

Study of grounding incidents: description of contact and frequency of occurrence

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Abstract

Accidental impacts of ships and other floating or fixed structures – collisions - or the sea bed – groundings - cause great concern, because of the catastrophic consequences they may have to the environment and the fatalities associated with them. The concern is much greater for ships that carry cargo that is harmful to the environment and in the case of passenger ships, whereby an accident may result in the loss of human lives. Accidental Limit State analysis provides a basic methodology for the assessment of the grounding behaviour of a ship. The application of the method requires the definition of grounding scenarios and the associated probability of occurrence. The paper investigates on one hand the grounding actions to which a ship structure is subjected to during grounding and on the other hand grounding related statistics. The investigation is based on a database of accidents involving Greek ships from 1992 to 2005 and on the examination of actual grounding incidents.

Keywords

Grounding; accident statistics, grounding actions; Greek fleet.

1. Introduction

The design of conventional vessels aims in a structure that has a strength capacity higher than the minimum required to avoid structural failure from operational loads and environmental loads. Accidental loads are usually not explicitly considered in the design of conventional vessels, with the exception of loads acting as a consequence of flooding, in accordance with the assumptions made in IMO regulations. However accidental impacts of ships and other floating or fixed structures – collisions - or the sea bed – groundings - cause great concern, because of the catastrophic consequences they may have to the environment and the

fatalities associated with them. The concern is much greater for ships that carry cargo that is harmful to the environment and in the case of passenger ships, whereby an accident may result in the loss of human lives.

In order to mitigate the consequences of a collision of ships that present particular hazards, designers have proposed design configurations, which exhibit relatively improved behavior during collisions, and competent authorities have issued rules or guidelines defining requirements that a ship structure must meet to decrease the risk involved in case she is involved in a collision. Examples of designs against collision actions are those of the collision barriers of nuclear powered merchant or navy ships – see for example Dodd et al (1960) and Woisin (1979) - and of vessels transporting irradiated fuel (Suzuki et al, 2000). In those cases the volume containing the reactor or the hazardous cargo was protected by a collision barrier consisting of relatively closely spaced plates. A more recent example of a structural design with improved collision behavior is the design of a novel side structure for a 8500 ton DWT chemical tanker for inland shipping (Vredevelt et al, 2004). In the later case the improved design allowed the increase of volume of cargo tanks from 380 m³ to 758 m³, without increasing the risk involved in a collision. Examples of rules or guidelines relevant to collision actions that affect the structural design of ships are these issued by Germanischer Lloyd (2004), DNV (2004) or the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (AND, 2005). A survey of design requirements relevant to collisions have been reviewed by Samuelides et al (2006).

Although groundings occur more often rather than collisions, the rules for building vessels do not explicitly refer to grounding actions. Mitigation of the consequences of such accidents is usually achieved through defining a certain distance between inner and outer bottom, defining appropriate arrangement of

cargo and fuel tanks and limiting their size IACS (2006).

2. Accidental Limit State

A general method for the assessment of the behavior of a ship involved in accidents is the Accidental Limit State (ALS) analysis. In accordance with it, the ship is tested against accidental scenarios and it is assessed whether the results of the accident or the accidents are acceptable or not. Similar procedures exist for the assessment of the behavior of the vessels under service loads (Serviceability Limit State – SLS), ultimate loads (Ultimate Limit State – ULS) and fatigue loads (Fatigue Limit State – FLS). Obviously each of the four limit states is associated with different set(s) of actions that are imposed on the ship under assessment and different acceptance criteria.

In order to perform an Accidental Limit State assessment, associated with the strength of the ship structure in case she grounds, there is a need

- a) to define one or more grounding scenarios, in which the ship under assessment will be involved,
- b) to perform structural analysis to determine the structural response of the ship under grounding actions,
- c) to define acceptance criteria associated with grounding of a ship, and which primarily aim in avoiding the loss of human lives, environmental pollution and acceptable financial losses, and
- d) to compare the response of the ship with the acceptance criteria.

