattern of large tankers accidents), and also the identification of important trends in the safety of oil transport by all major types of tankers, besides the determination of accident and pollution rates, as necessary for the implementation of risk based methodologies in tanker design and operation.

In the following, we elaborate on the methodology of work (source of raw data, sampling plan and fleet at risk) in section 2, analyse the frequency of accidents leading to Loss of Watertight Integrity (LOWI) in section 3, discuss the consequences of tanker accidents in section 4 and 5, and we conclude of the current status of tanker safety and on the way ahead in section 6.

2. Methodology of work

2.1 Field Data Model

In order to conduct a risk analysis assessment, historical casualty data was extracted from commercial casualty databases (IHS Fairplay, C4TX, GISIS), imported in a new purposely designed database (NTUA-SDL), critically assessed and enhanced by other information publicly available (internet search, etc.). The particular step is considered of paramount importance[1] for the reliability of the conducted risk analysis because:

- Commercial databases were originally not designed for potential application in risk assessment procedures;
- Their information is to a great extent available in textual form, whereas details of importance for formal risk assessment procedures (FSA) are missing.
- In several cases, there was lack of or erratic information about principal issues for the analysis, namely on the consequences of the incident or/and on several steps of Event Tree analysis (missing or erroneous spillage extent for important and well publicised major tanker accidents).

2.2 Sampling Plan

Fig. 1 presents the major undesired main top events that may lead a ship to a risk condition. The present study focuses on accidents that potentially lead to ship's Loss Of Watertight Integrity (LOWI) and to accidental oil pollution, thus only the first six (6) categories of accidents are investigated as illustrated in Fig. 1 (shaded box). It should be noted that incidents of the other categories (machinery, hull fittings) were considered via the other categories, when escalating, and for instance leading to collision or grounding.

Figure 1. Generic casualty main top event categorisation for risk assessment

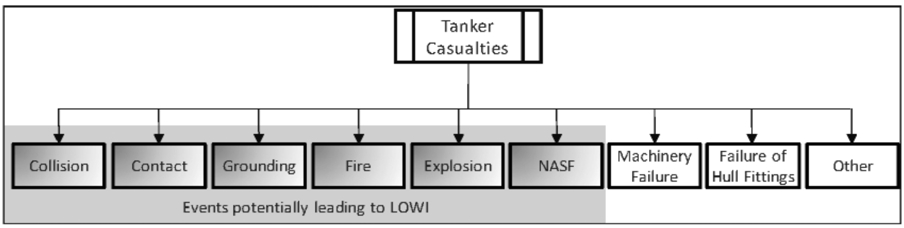


Table 1. Sample of casualty data[2]

	***Medium* Tankers (1990-2009)**		***Large* Tankers (1990-2008)**	
Casualties	**Number**	**%**	**Number**	**%**
Collision	239	33%	288	**34%**
Contact	113	16%	97	**11%**
Grounding	205	28%	205	**24%**
Fire	53	7%	78	**9%**
Explosion	33	5%	39	**4%**
NASF	78	11%	151	**18%**
Total	**721**		**858**	

1. This was reiterated in the recent IMO-MSC Group of Experts (GoE) meeting (November 2012) reviewing the tanker FSA submitted by Denmark in 2008 (Eliopoulou and Papanikolaou, 2007).

2. Refers to casualties that occurred during ship's operation; excluded incidents that happened in shipyards and drydocks.

Studied time period on tanker incidents is confined to the last two decades, namely it takes into account accidents between year 1990 and up to October 2009. Year 1990 is considered a landmark year because of the introduction of the double-hull tanker concept through OPA 90 in USA (in the aftermath of the catastrophic Exxon Valdez accident in 1989) and its tremendous effect on related regulatory developments thereafter. It is believed that this period is quite representative for assessing today's situation. It is noted that previous studies on the same subject showed a significant reduction of accident occurrence in the post-90 period, taken into consideration that a series of introduced key regulations was found to be related to the significant decrease of the frequency of tanker accidents (Delautre, 2005).

