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ECOLOGICAL PERFORMANCE OF THE OIL TANKERS AND POLLUTION RISK

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Abstract: *The international practice in the environment management field shows that the analysis of pollution prevention and decrease is oriented on the following directions: pollution sources with causes which produce the environment pollution, pollution effects, the evaluation of the vulnerability type and the sensitivity of the polluted areas. In this paper elaboration of the pollution evaluation risk based on an index as a three parameters function, as well as the alternative constructive variant without double hull. The method used for the evaluation of the discharged merchandise quantity is made based on the statistic processing. This project proposes an instrument for the evaluation of the pollution risk at tanker oils in accordance with the international regulations. This method can be useful to all “the actors” who develop their activity in the naval industry (transporters, oil terminal operators, naval constructors, insurance companies etc). This project, by it's content and by the information offered, can constitute a solid base for the ulterior developments in this field.*
Key words*: oil tanker, oil pollution, pollution evaluation risk.*

1. INTRODUCTION

Crude oil and oil products are transported mainly by ships and pipelines from drilling areas to refineries plants and to end users regions. Referring to the involved quantities, as for 2007 about 2.6 billion tons of petroleum were shipped by maritime transportation, which is roughly 63,8% of all the petroleum produced. The remaining 36,2 % is delivered either using pipelines (dominantly), trains or trucks. Crude oil alone accounted for 1.86 billion tons (Rodriguez et al. 2006).

The maritime circulation of petroleum follows a defined set of maritime routes.
The routes are nearly obliged from the production to the consumption areas, showing that a great quantity of oil travels from the Middle East towards USA, Far East and Europe. Other important production areas are West Africa, Venezuela and the North Sea. Oil transportation represents more than one third of the goods sea traffic and tanker ships in general embody a significant part of the merchant fleet. In 2007 the number of crude oil, product and oil/chemical tankers, all together was around eight thousand, with an increasing trend in terms of total DWT and increasing ship size for each single oil tanker typology. This is in line with the oil trade volume increment, as a result of the world economic growth. An oil tanker fleet subdivision can be proposed in terms of size and specifically in terms of deadweight (DWT), with the definition of six main groups, as shown in the following Table 1.

Table 1. Oil tanker typology: sizes in DWT

Type	From	To
Product	10k	60k
Panamax	60k	80k
Aframax	80k	120k
Suezmax	120k	200k
VLCC	200k	320k
ULCC	320k	550k

Product tankers represent more than one half of the total oil tanker population, as far as number of vessels is concerned, but in terms of oil transportation capability, the significant size of the VLCCs permits to this ship category to cover half of the transportable oil, even with the small number of VLCC units in the world. It is possible to generally indicate the field of application/navigation for each category defined above.

Product Tankers: they are the smallest oil tankers used to transport both crude oil and refined products and they are applied in local markets such as within the Mediterranean Sea, the Caribbean Sea or the North Sea.

Panamax Tankers: as suggested by the name, they are allowed by their dimensions to pass through the Panama Canal; nowadays they are exploited not only through Panama but even in the local markets to carry crude oil.

Aframax Tankers: are characterized by an intermediate size much appreciated by the market; they are the so called “workhorses” because of their flexibility and their extensive use in all the seas; they carry significant amounts of oil but their dimensions are not too large, so that they can dock in many harbors. Suezmax Tankers: as suggested by the name, are those oil tankers whose dimensions allow them to pass through. The Suez Canal; they are employed mainly from the Middle East to Europe and nowadays even to the Far East.

VLCC and ULCC (Very Large Crude Carrier and Ultra Large Crude Carrier): are the biggest ships ever built; ULCCs can be 500 m long and can carry more that 3 millions of oil barrels. The commercial short-coming of these ships is about their dimensions; there are not many harbors in the world that can host them. They are used from the Middle East of the United States and to the Far East. More over the ULCCs have faced a deep crisis in the last years and now a day there is uncertainty about their future. The attention on oil tankers is rather high in relation with their possible environmental impact due to oil spill, both in operational and accidental context.

It is to be mentioned that, although they get most of the publicity, oil spills from tanker ships are only a part of contamination caused by goods maritime transportation that in turn is evaluated around the ten per cent of the overall marine pollution caused by human activities.

