

Review of statistical data on ship accidents

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ABSTRACT: The present study reviews several recent analyses occupied with statistics of ship accidents. The review is focused on major types of accidents having the potential to lead to ship total loss. Available references dealing with statistics of ship accidents are mutually compared with respect to frequencies of accidents for certain period, type of accident, ship type, ship design and age, the degree of accident severity, geographical areas and weather conditions in time of accident. The aim of the present review is to identify possible uncertainties in statistical data from various sources which are necessary for the risk assessment studies of the maritime transportation. Although different ship types are covered by this review, the focus is on oil tankers as the most important pollution sources.

1 INTRODUCTION

Safety of ships at sea is one of the main concerns of all the parties involved with maritime industries – ship designers, shipbuilders and ship owners, and all of them want to avoid serious outcomes of ship accidents leading to the enormous penalties, in terms of lives lost, damage to the environment and to cargo. Therefore, last 40 years more attention is given to the design and building activities, to the operation of the ships and the education and training of the ship operators. Risk-based methods are nowadays introduced in ship design process to provide rational basis for making decisions regarding new design concepts and regulating different operational aspects (Downes et al. 2007). One aspect that cannot be avoided in the risk assessment is the probability of occurrence of the accidental damage. Such probabilities of different accidents are mostly obtained from statistics of historical data of ship incidents. This is the main purpose of the present study, i.e. to provide necessary input data for risk assessment of the maritime transportation. In particular, the paper deals with accident statistics of the events that could precede to the ship capsizing or ultimate hull girder failure of the ship, being the most unfavorable outcome of the marine accident.

Grounding, collision or other similar type of damage can lead to water intake and capsizing. As the direct consequence of the well-known accident of the Titanic in 1914 is the enhancement of the concept of subdivision of ships in watertight compartments. This concept was probably one of the early ones with probabilistic assessments of risk of failure (Guedes Soares and Teixeira 2001).

The ultimate structural failure as another major type of ship accident may occur due to unfavorable

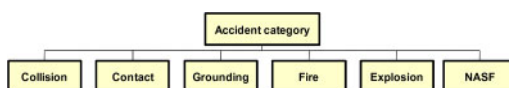


Figure 1. Casualty categorization for risk assessment (NASF: non-accidental structural failure).

environmental conditions or due to human errors during the design or operation of the ship. The most frequent ways of ship accidents leading to ultimate structural failure are collision or grounding, but still there are more types of main hazards. Structural reliability theory has been used for some time to quantify the probability of structural failures and the contribution of different components to it.

In order to conduct a risk assessment, it is necessary to analyze the available casualty data and to investigate the historical risk as a first step in the process of comprehensive potential risk evaluation. This paper provides review of published statistics dealing with different ship accident aspects of different ship types. However, the accent is given to the tankers as the biggest pollution sources. The focus of the present review is on the comparison of data originating from different sources, aiming to find out degree of the agreement among different statistical studies.

2 SHIP CASUALTY STATISTICS

The main six categories of accidents are covered in the contemporary statistical analyses, namely collision, contact, grounding, fire, explosion and non-accidental structural failure (NASF) (Figure 1).

2.1 General statistics of serious accidents and total ship losses

Total loss analysis is performed by Guedes Soares and Teixeira (2001) for the purpose of Formal Safety Assessment (FSA). They considered the operational fleet at risk, covering all ships larger than 100 gross tons, except fishing vessels. The fleet at risk has been steadily increasing although from 1978 to 1986 the tendency has slowed. The total loss rates per ship year were calculated by dividing the total yearly number of accidents by the number of ships operational in that year (annual fleet at risk). An evident decreasing trend of the ship losses rate is found.

The number of total annual losses of all ships for period 1997–2013 are published in two independent studies performed by Southampton Solent University (Butt et al., 2013) and Allianz Insurance (Allianz Global Corporate & Specialty) (AGCS, 2014).