Concerning the size of tanker ships involved in the incidents, the following DWT size segments were considered:

- *Medium Oil Tankers* (studied period: 1990-Oct. 2009): contains HANDYSIZE tankers (20,000-34,999 DWT) and HANDYMAX tankers (35,000-60,000 DWT).
- *Large Oil Tankers* (studied period: 1990-Oct. 2008): contains PANAMAX tankers (60,000-79,999 DWT), AFRAMAX tankers (80,000-119,999 DWT), SUEZMAX tankers (120,000-199,999 DWT), VLCC tankers (200,000-319,999 DWT) and ULCC tankers (greater than 320,000 DWT).

With respect to the tanker subtypes/subcategories considered in the study, only categories relevant to *oil tankers* were considered in the current investigation, namely according to the definition of IHS casualty database: Oil Tankers, Crude Tankers, Shuttle Tankers, Product Carriers and Chemical/Oil Tankers. It is noted that OBOs, Ore/Oilers and Chemical Tankers (and the related accidents that may have led to maritime pollution) were excluded from the present analysis, because these tanker subtypes have special design/layout and operational features, which are not representative of the whole class of tankers.

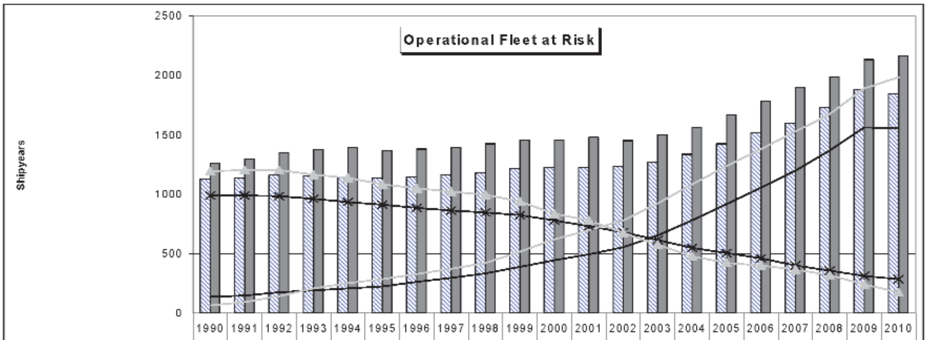
An overview of the analysed sampling plan accounting for non-serious as well as accidents with serious degree of severity is given in Table 1. The definition of accident's *degree of severity* is taken by default according to the notation in the used commercial databases IHS; note that recent studies of the authors indicated sporadic inconsistencies in the particular definition (CONTIOPT, 2013).

2.3 Operational Fleet at Risk

Annual Operational Fleet at Risk is defined as the number of ships that operate in the corresponding period and it was calculated according to the monthly operation of each vessel based on data from the IHS database. Fig. 2 presents the corresponding fleet at risk of large and medium tankers along with the annual distributions of Double Hull (DH) Fleet and Non-Double Hull Fleet. In difference to the analysed casualty data period, Table 1, it is noted that the shown data for the operational fleet at risk cover the period until the end of 2010.

Annual DH-ships population was significantly small in the first years of the analysis period, namely 1990-1995, but it steadily increased as could be expected because of the gradual enforcement of the requirements of double hull ship concept worldwide (and the corresponding phase out of single hull ships), surpassing for the first time the non-DH fleet in the period 2001-2003.

Figure 2. Operational Fleet at Risk of medium and large size tankers – Double and non-double hull ships