The environmental impact of oil tankers can be viewed as the result of errors in the operational procedures, for example during loading/unloading activities in harbor, and as the consequence of major accidents during ship navigation. After an investigation about trends in oil pollution by tanker ships (Huijer 2005), from 1995to 2004, in terms of quantity, minor oil spills are equally likely to occur both from operational procedures and from accidents like collisions, grounding, hull failures, fire and explosions, while these second events are nearly the main reasons (94%) of significant oil spills. It is to be underlined anyway that, fortunately enough, the number of outflow events with significant oil spill into the sea, due to tragic accident, is very low. The principal accidents oil outflow is evidenced in Figure 1.

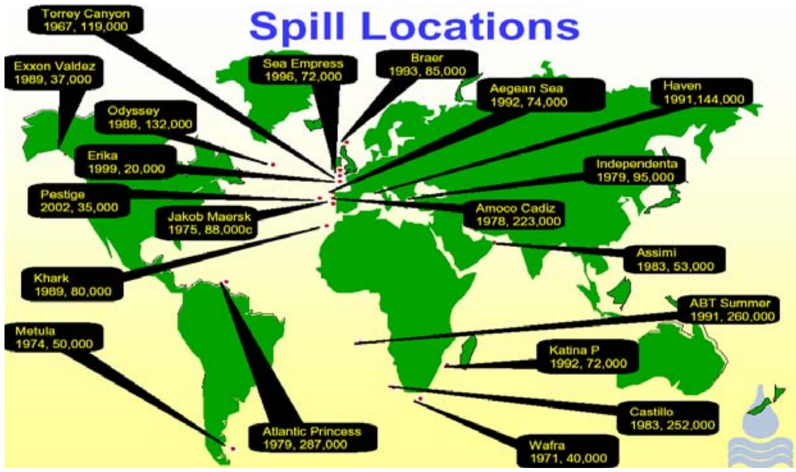

Figure 1. Principal accidents of oil tankers

In the following paragraphs, an investigation about the environmental impact of different oil takers, in terms of size, is performed. As suitable tools for the assessment, some probabilistic parameters can be selected within the IMO procedure (Marpol 2002, Appendix 7) created to evaluate alternative designs of oil tankers under regulation 13F.

2. OIL OUTFLOW ANALYSIS

The methodology was originally developed to assess alternative oil tanker designs, comparing their efficiency to that one of a reference double hull tanker, by means of a global index, denominated pollution prevention index *E*. The three single outflow parameters that are combined in that global index *E* can supply interesting information about the environmental impact of the investigated ships, if they are used in a comparative context.

The three useful parameters are:

- P_o = probability of zero outflow;
- O_M = mean oil outflow parameter;
- O_E = extreme oil outflow parameter.

The methodology implies the definition of a full load condition assumed with zero trim and heel. All cargo oil tanks are regarded as filled to 98% of their capacities.

For the present investigation only side damage have been considered and for a limited number of cases: 180 different damage scenarios are investigated, generated with 10 different longitudinal locations (X_i), 3 different longitudinal extents (Y_j) and 6 different transversal penetrations (Z_k). The vertical damage amount is always deemed unlimited. Using the density distribution functions available in the Marpol guidelines, obtained from the analysis of previous accidents database, and expressed in terms of dimensionless extents, a probability of occurrence can be associated to each damage case.

For each of the 180 damage cases, the probability of occurrence is calculated as follows:

$$P_{ijk}\,(X_i,Y_j,Z_k)= P\,(X_i)\bullet P\,(Y_j)\bullet P\,(Z_k) \qquad (1)$$

Using the capacity plan of the ship under investigation, it is possible to determine the compartments involved by each damage case and to compute the relevant oil outflow.

The probability of zero oil outflow P_o is evaluated as:

$$P_0 = \sum_{i=1}^{n} P_i \cdot K_i \qquad (2)$$

where:

- i - represents each compartment or group of compartments under consideration for a ship (i.e. each damage case), running from i = 1 to i = n.
- Pi - accounts for the probability that only the compartment or group of compartment under consideration are breached;
- Ki - equals 0 if there is oil outflow from any of the breached cargo spaces in i. If there is no outflow, Ki equals 1.

The oil outflow (O_i) from all cargo spaces breached in a damage case is evaluated using the volume capacities, regarding of course only cargo tanks. Water ballast tanks, engine room, and forepeak and after peak do not cause any cargo oil outflow.