Number of the total vessel losses for the period 1997–2011 is nearly constant according to Butt et al. (2013). On the other hand, the AGCS (2014) analysis shows firstly constant trend followed by significant decrease. Comparing the values of these two statistics for the overlapping period 2002–2011, the AGCS statistic presents higher total loss values from 2002 to 2008, while much lower annual number of losses between 2009 and 2013.

Accident data extracted from the Information Handling Services (IHS) Seaweb database and operational fleet at risk calculated from the Lloyd's Register of Shipping database, for ships of different types built after 1980, regardless ship size, are presented by Papanikolaou et al. (2015). In total, 10841 serious accidents were considered for the period 1990–2012, among which 960 total losses. Total number of ships in fleet at risk for that period reads 602998. From that, one may calculate average annual accident frequency of $1.8E-02$, while average annual frequency of total losses reads $1.6E-03$. Concerning large oil tankers, average annual frequency of serious accidents in period 2000–2012 reads $1.28E-02$. Total losses of large crude oil tankers are so rare, that average annual frequency of their total losses is equal to zero.

One interesting conclusion by Papanikolaou et al. (2015) is that frequency of accidents has increased for most ship types for period 2000–2012 compared to 1990–2012. The increase was explained by growth of the traffic intensity in some areas in the case of navigational accidents and by improving of the practice of accident recording in the last decade.

Annual frequencies of total losses by Guedes Soares & Teixeira (2001), Butt et al. (2013) and AGCS (2014) are presented together in Figure 2, for the comparative purpose.

2.2 Accident statistics considering the type of accident

Comparison of the relative values of ship losses for each accident category in relation to the total number of losses is presented in Figure 3. It appears that

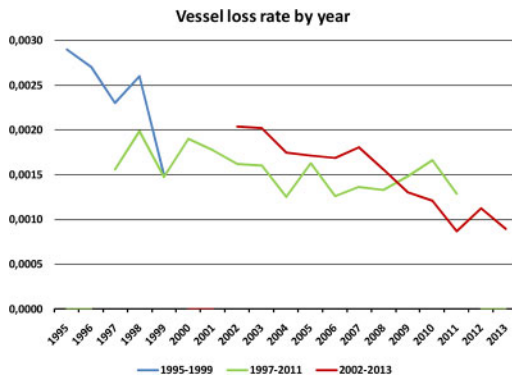


Figure 2. Comparison of frequencies of total losses (blue – Guedes Soares & Teixeira, 2001; green – Butt et al., 2013; red – AGCS, 2014).

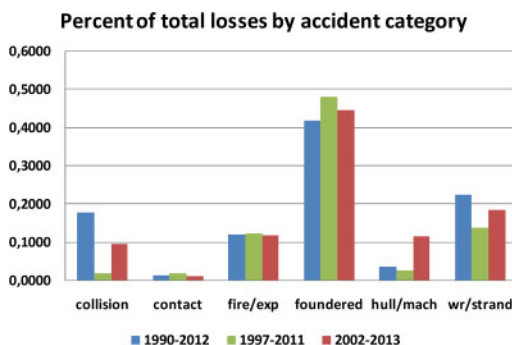


Figure 3. Percent of total losses by accident category for different periods (blue – Papanikolaou et al., 2015; green – Butt et al., 2013; red – AGCS, 2014).

percent of losses due to foundering is very high, i.e. between 40% and 50% of losses. Foundering is defined as sinking due to rough weather, leaks or breaking in two. The next most important accident is stranding, followed by collision and fire/explosion.

Comparison of the numbers of large and medium oil tanker accidents by accident categories is given by Papanikolaou and Eliopoulou (2008) and Eliopoulou et al. (2010). The highest percentage are collision accidents (33% of all accidents), while grounding accidents are on the second place (24% and 28% for large and medium oil tankers respectively). Contact accidents, which are often considered together with collision, represent 11% and 16% of all accidents for large and medium oil tankers respectively.

Obviously, the level of susceptibility of certain ship type relating kind of casualty is different. The analysis of initial events preceding total loss is performed for tankers, bulk carriers and containerships in the period 1983–1993 (Guedes Soares and Teixeira 2001). The most important initial cause of accidents was fire/explosion for tankers while grounding, fire/explosion and hull problems for bulk carriers.

