NATIONAL TECHNICAL UNIVERSITY OF ATHENS

SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

DIVISION OF SHIP DESIGN AND MARITIME TRANSPORT

DIPLOMA THESIS

Analysis of Non Accidental Structural Failures and Machinery Failures on Large Tankers

(studied period 1990-2011, independently of year of built)

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1 Introduction

1.1 Abstract

The subject of the present thesis is the statistical analysis of the Non Accidental Structural Failures (NASF) and machinery failures on tankers with deadweight larger than 60.000t ("large tankers"), that occurred in the period 1990-2011 independently of year of built. We may distinguish 8 main categories of tanker accidents, namely:

- Non Accidental Structural Failures (NASF)
- Machinery failures
- Collision
- Contact
- Grounding
- Fire
- Explosion
- Hull fittings failures

All necessary data for the present analysis were deduced from the NTUA-SDL tanker accidents database (National Technical University of Athens-Ship Design Laboratory). Germanischer Lloyd disposed also very useful data concerning mainly the annual Fleet at Risk, broken down by age, ship size and hull type for the studied period.

1.2 Scope of the thesis

The subject of the present thesis is the statistical analysis of the Non Accidental Structural Failures (NASF) and machinery failures on tankers with deadweight larger than 60.000t ("large tankers"), that occurred in the period 1990-2011 independently of year of built.

Shipping is of great importance, because goods should be somehow transported and the most efficient way to transport large quantities of cargoes till today is on ships. Ship's operation is not free of hazards, as it poses threat against human life, environment and lastly financial interests. These hazards should be identified, recorded and analyzed in order to be restricted.

The aim of this thesis is to analyze existing data for NASF and machinery failures. The general assessment criteria taken into consideration are:

- Event location, ship operation, environment
- Outcome of event
- Fatalities, injuries

- Oil spill information
- Shipyards, flags, classes

Additionally the greater part of this research concerns NASF. NASF were analyzed with additional parameters:

- Basic hull type (double hull or non double hull)
- Ship's size (Panamax, Aframax, Suezmax, VLCC, ULCC).

Hull type and ship's size were not considered as important parameters for the study of machinery failure.

Furthermore, two models were developed in the course of this thesis:

1 A fault tree for NASF.
2 A model that describes failures of machinery systems.

As far as NASF are concerned, two characteristic accidents have been analyzed in order to show possible causes and consequences of (large scale) NASF:

- Loss of "PRESTIGE" (19/11/2002)
- Loss of "KATINA P" (26/04/1992)

Lastly, comments and conclusions are drawn after each chapter, giving a general overview of each examined tanker's accident category.

2 General information about large tankers

2.1 Definition

A tanker is a merchant vessel designed to transport liquids or gases in bulk. Major types of tanker ships include the oil tanker, the chemical tanker and the gas carrier.

Figure 2.1. Typical oil tanker

Figure 2.2. Typical chemical tanker

Figure 2.3. Typical gas tanker

2.2 Background

Tankers can range in size of capacity from several hundred tonnes, which includes vessels for servicing small harbours and coastal settlements, to several hundred thousand tons, for long-range haulage. Besides ocean- or seagoing tankers there are also specialized inland-waterway tankers which operate on rivers and canals with an average cargo capacity up to some thousand tons . Tankers are used for bulk transporting of crude oil **,** finished petroleum products, liquefied natural gas (LNG), chemicals, edible oils, wine, juice, molasses, fresh water, and other liquids.

Tankers are a relatively new concept, dating from the later years of the 19th century. Before this, technology had simply not supported the idea of carrying bulk liquids. The market was also not geared towards transporting or selling cargo in bulk, therefore most ships carried a wide range of different products in different holds and traded outside fixed routes. Liquids were usually loaded in casks, hence the term "tonnage", which refers to the volume of the holds in terms of how many tuns or casks of wine could be carried. Even potable water, vital for the survival of the crew, was stowed in casks. Carrying bulk liquids in earlier ships posed several problems:

- The holds: on timber ships the holds were not sufficiently water, oil or air-tight to prevent a liquid cargo from spoiling or leaking. The development of iron and steel hulls solved this problem.
- Loading and discharging: Bulk liquids must be pumped - the development of efficient pumps and piping systems was vital to the development of the tanker. Steam engines

were developed as prime-movers for early pumping systems. Dedicated cargo handling facilities were now required ashore too - as was a market for receiving a product in that quantity. Casks could be unloaded using ordinary cranes, and the awkward nature of the casks meant that the volume of liquid was always relatively small - therefore keeping the market more stable.

- Free Surface Effect: a large body of liquid carried aboard a ship will impact on the ship's stability, particularly when the liquid is flowing around the hold or tank in response to the ship's movements. The effect was negligible in casks, but could cause capsizing if the tank extended the width of the ship; a problem solved by extensive subdivision of the tanks.

Tankers were first used by the oil industry to transfer refined fuel in bulk from refineries to customers. This would then be stored in large tanks ashore, and customized for delivery to individual locations. The use of tankers caught on because other liquids were also cheaper to transport in bulk, stored in dedicated terminals, then prepared for delivery to consumers. Even the Guinness brewery used tankers to transport the stout across the Irish Sea.