For side damage, the 100% of the oil stored into the damaged cargo tank is assumed to outflow into the sea.

The mean oil outflow O_M parameter has been evaluated, as follows:

$$O_M = \sum_{i=1}^{n} \frac{P_i \cdot O_i}{C} \qquad (3)$$

where *C* represents the total cargo oil capacity of the ship, at 98% tank filling.

Then, all the calculated data have been put in an increasing order in terms of oil outflow amount and the cumulative probability, by progressive sum of P_i, is obtained. Only cases falling within cumulative probability range between 0,9 and 1 have been considered and a weighted average is performed: therefore only the extreme of the oil outflow in the distribution has been considered (only the most dangerous cases).

The extreme oil outflow O_E has been calculated as follows:

$$O_E = 10\left(\sum \frac{P_{ie} \cdot O_{ie}}{C}\right) \qquad (4)$$

where *ie* represents the extreme outflow cases.

3. APPLICATIONS & RESULTS

Four oil tankers of a different size (Product, Panamax, Aframax, VLCC) have been analyzed and their main features are summarized in Table 2.

Their original internal subdivision is schematically represented. Of course, it is only a qualitative illustration of internal subdivision, without any reference to the real relative proportions among the ships.

It appears that the investigated ships have different typology of internal subdivision. All of them are provided with the double hull, but the number of transversal and longitudinal bulkheads for the cargo volumes subdivision is different.

Table 2. Main features of the considered ships

Type	L[m]	B[m]	D[m]	T[m]	DWT [t]
Product	165	25.30 217	15	10.40	28.4 k
Panamax	32.20 245.30	42.60	19.60	12.75	68 k
Aframax	319	60	19.80	10.40	110 k
VLCC			30.10	21.06	318 k

In the following investigation, a special attention is paid to the effect the longitudinal bulkheads within the ship volume devoted to cargo tanks. In a first approach, the methodology is applied for the subdivision configuration in the original form, as represented in Table 3 the obtained values of P_O, O_M and O_E are reported. The different internal subdivision scheme of the analyzed ships influences the coefficients values and in some way the comparison is not strictly congruous and consistent.

Table 3. Obtained values of P_0, O_M and O_E for tankers in their original configuration

Type	O_M	O_E	P_O
Product Tanker	0.0234	0.1613	0.8177 0.2980
Panamax	0.0481	0.7935	
Aframax	0.0578	0.2907	0.7063
VLCC	0.0196	0.1132	0.5822

Therefore, in order to perform a more meaning full comparison, the computations are carried out for ships with homogeneous internal subdivision and the values of P_O, O_M and O_E are properly compared with the variation of the DWT. To reach this aim, some artificial tankers are created, with the same number of longitudinal bulkheads: in a first step, a series of ships without any central bulkhead is generated with a Product tanker studied without the presence of the central bulkhead; in a second step, a series of ship all provided with the longitudinal bulkhead is create fitting the Panamax and the Aframax with a central longitudinal bulkhead. The VLCC, as it presents two longitudinal bulkheads in its original configuration, has been consistently modified, and therefore fitted with zero and one longitudinal bulkhead. This further study has been performed in hypothesis that there is no variation of weight and trim of the ship due to addition or removal of bulkheads. The different bulkhead configurations only modify the distribution of oil amount contained in each cargo tank and not the total amount of the net weight. As already mentioned, the O_M and O_E parameters are sensitive to the subdivision configuration. O_M presents a slow but evident increasing trend in relation with ship size, more precisely with ship deadweight

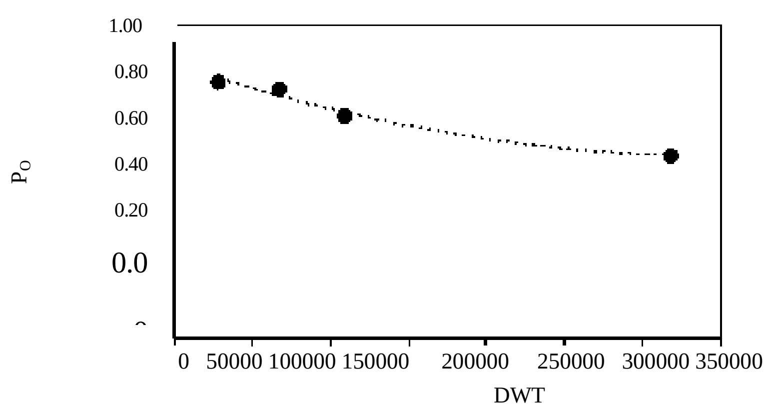

Figure 2. Comparison of probability of no outflow P_O calculated for the different oil tanker sizes

The O_E parameter, relevant to the most dangerous cases, seems to capture a sort of minimum value in correspondence of the Aframax size that is more evident for subdivision configuration without any longitudinal bulkhead.