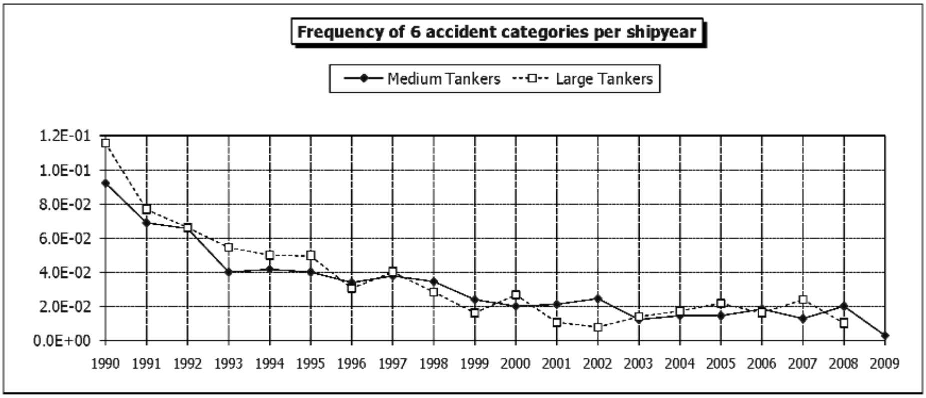


	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Medium Tankers	1128	1142	1162	1159	1143	1142	1150	1165	1184	1218	1229	1228	1239	1274	1338	1424	1521	1605	1728	1877	1844
Large Tankers	1260	1300	1351	1377	1391	1372	1383	1394	1424	1462	1458	1484	1455	1506	1564	1663	1784	1899	1990	2132	2158
Medium DH-Fleet	137	151	174	194	209	228	262	299	334	391	446	497	554	654	784	920	1057	1203	1370	1564	1557
Medium Non-DH-Fleet	991	990	988	965	934	914	888	866	850	827	783	732	685	619	553	504	463	402	358	313	287
Large DH-Fleet	66	92	143	208	253	286	330	372	427	519	623	700	779	926	1085	1237	1382	1529	1672	1888	1982
Large Non-DH-Fleet	1194	1208	1209	1170	1138	1087	1053	1022	998	943	835	784	676	580	478	426	402	370	318	243	177

3. Frequency of accidents leading to LOWI

Fig. 3 presents the annual frequency of the sum of the six (6) investigated main accidents types in the post-90 period, confirming the significantly decreased trend in that period (Papanikolaou and Eliopoulou, 2008).

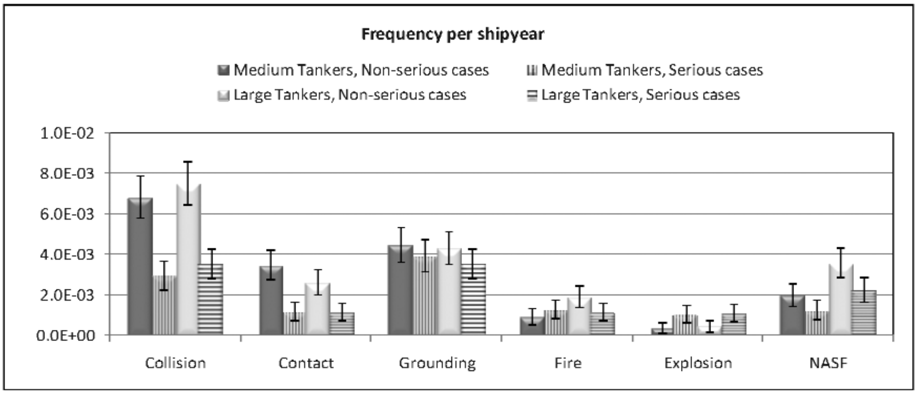
Figure 3. Frequency of occurrence of main tanker accidents per ship year – medium and large tankers



The accidental frequency behaviour is quite similar for both main tanker size categories (medium and large), with high peaks observed in year 1990 and progressively decreasing values in the years after by a factor 5 to 6, while presenting quite stable low values after 1999. Note that after 1999, the DH-fleet started having a considerable share in the overall tanker fleet, which means that the newbuildings entering the operational fleet at the year of census, have had enhanced implemented formal IMO procedures, complying with stricter rules, disposing enhanced design (double hull concept) and their crew undergoing enhanced safety training. Furthermore, even the existing single hull fleet had at that time to comply with a series of stricter regulations until their phase out, so that as a consequence the overall frequency of accidents decreased.

In Fig. 4, the average overall frequency for medium and large tankers is presented per accident category and degree of accidents' severity. Because of the nature of statistical data, it considered essential to establish the uncertainty margins of the obtained averaged values. Thus, confidence intervals were presented based on *binomial confidence analysis;* they are herein calculated as 95% confidence intervals correspond to the 95% probability that certain values will be met.