The ALS analysis may be deterministic or probabilistic. If a deterministic analysis is chosen, the ship is tested under one or more unfavorable grounding scenarios with relative low level of occurrence probability. In the case of a probabilistic analysis the researcher must define a number of grounding scenarios, each one associated with a probability level. The behavior of the ship is then calculated as the sum of the products of the consequences related to each grounding scenario times the probability of its occurrence, i.e. the associated risk. In both cases the definition of the grounding scenario requires on one hand the selection of a number of parameters, which could describe at least the condition prior and during grounding, such as the speed of ship, sea bed topology, weather conditions, and on the other hand the probability of occurrence that is associated with the scenario.

The paper addresses the definition of grounding scenarios, which could be used for an Accidental Limit State analysis of ships involved in grounding. Both aspects, i.e. a) the probability of grounding occurrence, and b) the definition of grounding scenarios are investigated and discussed.

3. Grounding statistics – Review

The probability of grounding occurrence and in general accident occurrence may be computed from statistics

from historical data, expert opinions and predictive calculations. Historical data provide realistic figures, which nevertheless should be used with caution for future predictions, because a) they are relevant to structures, which may differ from those in use today, and b) operation methods are usually improved with time, in order to offer higher safety standards.

Using the data from LR of Shipping's World Casualty Statistics, Zhu et al (2001) reported that the total losses of all ships during the years 1995–1998 are 674 in number and 3.26 million in gross tonnage. Grounding accounts for total losses amounting to 17% in number and 24% in GT. The grounding incident rate for Ro-Ro and merchant navy ship types with lengths greater than 100 m for incidents in the period 1990–1999 inclusive is approximately 0.02 per ship year, which is about half the incident rate for ship collision and implies that if it is assumed that the life of a ship is 25 years, every second ship is expected to experience grounding in her life. Only one grounding incident resulted in a total loss, all the others were recovered. The figures were extracted from data of 1800 ship years.

A study at the Helsinki University of Technology, Kujala et al (1999), revealed that according to an accident data base maintained by the Finish Board of Navigation, over half of all impact incidents were groundings and 48% occurred near islands or in narrow waters.

4. The Database to be Elaborated

The following sections present statistical figures, that are computed on the basis of the accidents of ships with Greek flag from 1992 to 2005.

In order to proceed to a thorough and in depth statistical analysis, data of adequate quantity and quality should be found. The identification of such data is not a trivial task and should be dealt with extreme caution. More specifically, the records should contain all necessary information and therefore be able to support an exhaustive exercise; this way, the statistical approach can lead to exploitable and useful results.

In effect, the main body of data that it was used for the needs of this analysis came from the Hellenic Ministry of Mercantile Marine and, in particular, from the Directorate of the Safety of Navigation with accident records covering the time period from 1992 to 2005. The database contains all the cases of accidents (incl. groundings) of ships sailing under the Greek flag with size over 100GT, in a worldwide basis. Its high-level structure comprises of the following fields of information:

- DATE of ACCIDENT;
- SHIP TYPE;
- SHIP NAME;
- NUMBER & PORT of REGISTRY;
- IMO NUMBER;

- SHIP SIZE (GT);
- AGE of BUILT;
- AREA of ACCIDENT;
- TYPE & CAUSE of ACCIDENT; it refers to the first misfortunate event in a chronological order, indicatively:
 - Collision/Allision;
 - Grounding
 - Fire/Explosion;
 - Non Accidental Structural Failure
 - Mechanical damage;
- RESULT of ACCIDENT, indicatively:
 - Towing;
 - Loss of steering;
 - Pollution;
 - Insurance loss;
 - Total loss;
- LOSS of LIVES;
- NUMBER of INJURIES;
- ACCOUNT of RESPONSIBILITY, a decision derived by the Interrogation Council of Marine Accidents of the Hellenic Ministry of Mercantile Marine.

It is noted that the Interrogation Council of Marine Accidents of the Hellenic Ministry of Mercantile Marine is the responsible body for the conduction of inquiries with regards to marine accidents that involved Greek flag vessels all over the world. It comprises by Coast Guard officers, engineers, lawyers, etc. Hence it is charged to assign responsibility to crew members or onshore personnel in case their guilt/involvement is adequately proven (Psarftis et.al., 1998).