Table 1. Percent of total losses by common ship types (Papanikolaou et al., 2015; Butt et al., 2013; AGCS, 2014).

Ship type	1990–2012	1997–2011	2002–2013
General Cargo	52	42	41
Bulk Carriers	10	8	7
Fishing	24	24	19
Passenger	7	6	6

2.3 Accident statistics considering the ship type

Comparison of percentages of total losses by ship types published by three different authors is given in Table 1. The highest percent belongs to general cargo ship type and it amounts around 40–50% of total losses. As general cargo ships can carry a multitude cargo, they are often operating short sea shipping routes and navigating in congested coastal areas with the higher risk of being damaged by submerged reefs and rocks.

Samuelides et al. (2009) have analyzed probability of occurrence of grounding, based on a database of accidents involving Greek ships from 1992 to 2005. The calculated yearly grounding probabilities for different ship types in the period 1995–2005 are as follows: Cargo – $1.43\text{E}-02$, Tankers – $6.94\text{E}-03$, Passenger and other ship types – $8.33\text{E}-03$. These values are slightly reduced for period 2001–2005, except that for tankers this value is reduced by factor of two.

2.4 Influence of the regulation on the accident statistics

Majority of the present databases, statistic analysis and projects relate to tankers, as the biggest environmental pollutants if we consider all ship types. As the result of the attention given to the tragic accidents involving tankers over the last decades, the influence of the regulations development and enhancement can be qualified as very positive. Navigational accident rates for Aframax tankers are shown with accent on regulation influence over the period 1978–2003 by Eliopoulou and Papanikolaou (2007) and IMO (2008). The effect of the regulations is noticeable with some phase-lag in relation to the years of their implementation. Papanikolaou and Eliopoulou (2008) presented decrease of the accident rate by the main accident categories (LOWI) for all tanker types over the period 1980–2007.

There was a significant reduction of accidents occurrence in the post-90 period due to the introduction of a series of regulations (with the most prominent one being OPA 90) on the prevention and mitigation of accidents. Eliopoulou and Papanikolaou (2007) showed, taking into account accidents with serious consequences only, including ship total losses, a considerable reduction of accident frequencies in the post-1990 period. Thus, for all types of tankers, frequency of serious accidents or total losses was reduced from about $2.0\text{E}-02$ to about $8.0\text{E}-03$ for pre-1990 and post-1990 period respectively.

2.5 Accident statistics considering the degree of accident severity

The degree of accident severity can be expressed in terms of loss of lives/injuries, environmental pollution and loss of property.

Overview of the number of lives/injuries by ship type is shown by Papanikolaou et al. (2015). Number of recorded fatalities (i.e. sum of “killed” and “missing” persons) per ship type, shows that about 64% is relating the ships carrying a relative large number of persons on board.

The main parameters of environmental pollution usually used for evaluation of the risk are number of oil spills, volume of oil spilt and the spill rates in tonnes per ship-year. The spills are generally categorised by size, i.e. <7 tonnes, 7–700 tonnes and >700 tonnes. It is interesting to mention that, according to IMO FSA (2008), tanker accidents participate with only 4.7% in the entire pollution quantity.

According to International Tanker Owners Pollution Federation (ITOPF) database of oil spills from tankers, combined carriers and barges, excluding those resulting from acts of war, approximately 5.74 million tonnes of oil were lost in the period 1970–2014 (ITOPF, 2015). The same reference shows that the number of oil spills and volume of oil spilt are significantly reduced through the decades.

Eliopoulou et al. (2013) compared the amount of oil spilt in the case of medium and large oil tankers in the period 1990–2009. They concluded that accidental LOWIs of large ships result in the more severe environmental pollution for all types of damages. Pollution caused by medium-size tankers was primarily attributed to the accidents of the oil tanker Thanassis in 1994 and Erika in 1999, while the consequences of the accident of large-size tanker Prestige in 2002, resulted in stricter controls of tanker operations and the accelerated phase-out of single-hull tankers from European waters.