Figure 4. Frequencies of serious and non-serious events per ship year with uncertainty margins – main top events

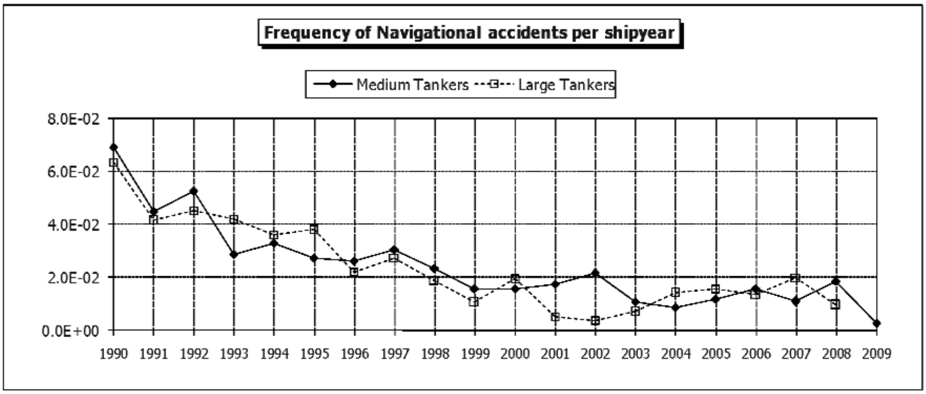


Focusing on the accidents with serious degree of severity, Fig. 4 (shaded columns), the following comments can be made:

- *Navigational accidents* (collision, contact and grounding) as well as *Non-accidental Structural Failures (NASF)* exhibit significantly lower frequencies of serious cases, compared to the non-serious ones; this is confirmed for both the medium and large tankers. However, latest investigations (IACS 2010, Hamann *et al.*, 2011) showed *significant underreporting* in cases of accidents with non-serious degree of severity, thus the particular difference may be actually *erratic*; in general, frequencies of accidents in the various categories appear similar between medium and large tankers, except for the NASF accidents, for which the frequencies of the large tankers are higher by an about factor 2.0.

- *Fire and Explosion* accidents appear to exhibit a different behaviour with respect to seriousness of accidents (with the recorded serious accidents prevailing), indicating that if such accident happen, higher probabilities of having serious consequences (and fatalities) should be expected.

Figure 5. Navigational accidental events, Frequency per ship year



3.1 Navigational Accidents

The frequency of navigational incidents' occurrence exhibits a steadily decreasing trend within the studied period, Fig. 5. Practically, after year 1999, the annual frequency of navigational accidents does not further decrease, but starts oscillating below an upper limit of about 2.0E-02.

Although the DH tanker concept does not affect the frequency of navigational incidents' occurrence, the entrance of new-built ships to the world fleet (in that case of DH concept) along with the more stringent regulations entering into force, contributed to the increase of tanker safety. The rationalization of shipping companies' operational procedures and management systems through the ISM Code, STCW, ETS, SOLAS provisions on routeing systems etc., that became mandatory for all ships, are some principal regulations that may have led to the particular frequency decrease.

Based on the collected data, some refined information regarding the probability of side damages vs. bottom damages can be extracted, which can be used for a rough verification of the corresponding probability assumptions embedded in MARPOL's provisions for the estimation of accidental oil outflow. Focusing on the sampling plan of serious navigational accidents and assuming that accidental side damages are related to collisions and contacts, whereas bottom damages are attributed to grounding events, the following probabilities were calculated:

- Medium tankers: 57% side damages – 43% bottom damages, related frequencies: 4.62E-03 side, 3.51E-03 bottom.
- Large tankers: 51% side damages – 49% bottom damages, related frequencies: 4.06E-03 side, 3.90E-03 bottom.

The above relationships should be compared to the 40% to 60% assumption of MARPOL's reg. 23 (Resolution MEPC.117 (52), 2004), which appears erratic and needs to be revisited.