It is manifest how relevant is the influence of a central longitudinal bulkhead on oil outflow parameters: as it could be expected, the values of O_M and O_E of the configuration with one central longitudinal bulkhead are the half with respect to the configuration without any central longitudinal bulkhead.

Because of its definition, obviously the P_O value reported in Figure 2 doesn't change for the modified ships, being not influenced by the cargo space sub-division. If the investigation only regards the P_O, i.e. probability of no outflow, the VLCC would appear as the less environmental friendly.

The difficulty to define and quantify oil spill costs is well evidenced and discussed by Sirkar et al. (1997) in the same paper, assumed hypothetical relations between total spill costs and spill amount in m^3 are proposed, derived also from some studies performed when trying to evaluate the cost effectiveness of double hulls.

For the present investigation, a hypothetical linear function has been selected, with an assumed average cost of a cubic meter of spilled oil of \$ 50000 per m^3, at least for spills up to 100000 m^3, derived from the above mentioned paper.

In case of a major accident like collision, the amount of mean oil outflow expressed in cubic meters can be estimated from previous calculations, for each type of oil tankers.

Table 4. Total spill cost for each sizes depending on the number of longitudinal bulkheads indicated as l.b

Type	Mean oil outflow [m^3]	Total spill cost [millions $]
Product Tanker (1 l.b.)	878	44
Panamax (no l.b.)	3761	188
Aframax (no l.b.)	6471	324
VLCC (2 l.b.)	6966	348
Product Tanker (nol.b.)	1756	88
Panamax (1 l.b.)	1881	94
Aframax (1 l.b.)	3235	162
VLCC (1 l.b.)	12008	600
VLCC (no l.b.)	24016	1201

Table 5. Total spill cost per ton of DWT

	Total spill cost per ton of DWT [$/t]		
Type	Original	Zero central Long, Blkhd	One Central Long, Blkhd
Product	1335	2773	1335
Panamax	2765	2765	1382
Aframax	2945	2945	1473
VLCC	1160	4003	2000

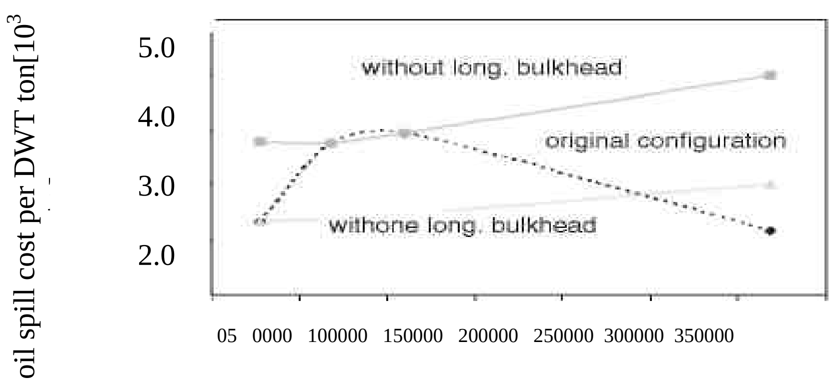

Figure 3. Spill cost per ton of DWT estimation

In order to attempt a translation from probabilistic parameters into monetary terms, as a first step, it can be possible to give an estimation of the relevant oil spill cost, exploiting the hypothetical linear function. The results are reported in Table 4, for all the analyzed ships in the several configurations, with zero (no l.b), one (1 l.b) and two (2 l.b, only for VLCC) longitudinal bulkheads. It is also possible to obtain an estimation of the spill cost per DWT ton, for any ship type as shown in Table 5. The same results are reported in Figure 3 (where lines are drawn only to help following homogeneous data).