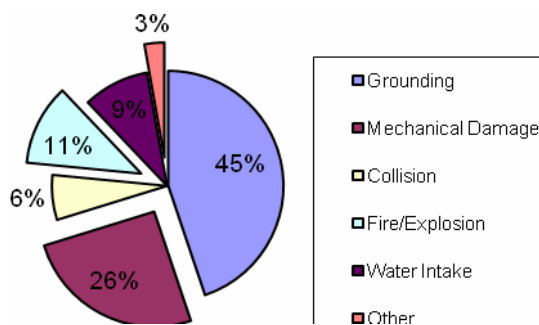


Fig. 1: Distribution of marine accidents per type.

The initial developed database was submitted to several screening phases in order to avoid duplicate records, records with ships of size smaller than 100 GT etc; in effect the final version of the utilized database comprised for the period 1992-2005 of more than 570 valid records. If the focus is put on groundings then the respective figure (for all types of ships) reaches the 256 accidents. Figure 1 gives the distribution of accident types vis-à-vis Greek vessels for the aforementioned period in a worldwide basis.

Furthermore, the Statistical Service of the Hellenic Ministry of Mercantile Marine was the source for the gathering of important data in relation to size of the

Greek merchant fleet in terms of number of ships, fleet size (in GT) and type of vessels, for the examined period.

5. Statistical Results and Charts

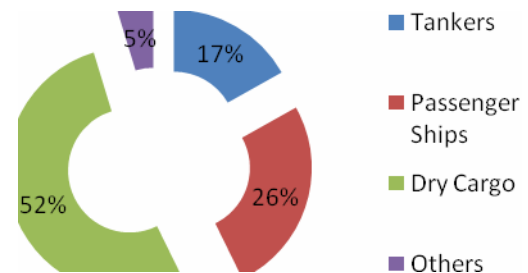


Fig. 2: Distribution of groundings per ship type.

The results from a thorough statistical analysis can provide a complete picture of the status of the Greek fleet in relation to marine accidents and if this is the case in relation to grounding. As already depicted in Figure 1 grounding is by far the most frequent marine accident type that is encountered in the utilized database. This means that if the causes that lead to groundings can be identified then there is a good chance for some corrective actions in order to act proactively and strengthen the overall safety of the Greek merchant fleet. Figure 2 shows the distribution of groundings in the Greek fleet for the period 1992-2005 per ship type; hence it is the dry cargo vessels (e.g. bulk carriers, container ships, general cargo vessels etc) that seem to be suffering the most from the specific type of accident. This finding becomes more apparent if we take into account that cargo ships account for only 33% of the Greek fleet over 100GT for the 11 year period, from 1995 until 2005 (see composition of Greek fleet presented in Figure 3).

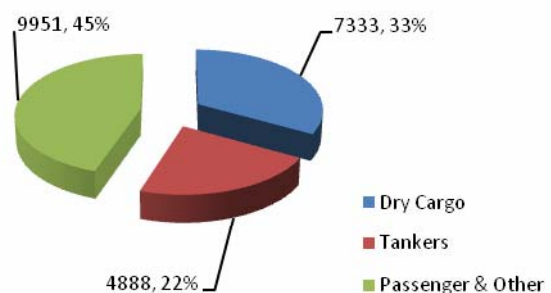


Fig. 3: Composition of Greek fleet over 100 GT in ship years from 1995 to 2005.

Figure 4 gives the distribution of groundings (when recorded as first events in the accident timeline) for Greek vessels with regards to whether they have led to oil pollution or not, and according to the vessel type. In effect, the vast majority of groundings (98%) for the

period 1992-2005 did not give any oil pollution. The remaining 2% polluted the seas with a percentage 3:1 between tankers and dry cargo vessels. Thus, Greek ships seem to avoid pollution when they initially get grounded; nevertheless if there is pollution, then the tankers are the most dangerous ones according to the elaborated database.