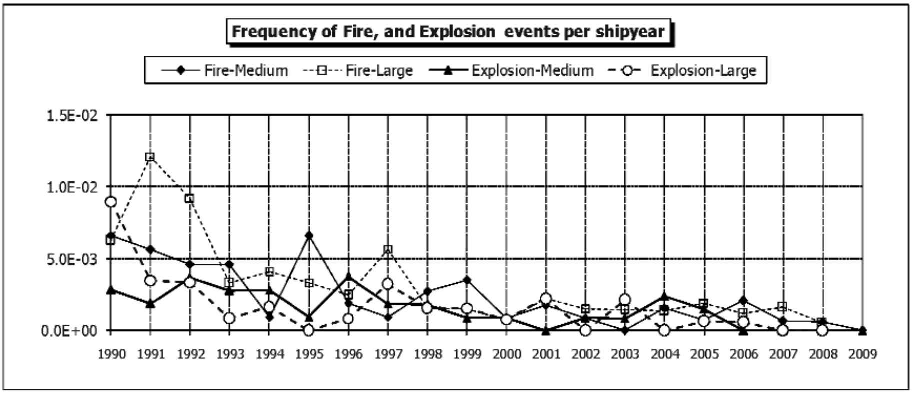
3.2 Fire and Explosion Accidents

According to the casualty analysis, fire was initiated inside the vessels in 92-96% of the reported events for both ship sizes. Considering these cases, fire started in ship's aft area in 89-95% of relevant cases, from which 83% started in the Engine Room.

Regarding the explosion events, there is a considerable probability of about 45% of cases for which fire followed an explosion, which is very important for the event sequence.

Fig. 6 presents a slightly decreasing tendency in the annual frequency of fire and explosion events along the studied period. Especially, in the second decade (after 1999), annual frequencies are confined within significantly smaller margins compared to the corresponding dates in the first decade of statistical analysis.

Figure 6. Fire, and Explosion events, Frequency per ship year



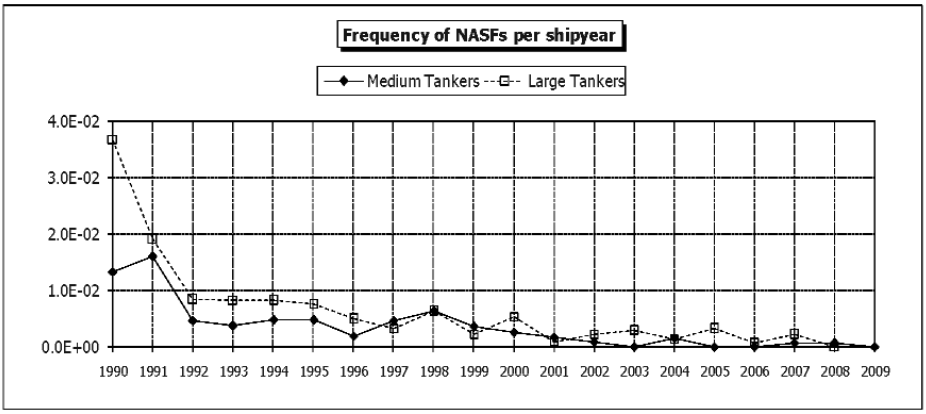
It is believed that the introduction of the ISM Code, the stricter requirements for *oil fuel lines' protection (SOLAS Chapter II-2)* that entered into force in 1998 for newbuildings, as well as the temperature sensing devices applied after 2002, have enhanced the safety of ships against fire and explosion events, as reflected in the above statistics.

3.3 Non-Accidental structural failures and the impact of ship's age

Fig. 7 presents the annual frequency of non-accidental structural failures for both tanker sizes within the studied period. In year 1990, large tankers exhibited a significant peak for the NASF frequency, namely 3.7E-02 (41 incidents), noting that about half of the occurred cases (19 incidents) were related to the largest size tanker ships (VLCC&ULCC size).

At first, the two main parameters of NASF risk analysis (frequencies and consequences) are studied in relation to ship's basic hull type of design (DH and Non-DH ships). Clearly, the consequence analysis is highly dependent on ship's basic design, because the DH concept gives a lower probability of pollution in scenarios with small hull penetrations in the cargo area. This effect of double hull can also be concluded from MARPOL's oil outflow model (MEPC.122 (56), 2004). Furthermore, the frequency parameter appears non-highly correlated to ship's basic design in cases of navigational events (collision, contact and grounding) or fire and explosion events. However, in cases of non-accidental structural failure (NASF), the frequency parameter is expected to be significantly dependent on hull type, because the particular event category is strongly correlated to ship's internal structure design and to related manufacturing/maintenance quality.