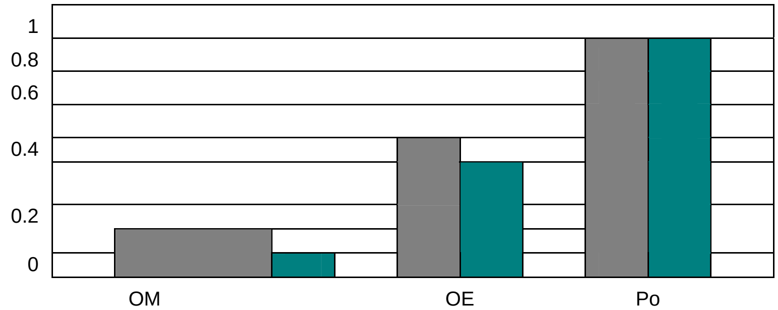

Figure 4. O_M, O_E and P_O considering the survivability attitude of the Panamax ship

Considering the oil tankers in their original sub-division, the VLCC is the best option; on the other side, performing the evaluation at the homogenous internal subdivision configurations, in terms of longitudinal bulkheads, the other ship sizes show a better performance. During the above mentioned investigation, ship survivability has not been taken into account. The matter is not negligible because the possible total loss of the ship can imply that the total amount of cargo oil is released into the sea. Taking this last option as a calculation hypothesis, it can influence the outcomes for the three parameters, for example significantly modifying, for a certain damage scenario, the amount of the oil outflow (O_i) that should be considered equal to the total amount of transported oil.

In all the 180 cases, even if significant damage length are analyzed (up to 0.25 L), the Aframax and the VLCC evidenced a considerable survivability attitude, always complying with the MARPOL damage stability standards; on the contrary, the Panamax fails in seven cases. In those seven cases, all the cargo has been considered outflow; this fact obviously modifies the values of O_M , O_E and P_O. The values of the oil outflow coefficients, updated with new information about ship survivability, for the Panamax size are shown in Figure 4; as it could be expected, the influence on the O_M parameter in not very important, due mainly to the reason that O_M is weighted on all the cases that give an outflow, whereas O_E shows a relevant increase due to

The fact that it expressly refers to the 10% most important outflows. P_O has faintly decreased because some cases that pre-viously didn't give any outflow (i.e. not involving cargo volumes), now are responsible of the ship failure to comply with the damage stability and buoyancy criteria, situation that has been interpreted as coinciding with the ship loss.

4. CONCLUSIONS

A methodology to compare the potential threat of tanker ships analyzed in terms of their increasing size has been proposed and applied to a Product Tanker, a Panamax, an Aframax and a VLCC. When analyzed in terms of O_M and O_E parameters, with her original internal subdivision, the VLCCs, although transporting the biggest amount of oil, presents the least environmental harmful attitude. This fact is due to the presence of two longitudinal bulkheads that reduces the amount of spilled oil in case of damage.

The determinant importance of one or two longitudinal bulkheads to reduce the possible environmental threat of oil tankers is evident also observing the parameters obtained for the other ships, lower in size. The survivability of the ships has been considered in the different damage scenarios in order to appreciate in principle the impact of ship loss and the relevant assumed total cargo oil spill on the O_M, O_E and P_O coefficients. For the investigated damage cases the two biggest sizes, the VLCC and the Aframax ships, have always succeeded in complying with the survivability criteria and therefore it was not possible to evaluate and compare the effects of their total cargo out-flow, as it could be permitted in principle by the methodology. An important point to discuss is that, even if the damage ship seems to have a sound survivability attitude, the evolution of the damage conditions due to actual loads after damage, residual structural strength and their interaction with environmental, possibly severe, conditions are phenomena that have always strongly contributes to the definition of a sea pollution disaster and that can be hardly computed in advance in theoretical investigations. It is important to point out that the evaluation of oil spill cost, starting from the probabilistic parameter O_M, has exploited a linear function with the outflow oil quantity, while it might be more realistic to consider a non linear dependency, decreasing with the spilled oil quantity increment.

Anyway, although this hypothesis penalizes the biggest tankers like VLCC, these tankers typology, in case of ship major accident, seems to result "less expensive" when analyzed in terms of spill costs per ton of DWT, but only if considered in their original configuration, with two longitudinal bulkheads.

5. REFERENCES

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