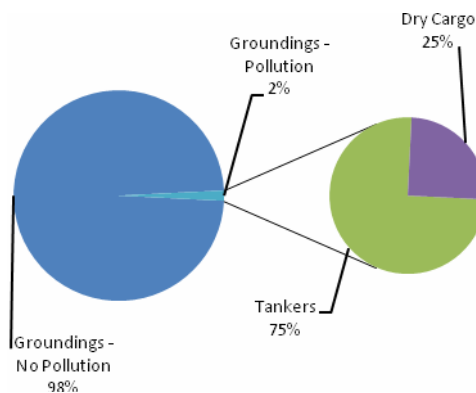


Fig. 4: Groundings in relation to oil pollution.

Figure 5 presents the number of marine accidents and of groundings (in particular) per 100 ships of the Greek fleet. The trend of the two lines might look similar; the results though from the statistical tests give a completely different picture. More specifically, the decrease with time of the total number of accidents is proven to be statistically significant (Kendall's $\tau = -0.473$ with $p\text{-value} = 0.019$). On the contrary, the trend for groundings cannot be registered as statistically significant since the Kendall's τ equals to -0.209 but with a $p\text{-value}$ of 0.298 . It is noted that Kendall's tau (τ) is used to assess the statistical significance of a recorded trend and more specifically it usually measures the degree of correspondence between two rankings (Conover, 1999).

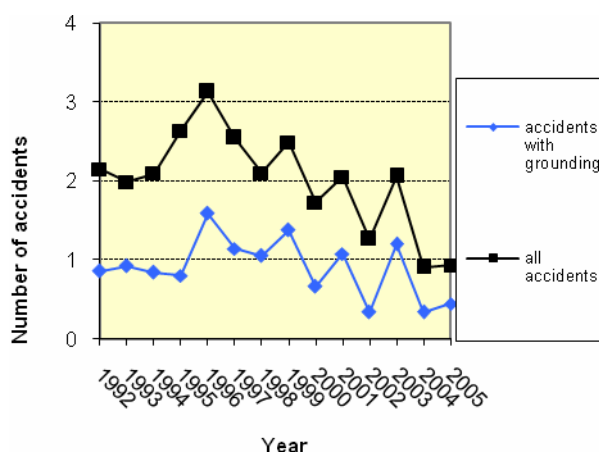


Fig. 5: Number of accidents per 100 vessels.

Figure 6 depicts the distribution of grounding accidents in relation to ship types and their contribution into the total Greek merchant fleet. Hence it is the dry cargo vessels that suffer the most from groundings even though the aggregated number of this type of ships cannot justify such a result. The passengers vessels can be found in the second place whereas the tankers in the

third place. It is noted that tankers due to their cargo and its potential to cause extended environmental damages has long been under the spotlight in terms of marine safety and avoidance of accidents; hence the results for the Greek fleet shows that these campaigns have given results in the sense that tankers seem to perform adequately as far as grounding is concerned.

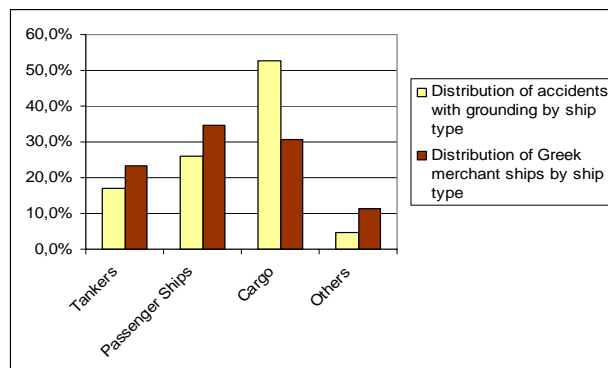


Fig. 6: Groundings in relation to ship type.

Figure 7 gives the distribution of groundings with regards to ship age and its categories into the total Greek merchant fleet. Hence it is the two older categories (i.e. 21-30 years old and 30+ years old) that suffer the most from groundings even though the aggregated numbers of these age categories are the smallest ones within the examined fleet. Moreover, the youngest vessels, that of age from 1 to 10 years, present the smallest problems with the accident of grounding regardless their large share in the Greek fleet; this can be attributed to advanced navigational equipment onboard the vessels, to more reliable mechanical parts etc.