Figure 7. Non-Accidental Structural Failure, Frequency per ship year

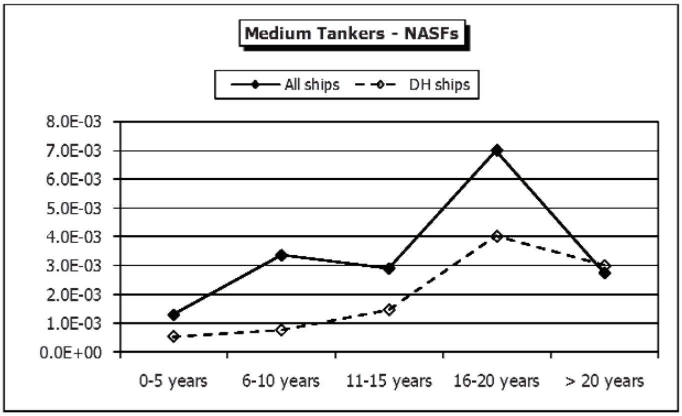


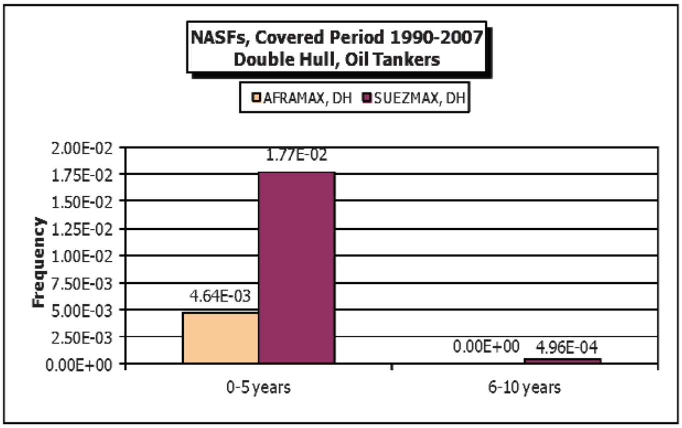
Focusing on the Double Hull large tankers, 22 non-accidental structural failures occurred over the studied period resulting to an average frequency of 1.8E-03; it is noted that *16 cases out of 22 registered NASF cases were reported for newly built ships,* namely in the group age of 0-5 ship's years old. Medium Double Hull Tankers present 12 occurred non-accidental structural failures yielding a frequency of 1.1E-03, which is actually lower than the corresponding one of large tankers and without any indication of higher frequency for the new-built ships.

In order to analyze this interesting relationship between NASF and ship's age, the ship age categories were broken down into five years periods and the corresponding number of accidents as well as the number of ship years were determined. At first, as single hull ships are inherently of higher age than double hull ships, it is essential to evaluate both ship types on a common age basis during the study period. Considering this and focusing on the NASF by group age, it is found that there is a peak in the middle age (16-20 years) group, whereas frequencies for more aged DH ships (over 20 years) are lower, Fig. 8 (diagram A). The latter can be explained by the fact that there are only very few operating DH ships over 20 years of age, therefore the uncertainty of the particular result is rather high.

Comparable results for large oil tankers show also complex (and may be unexpected) patterns of frequencies, namely high frequencies in the young age group (0-5 years), and then continuously increasing frequency after the 6-10 years of built. In the young age group (0-5 years) there is a remarkable structural failure rate for all large ship sub-sizes, except for VLCC/ULCC, Fig. 8 (diagram B) (Papanikolaou and Eliopoulou 2008).