2.6 Accident statistics considering ship design

As a consequence of catastrophic accident of Exxon Valdez in 1989, only one year later the new double-hull (DH) concept was introduced by adoption of the first major regional agreement OPA 90 (Eliopoulou et al. 2013). This document had a significant influence on regulatory developments in the post-1990 period, resulting in the significant decrease of the frequency of tanker accidents.

Considering the spillage into the sea as ship accident consequence, in relation to ship’s basic design, it is obviously highly dependent for all types of accidents, because the DH concept gives a lower non-pollution probability for accidents with small hull penetrations in the cargo area (Papanikolaou and Eliopoulou 2008).

Furthermore, the analysis of the relationship between the accident frequency as the risk parameter and ship’s design, shows that only in the cases of NASF, it may differ significantly depending on the hull type,

because only this accident category is highly related to the ship's internal structure.

In year 2006, Common Structural Rules (CSR) for Tankers are adopted as the consequence of structural defects statistics presented in ABS et al. (2005). Damage statistics for double hull tankers was performed by Classification Societies based upon their damage database records for all tankers of 150 m in length or greater. By relating the number of ships with some structural defects to number of ships in class, the following percents are obtained: Product – 8%, Panamax – 13%, Aframax – 18%, Suezmax – 26%, VLCC – 21%. Altogether 15% of the ships in the fleet had some type of structural damage. The consequences, in term of damage statistics, of application of CSR are still not known, but it will be interesting to see such data in the future years.

2.7 Accident statistics considering the age of ships

Analysis performed for large oil tankers accidents from the period 1990–2007 is presented by Papanikolaou and Eliopoulou (2008). They concluded that the frequency of navigational accidents increases for ships of 15 years and older. But the highest frequencies of accidents have young ships, within first 5 years of their lifetime. According to authors of that study, high accident frequencies of young ships are related to crew's proper training, communication problems and to crew's ability to handle new technology equipment.

In the case of fire and explosion, higher frequencies are calculated for higher ship ages independently of the hull type.

Considering NASF and ship's age of all large oil tankers, it is concluded that frequency of accidents steadily increases after the ships reach the age of 10 years. A peak for Aframax and Suezmax tankers is noticed at the age group 11–15, which might be attributed to insufficient maintenance of the ship's hull structure when approaching her assumed design economic life of about 20 years. Surprisingly, young ships of age up to 5 years, show remarkable structural failure rate for all large tanker subtypes, except for VLCC/ULCC. Additionally, it would be important to mention, that for period 1990–2007, all the DH ships involved in accidents during bad weather conditions were at the group age up to 5 years, too early for the maintenance problems.

As the part of the tanker defects statistics presented in ABS et al. (2005), the distribution of defects over the ships life for each ship size category is given. It seems important to notice that almost 37% of the tankers with defects were 5 to 9 years old, while in more than 80% cases, defects have been recorded on ships younger than 15 year.

According to statistic for period 1997–2006, presented by ISSC (2009) Committee for Condition Assessment of Aged Ships and Offshore Structures, non-accidental hull damage ranks the top five causes leading to total vessel loss for vessels greater than 500 GT, with the increasing trend during the last four years 2002–2006. In that report, statistical analysis of total

losses for tankers and bulk carriers shows the increasing trend of vessel losses related to the age of the vessels, although the previous ISSC reports mentioned that the average age of vessels lost was only slightly more than the average age of the existing fleet.

2.8 Accident statistics considering the adverse weather conditions

Database compilation and statistical analysis of marine accidents in heavy weather conditions for different ship types and period 1990–2013 are presented by Ventikos et al. (2015). 239 accidents were analyzed. It was found that number of accidents involving Ro-Ro ships (24% of accidents) is relatively much higher comparing to the number of Fleet at Risk for these ships (8%). Also, there are significantly less Container ships accidents (4%) comparing to Fleet at Risk number (12%).