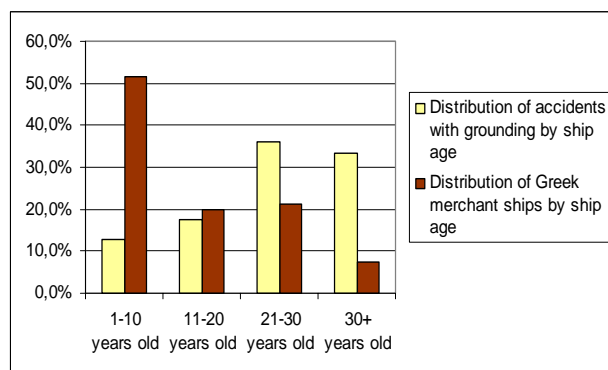


Fig. 7: Groundings in relation to ship age.

Figure 8 shows the distribution of groundings with regards to ship size in gross tonnage (GT) and the respective shares into the total Greek merchant fleet. It is the category of the smallest ships (i.e. 100-1000 GT) that encounter the biggest problems from groundings when at the same time they also have the lion's share in the examined national fleet. The rest of the size categories do not draw more or less an even picture with the bigger vessels (i.e. 30000+ GT) giving the best performance records. A reason that could justify such a finding could be the fact that smaller ships usually operate closer to ports and coasts, therefore into areas

where the probability of a grounding occurrence is proven to be more significant (Psaraftis et.al., 1998). Another reason might be the advanced navigational aids that the big ships carry onboard.

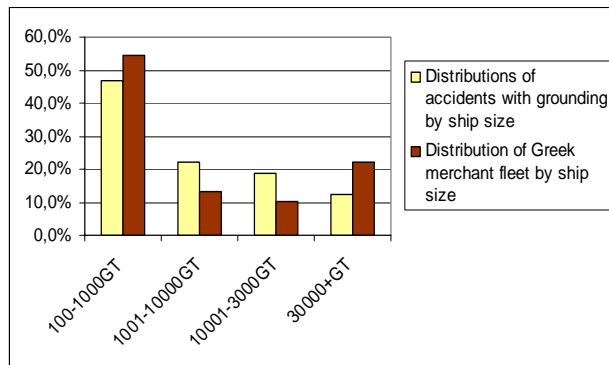


Fig. 8: Groundings in relation to ship size (GT).

6. Hypothesis Tests and Results

The application and elaboration of various statistical tests can identify and reveal trends and patterns that cannot be otherwise recorded by a simple statistical approach. In effect, a well defined hypothesis test is in position to give the statistical independence and/or significance between predefined data sets so as to draft their complete statistical picture and magnitude. This way the application e.g. of the chi square test can give valuable information that can shed more light to the importance of results such as the ones presented in the previous Section. It is noted that the specific type of test is usually preferred to statistically check the null hypothesis that the two variables are independent, due to its “goodness-of-fit” properties. The null hypothesis is rejected when χ^2 (the sample value) is greater than $\chi^2_{\alpha, \nu}$ which is the critical value for the particular level of significance α and degrees of freedom ν (Bernstein R. & Bernstein S., 2000).

Table 1 presents the results derived from the application of the aforementioned chi square test for the type of accident and the size of the involved ship. The target of this effort was to determine whether grounding “prefers” or not larger or smaller Greek vessels.

Table 1: The chi square test for type of accident and size of ship.

χ^2	12.48
degrees of freedom	3
p-value	0.006 < 0.05
$\chi^2_{0.05,3}$	7.82
α	0.05

Hence from Table 1 it is evident that these two variables (i.e. the type of accident and the size of involved ships) are not statistically independent. This can also be translated into Figure 9; a very interesting figure that depicts rather clearly that groundings seem to “attract” the involvement of large ships compared to the rest types of marine accidents that are recorded in the implemented database.