Figure 8. Medium Tankers, NASF and group age, Large Tankers, NASF and group age



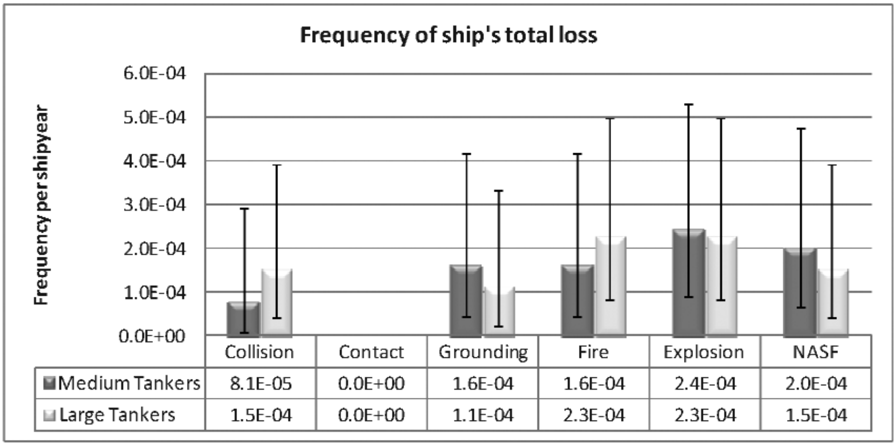


The above identified problems of NASF for tanker ships of relatively young age (especially for the large tankers) suggest problems in the *quality of recent newbuildings*, rather than typical fatigue type structural failures of properly fabricated ship structures (see, also, Papanikolaou and Eliopoulou, 2008). Thus, though one may expect that NASF problems are directly related to ship's age, this relationship is not straightforward but needs careful investigation of the actual causes of NASF in order to identify upcoming problems in due time.

4. Ship's total loss

Fig. 9 illustrates the frequency of ship's total loss for each incident category for large and medium tankers. Medium tankers present higher frequencies for grounding, NASF and almost the same value in case of explosion events, compared to the corresponding ones derived from the large tankers analysis. Moreover, large tankers exhibit higher corresponding frequencies in cases of collision and fire accidents. These observations, however, need to be considered with caution, because of the large statistical uncertainty due to the scarcity of related historical data.

Figure 9. Frequency of ship's total loss



5. Marine pollution

For the investigated tanker ship sizes, it is trivially confirmed that the larger the ship the more severe is the environmental impact in case of accidental loss of watertight integrity. Figs 10-11 present the oil released to the sea as a consequence of medium and large size oil tanker accidents during the studied time period.

Tables 2-3 present the Spill Tonne Rate per ship year along with the 95% confidence intervals (C.I.) that were determined for the mean obtained value. The spill tonne rates for large and medium tankers are not comparable, as could be expected, because of the large difference in the carried cargo capacity. It is acknowledged that the 95% confidence intervals with respect to the noted average values are quite wide, indicating that the spill tonne rates are decisively determined by a very limited number of individual accidents with large oil spills (catastrophic accidents), rather than by many small pollution events or average size.