Considering type of accident and location, it was found that the highest percents belong to accidents due to grounding and accidents which took place in the ports. Most accidents that happened in the port involve Ro-Ro Ferries (19%), General Cargo Ships (14%) and Bulk Carriers (10%). High frequency of accidents for General Cargo Ships is explained by trading routes with frequent port calls, while for Ro-Ro Ferries high wind profile area is the most influencing factor in the hampering the ship under adverse weather conditions.

Ventikos et al. (2015) reported also increasing trend in number of accidents up to 2007, which is mostly caused by greater number of ships that were in service during that period, i.e. increase of demand for cargoes for China's infrastructure development influenced the increase of 230% for Bulk Carrier Fleet at Risk and 40% for General Cargo Fleet at Risk in the period 2001–2010.

2.9 Accident statistics considering the geographic area

Regarding the geographic areas in which accidents have occurred, the IHS Sea-web database uses the "SIS zones" topological system, according to which, the surface on earth has been divided into 31 zones i.e. the major areas of interest. 18 geographic areas with more frequent accidents are identified and signed according to SIS zones system: South China, Indo China, Indonesia and Philippines (12); East Mediterranean and Black Sea (4); Japan, Korea and North China (13); British Isles, North Sea, Eng. Channel and Bay of Biscay (1); Arabian Gulf and approaches (8); West African Coast (19); (West Mediterranean (5); West Indies (23); East African Coast (9); Bay of Bengal (11); Canadian Arctic and Alaska (27); Baltic (2); Great Lakes (26); Gulf of Mexico (25); North American West Coast (21); Iceland and Northern Norway (29); Newfoundland (28); U.S. Eastern Sea Board (24).

The comparative statistics of different authors for these areas is presented in Figure 4. From Figure 21 it can be concluded that areas 1, 12, 13 and 4 are the most

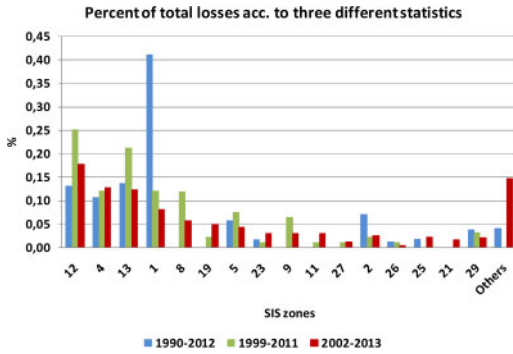


Figure 4. Percents of total losses by geographical regions for periods 1999–2011 and 2002–2013 (blue – Papanikolaou et al., 2015; green – Butt et al., 2013; red – AGCS, 2014).

Table 2. Average incident rates per shipyears and probability of LOWI for Aframax tankers (1990–2003) (Downes et al., 2007).

Incident type	Average rate	% of LOWI
Structural failure	1.82E-03	29.8
Collision	4.41E-03	16.7
Contact	1.48E-03	23.8
Grounding	3.64E-03	18.6
Fire	1.83E-03	1.00
Explosion	1.84E-03	12.8

accidentally risky area. Percentages of total losses in Figure 4 represent the number of total losses for certain geographical area in relation to number of all total losses.

2.10 Importance of accident statistics for ship structural risk and reliability analysis

The accident scenarios define possible situations, realistic as closely as possible regarding the risk to the ship and/or environment. As some incidents have major implications to the ship and/or environment, whereas others with less severe consequences occur much more frequently, the probability of occurrence should be taken into account. One of the approaches typically used for deriving the accident scenarios and their associated probability of occurrence is statistics from historical data.

Scenarios identification and accident probability calculation is undertaken for Aframax Tanker by Downes et al. (2007). If the structural failure analyses assume rupture of hull structure, then the incident rates of initial event need to be adjusted for the probability of loss of watertight integrity (Table 2).