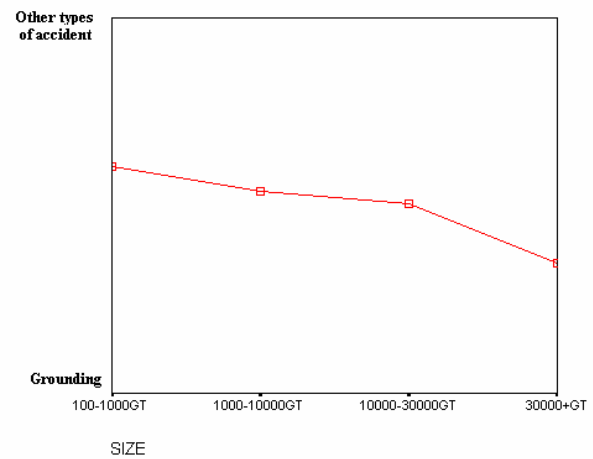


Fig. 9: The trend of the size of involved ships in relation to the type of accident.

The same effort was done in studying the relationship between the type of accident (i.e. grounding and the rest of accidents) and the age of the involved vessels. In this outline, Table 2 contains the results of this chi square test.

Table 2: The chi square test for type of accident and age of ship.

χ^2	2.01
Degrees of freedom	3
p-value	0.571 > 0.05
$\chi^2_{0.05,3}$	7.82
α	0.05

Thus the type of accident and the age of ship are statistically independent variables which can also be justified by Figure 10 where no trend/preference can be determined.

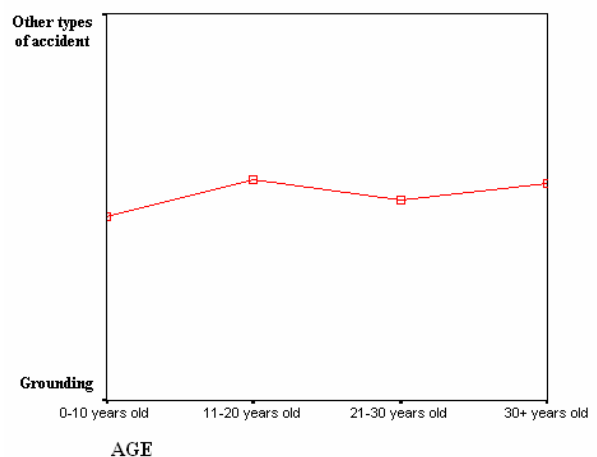


Fig. 10: The (no) trend for the age of involved ships in relation to the type of accident.

If the study is focused on the statistical relationship between the Greek tankers that are involved into groundings and (maybe) pollution with the size of these tankers, then the application of the t-test can give whether the aforementioned variables are or are not

statistically independent. It is noted that the Student's t-test allows testing hypotheses about differences between two means from two sample groups by comparing their variances. If the calculated t-value exceeds the theoretical value of the t-distribution at a chosen level of significance (α), then the null hypothesis (H_0) can be rejected and therefore conclude that variances are significantly different (Rice, 1989). Table 3 shows the results from the specific t-test.

Table 3: The t- test for grounded tankers that may lead to pollution and the mean values of the sizes of the involved tankers.

T	-2.486
p-value	0.017 < 0.05

Hence, the t-test depicts that there is a statistical difference between the mean values of the size (in GT) of the tankers that after grounding would produce pollution and of those that they will not lead to oil spillage. The grounding is taken into account only if it is recorded as the first of a chain of events that can give the result of the accident. Figure 11 presents clearly the above mentioned conclusion; it seems that the combination of grounding and pollution is able according to the records of the database to "attract" in average bigger Greek tankers in comparison to the mean size of tankers involved in groundings without subsequent spillage.