Fig. 10. Medium Tankers- Marine pollution over the studied period

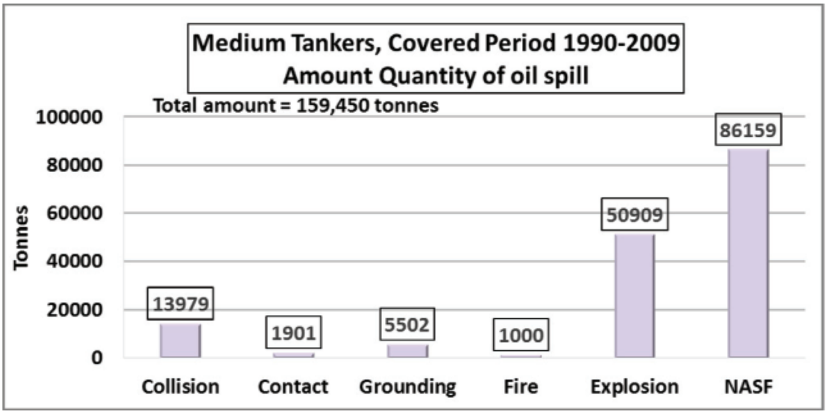


Figure 11. Large Tankers- Marine pollution over the studied period

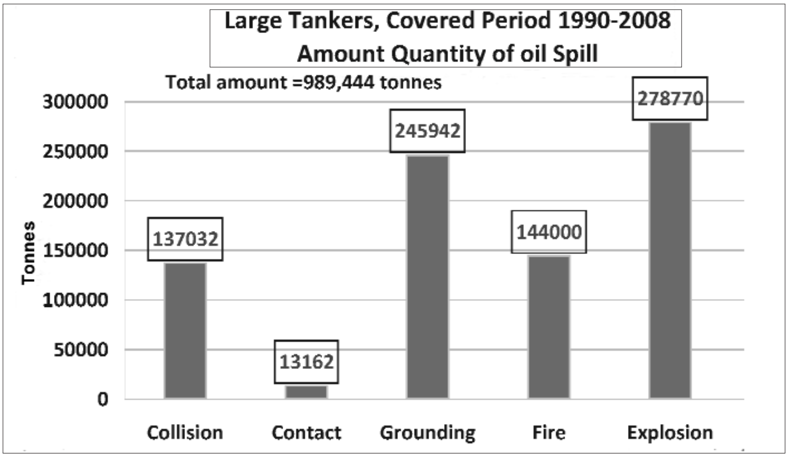


Table 2. Large tankers, Spill Tonne Rate per ship year

Large tankers		
Period	Spill tonne rates	C.I.
1990-2008	43.1	± 37.7
1990-1999	71.3	± 67.6
2000-2008	11.7	± 12.0

Table 3. Medium tankers, Spill tonne rate per ship year

Medium tankers		
Period	Spill tonne rates	C.I.
1990-2009	7.3	± 6.3
1990-1999	13.2	± 11.6
2000-2009	1.4	± 1.8

Proceeding to a more refined analysis for AFRAMAX tankers, the calculated oil released to the sea is 233,138 tonnes within the studied period (1990-2008). Taking into account that the AFRAMAX Fleet at Risk was calculated to be 9,786 shipyears and considering an average DWT value of 100,000 tonnes, also accounting for a ship's life cycle of 25 years period, this leads to about 0.6% DWT rate of oil per AFRAMAX ship, which is expected to be released to the sea within the ship's life cycle. This may be compared to the 0.015 (or 1.5% DWT) maximum allowable rate of oil spill for an AFRAMAX tanker according to MARPOL, reg. 23 (Resolution MEPC.117 (52), 2004) indicating that the MARPOL requirement is on the safe side.

6. Conclusions and the way ahead

The current study presented results of a systematic analysis of accidents pertaining to medium and large oil tankers (deadweight over 20 k tonnes) and covering the period after the introduction of OPA 90, namely 1990 to 2009 (October), continuing earlier studies of NTUA-SDL and Germanischer Lloyd on the design and safety of tankers. Calculated values derived from the statistics must be used with caution because available databases do not capture in general all accidents (problem of *under-reporting*), they partly include erratic information and provide always a snapshot of the status for a certain observation period. Thus, single accidents, when they happen, may have a significant impact on the accident frequencies and especially on the indentified consequences, especially when they are of *'catastrophic'* character. In order to show the uncertainty of the frequencies presented in this paper a confidence analysis was also presented referring to the initiating main top events.

The data in this paper provide the basis for the development of a risk model for medium size tankers, which complements earlier conducted studies for large tankers. Such a risk model should consider the uncertainty in the initial accident frequencies as well as in the dependent probabilities in the scenarios. This would allow considering the effect of uncertainty also in subsequent analyses, for instance in a cost-benefit analysis of design modifications (Hamann and Loer, 2010).

Having completed earlier the Formal Safety Assessment procedure for Large Oil Tankers (Denmark-IMO, 2008), the present study is the first one addressing systematically the effect of ship size in the frame of Formal Safety Assessment procedures providing information that will allow the development of more elaborated risk models taking into account the ship size. This is considered essential, particularly when dealing with ship types, for which their safety performance (here: safety of environment) may dramatically change with the increase of ship size. A comparison of the herein obtained results for the medium size tankers with corresponding ones for the large oil tankers enabled the identification of notable differences in the accidental pattern, though overall trends are comparable. Also, some important conclusions regarding relevant regulatory provisions of MARPOL regarding the accidental oil outflow index were enabled.

In the next stage of this research, which will be complemented by the analysis of accidental data of the *small tankers* (deadweight below 20 k tons), the societal risk will be calculated and expressed by FN diagrams (denoting cumulative frequencies of losses of human lives) and FT diagrams (denoting cumulative frequencies of oil pollution in tonnes, i.e. the environmental impact by oil spillage); this will allow even more comprehensive conclusions on the safety of oil transport by all sizes of tankers.

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