The annual probability of hull girder's failure caused by grounding of oil tanker is evaluated by Prestileo et al. (2013). They calculated the probabilities of hull girder's failure conditional to the bottom damage. Annual frequency of tanker accidents is taken

Table 3. Annual accident probabilities of oil tankers used in structural reliability studies

Ref.	Collision	Grounding
Downes et al. (2007)	1.19E-03	6.77E-04
Prestileo et al. (2013)	6.52E-03	4.64E-03
IACS (2014)	1.03E-02	7.45E-03

for year 2007, which, in the case of grounding and collision, reads $4.64E-03$ and $6.52E-03$, respectively. The accuracy of the probabilistic model is evaluated by comparing calculated ultimate failure probability with a prediction of ship losses based on statistics provided by International Organization of Oil and Gas Producers (OGP). According to that source, the total loss frequency for oil tankers per ship year is $1.90E-03$.

According to the report from the Committee V.1 (Accidental Limit State) within ISSC 2015, the annual probability of accident event extracted from the casualty statistics of tankers is taken as $7.45E-03$ and $1.03E-02$ for grounding or collision, respectively. ISSC report originates from the IACS background document used in development of Harmonized Common Structural Rules (IACS, 2014). Both documents are consistent to IMO (2008).

These results are summarized in Table 3, showing annual probability of collision and grounding accidents for oil tankers, assumed by different researchers in structural reliability studies of damaged ships. It should be mentioned that Downes et al. (2007) considered contact and collision together and that their values in Table 2 include also probability of LOWI.

Compared Table 3 to the presented survey of literature dealing with the statistics of ship accidents, it may be concluded that frequency of collision accidents for oil tankers is consistently higher compared to frequency of grounding accidents (section 2.2).

Annual grounding probability of $6.94E-03$ for tankers presented by Samuelides et al. (2009), also seems to be consistent with last two rows in Table 3. According to the recent analysis by Papanikolaou et al., (2015), frequency of serious accidents of oil tankers in period 2000–2012 reads $1.28E-02$. About 45% of all accidents belongs to collision and contact, resulting in the collision accident probability of $5.76E-03$. About 26% of accidents are grounding accidents, resulting in grounding probability of $3.3E-03$. Compared to the Table 3, it seems that annual accident probabilities used by Prestileo et al. (2013) are in the relatively good agreement with these values.

Total losses of large oil tankers are rare events, and empirical frequencies to be used in structural reliability studies are rather uncertain. The assumed total loss frequency for oil tankers per ship year of $1.90E-03$ (Prestileo et al., 2013) seems to be consistent to average annual frequency of total losses of $1.60E-03$ of all ship types (Papanikolaou et al., 2015). Annual frequency of serious accidents or total losses of oil tankers after 1990 of about $8.0E-03$ (Eliopoulou and

Papanikolaou, 2007) is higher than previous values as it includes serious accidents in addition to the total losses.

3 CONCLUSIONS

Recent references dealing with statistics of ship accidents are reviewed. It was found that statistics of accidents are highly dependent on the new maritime regulations and changes in ship design. The most important design modification is the introduction of the double hull concept for oil tankers in 1990. Consequently, a significant decrease of the frequency of tanker accidents causing pollution is evident in the post-1990 period. Therefore, usage of older statistical data not incorporating these important changes is not recommended. Another difficulty lies in a fact that new regulations are visible with some phase-lag in relation to the years of their implementation. Therefore, even the recent statistical data could be unreliable if the influence of new structural rules or new navigational equipment (such as Automatic Identification System, AIS) is not included.

According to statistics, the accident frequencies for the last decade have been increased in general, what is attributed to improved accidents recording practice and traffic increase in some areas. However, the frequency of total losses is decreasing, in particular for oil tankers. It is interesting to mention that young DH tankers show unexpectedly high frequency of NASF problems.

The highest accident rates by ship type are presented for General Cargo, Bulk Carriers, Passenger and Fishing vessels, respectively, what is mostly attributed to ship routes and certain features of the ship type i.e. the large windage area of the passenger ships.

Casualty databases provide important information for the structural reliability assessment of damaged ships. However, as may be seen in Table 3, there are still considerable uncertainties in definition of annual probabilities of oil tanker accidents. Uncertainties are not caused by wrong data, but because of high sensitivity of the accidental frequencies to the period of investigation, i.e. if annual accident frequency is calculated for one particular year or as an average value for several years. Also, differences could appear if different sub-types of ships are considered together or separately.

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