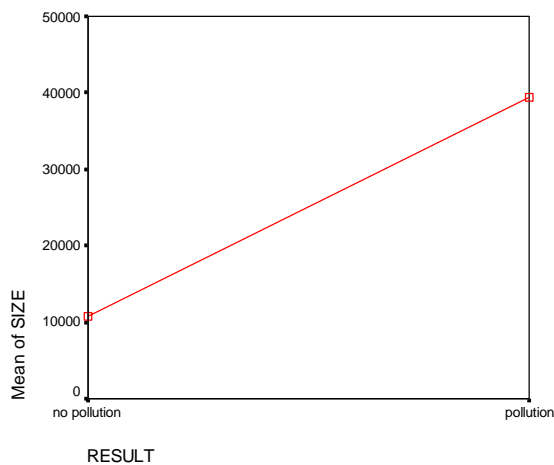


Fig. 11: The trend for the mean value of the size of the Greek tankers in relation to whether their grounding lead or not to pollution.

7. A Mini Risk Profile

A risk profile has the capability to come up with hands on description of a two dimension space – that of frequency/probability combined with the consequences of an undesired event. This way, a realistic picture can be drawn and subsequently elaborated in order to formulate an efficient framework which is capable to enhance the safety of shipping (Ventikos et al, 2006)

In effect, the study of the frequency for accidents within the Greek fleet combined with a specific consequence (i.e. pollution) can give a high level risk profile for the

examined portion of the fleet. Table 4 presents the results of such an approach.

Table 4: Mini Risk profile for the Greek fleet.

	<i>F</i> (Casualties/ Shipyears)	
All accidents with pollution	0,000175	1 accident with pollution every 5714 ships per year
Accidents of tankers with pollution	0,000665	1 tanker accident with pollution every 1503 tankers per year

Hence Table 4 shows that according to the records of the database (1992-2005) and if nothing changes for the Greek fleet, then the community may expect 1 accident leading to pollution (regardless of its magnitude) for every 5714 ship-years. Focusing on tankers then the risk is recorded as 1 tanker accident leading to pollution (mindless of its size) for every 1503 tanker-years.

The aforementioned figures provide a rather optimistic view, in terms of safety for the Greek fleet and its environmental friendliness and effectiveness. Furthermore, this type of approach should always give the margins of its usefulness; namely what has been and what has not been taken into account during its development. For example, the change of the composition of Greek tankers due to the phase out of single hull vessels can and if it can how will affect the above results? In general, this type of questions should be answered (if answered at all) with extreme caution.

8. Grounding Actions

As previously discussed, the definition of a grounding scenario requires to represent in a realistic manner the grounding actions, to which her structure is subjected to. These actions are not limited to the initial incident, i.e. when the ship first comes in contact with the sea bed, but also when she is set aground and is subjected to loading resulted from her weight, the environment as well as from rescue operations. In order to draw conclusions concerning the grounding actions and subsequently be able to define grounding scenarios, Samuelides et al (2006) reviewed grounding incidents that have been reported in the literature. The findings of the investigation are as follows:

- The bottom structure is subjected to a number of loading patterns, which depend, on the topology and type of sea bed and the impact geometry;
- The loading due to grounding, is not limited in time only in the initial phase of a grounding incident, i.e. when the kinetic energy of the ship prior to grounding is dissipated in structural energy, but may damage the ship's structure days after the incident. Weather conditions have an essential effect in the loading actions that occur after the initial grounding;

- c) Structural components of the ship structure that are damaged during the initial incident, may subsequently be subject to serious loading conditions, which may cause further damage.

A common loading pattern when a ship runs with forward speed on the sea bed is a contact force distribution, which is oblique with respect to the plane of the bottom shell. The figures of the damaged hulls of a tanker and an LNG carrier reveal that the shell of the vessels were subject to such type of loading while they were moving forward in contact with rocks. However it is interesting to note that although in both cases the energy that was dissipated was relatively high (1900 MJ in the former and 4200 MJ in the latter) the consequences of the grounding differed significantly: the side shell of the tanker has been removed from the action of the rock (Figure 12) and the accident resulted in severe pollution of the sea environment, whereas in the case of the LNG (Figure 13) there was no leak of cargo or fuel and it appears that the side shell was pushed inside the double bottom space.

The bottom structure may also be subject to transverse loading, when the ship moves vertically towards the sea bed, a mode that may occur statically or dynamically: such a transverse load is static when the ship sits on a pinnacle, which supports its weight, and dynamic in case the ship is relatively light and the wave action causes a repeated impact of the bottom to the sea bed (pounding impact). Transverse loading on the bottom plate also occur when the ship moves towards to the sea bed as a result of tidal actions. When the load to the bottom is transverse and the ship does not move horizontally, the bottom structure – girders and floors – suffer from crushing.



Fig. 12: Extensive tearing of the bottom plate of a single hull tanker under grounding action.

Loading on structural elements of the hull of a ship that rests on the sea bed may also result from hull bending either in the horizontal plane or in the longitudinal plane of symmetry of the vessel. The latter is the result of wave action on the hull, but it may also occur when the ship rests on a projection of the sea bed. This was observed in the case of grounding of a bulk carrier, whereby, scouring action developed a pinnacle under

the vessel's amidships, which caused hogging stresses to the ship's hull.



Fig. 13: Grounding damage of the hull of an LNG carrier.

Horizontal bending, which has been observed in the case of a naval vessel, results from the wave action on a side of a vessel, which is supported by the sea bed on her opposite side. In this case each wave impact caused bending that created compressive stresses on the side that is subjected to impact and tension on the opposite side. The side subjected to impact may suffer from buckling.

9. Conclusions – Future Concerns

The work that is reported in the present paper is part of the on-going research which aims, on one hand to determine the probability of occurrence of groundings and on the other to define the grounding actions to which a ship structure is subjected to during grounding. The ultimate result of the work is expected to be a comprehensive picture of grounding scenarios, which could be used in an Accidental Limit State for the assessment of the grounding behavior of a ship. Ideally we should have extracted both the grounding actions and the grounding statistics from the same population for incidents. However, at the current stage of the work, that was not possible, because we could not have access to the reports of the accidents of the Greek ships. Thus we have extracted statistical results from accidents that happened to Greek ships from 1992 and 2005, whereas the grounding actions that cause severe damages to ships were identified from the investigation of serious groundings that have been reported in the internet or in international journals. Currently the finding of the investigation reported in the present paper is compared with the results of similar investigations, which are based on accidents of other fleets.

The examination of actual groundings revealed complicated loading patterns that act on the ship hull that damage may occur days after the initial grounding, the effect of weather conditions in the loading patterns. Thus, a comprehensive assessment of the grounding behavior of a ship should be able to predict the response of the ship structure for days after the initial incident and under unfavorable weather conditions.

The investigations of accidents of ships over 100 GT, with Greek flag from 1992 to 2005 revealed that groundings were the most frequent accidents, 45% of

the total number of the reported accidents were grounding or caused grounding of a ship. However, fortunately only a few of those had catastrophic consequences. Other findings from the investigation are as follows:

- The decrease with time of the total number of accidents is proven to be statistically significant whereas the trend for groundings cannot be given as statistically significant;
- The dry cargo vessels suffer the most from groundings even though the aggregated number of this type of ships within the Greek fleet cannot directly justify this result;
- The two older categories (i.e. 21-30 years old and 30+ years old) suffer the most from groundings even though the aggregated numbers of these age categories are the smallest ones within the examined fleet;
- Groundings seem to “attract” the involvement of large ships compared to the rest types of marine accidents that are recorded in the implemented database;
- There is a statistical difference between the mean values of the size (in GT) of the tankers that after grounding would produce pollution and of those that they will not lead to oil spillage – hence the former are bigger than the latter ones;
- In risk terms the Greek fleet can give 1 accident with pollution (regardless of its magnitude) every 5714 ship-years and focusing on tankers 1 tanker accident with pollution (mindless of its size) every 1503 tankers per year.

The existing plans for a oil pipeline that will end in the north of Greece will increase traffic of tankers in the Aegean. The investigation of actual groundings in particular an in-depth analysis of the causes of groundings, and the grounding worldwide statistics in combination with up to date methods of grounding prevention and mitigation techniques should be used to set standards for the safe passage of the ships through the Aegean, and practically diminish the risk of environmental damage.

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