Different products require different handling and transport, with specialized variants such as "chemical tankers", "oil tankers", and "LNG carriers" developed to handle dangerous chemicals, oil and oil-derived products, and liquefied natural gas respectively. These broad variants may be further differentiated with respect to ability to carry only a single product or simultaneously transport mixed cargoes such as several different chemicals or refined petroleum products. Among oil tankers, supertankers are designed for transporting oil around the Horn of Africa from the Middle East. Supertankers are one of the three preferred methods for transporting large quantities of oil, along with pipeline transport and rail.

Despite being highly regulated, tankers have been involved in environmental disasters resulting from oil spills

2.3 Design considerations

Many modern tankers are designed for a specific cargo and a specific route. Draft is typically limited by the depth of water in loading and unloading harbors; and may be limited by the depth of straits along the preferred shipping route. Cargoes with high vapor pressure at ambient temperatures may require pressurized tanks or vapor recovery systems. Tank heaters may be required to maintain heavy crude oil, residual fuel, asphalt, wax, or molasses in a fluid state for offloading.

Nowadays double hulls or double bottoms have been required in all ships. (MARPOL conventions). The double hull concept provides some extra safety against environmental pollution, but does not protect against major, high-energy collisions or groundings which cause the majority of oil pollution, despite this being the reason that the double hull was mandated by United States legislation.

Additionally, design issues are raised. Examples: 1) The stability of the double hull ship can be less than that of a single hull. Because the double hull raises the center of gravity, the metacentric height is reduced. 2) A double-hulled tanker does not need longitudinal bulkheads for longitudinal strength, as the inner hull already provides this. Eliminating longitudinal bulkheads would result in much wider tanks, significantly increasing the free surface effect. However, this problem is easily corrected with the addition of anti-slosh baffles and partial bulkheads.3) Increased surface area of the structure inside the ballast tanks. Because these tanks are much longer and narrower than those in single hull tankers, their surface area can be two to three times that of the ballast tanks in a single hull ship. Thus, inspection issues become even more vital, as possibly weak structural points are multiplied.

2.4 Classification of tankers by size

Handysize: There is no official definition in terms of exact tonnages, but usually refers to tankers with a deadweight 10.000-35000t.

Handymax: There is no official definition in terms of exact tonnages, but usually refers to tankers with a deadweight 35000-50000(60000)t Handysize and Handymax tankers can enter smaller ports in order to pick up cargoes . In most cases they are fitted with cranes , which means that they can load and discharge cargoes at ports which lack cranes or other cargo handling systems. Most of them operate within regional trade routes.

Panamax: Panamax are the mid-sized tankers that are capable of passing through the lock chambers of the Panama Canal. They have a deadweight tonnage between 60000 and 79999 t. These tankers are primarily used for carrying crude oil and petroleum products. A typical Panamax tanker is 220 m long, 32 m wide, and 13.6 m in draught corresponding to about 70000 DWT.

Aframax: Aframax are medium-sized crude tankers with a deadweight tonnage (DWT) ranging between 80000 and 119999. The average fuel carrying capacity of Aframax vessels is approximately 750000 barrels. Due to their size, Aframax tankers are able to serve most ports in the world. A typical Aframax tanker is 240 m long, 43 m wide, and 14.3 m in draught corresponding to about 105000 DWT.

Suezmax: Suezmax are medium to large-sized tankers with a deadweight tonnage (DWT) ranging between 120000 and 199999 t. They are the largest marine vessels that meet the restrictions of the Suez, and are capable of transiting the canal in a laden condition. A typical Suezmax tanker is 275 m long, 48 m wide, and 16.2 m in draught corresponding to about 150000 DWT.

Very Large Crude Carriers (VLCC): VLCC are large size tankers with deadweight tonnage ranging between 200000 to 320000. These tankers are capable of passing through the Suez Canal in Egypt, and as a result are used extensively around the North Sea, Mediterranean and West Africa. A VLCC can measure up to 470 m in length, up to 60 m in width, and has a draught of up to 20 m.

Ultra Large Crude Carriers: ULCC or Ultra Large Crude Carriers are the largest tankers in the world with a size ranging between 320000 to 550000 DWT. Due to their huge size, they require custom built terminals. As a result, they are able to serve limited number of ports in the world. They are primarily used for very long distance crude oil transportation, especially from the Persian Gulf to Europe, Asia and North America. Today, ULCC are among the largest shipping vessels with standard dimensions of 415 meters length, 63 meters width, and 35 meters draught. Knock Nevis was the longest ULCC supertanker ever built in the world with dimensions of 458.4 meters length and 68 meters in width.

2.5 Fleets of the world

Flag states: As of 2005, the United States Maritime Administration's statistics count 4024 tankers of 10000 LT DWT or greater worldwide. 2582 of these are double-hulled. Panama is the leading flag state of tankers with 592 registered ships. Five other flag states have more than two hundred registered tankers: Liberia (520), The Marshall Islands (323), Greece(233), Singapore (274) and The Bahamas (215). These flag states are also the top six in terms of fleet size in terms of deadweight tonnage.

Largest fleets: Greece, Japan, and the United States are the top three owners of tankers (including those owned but registered to other nations), with 733, 394, and 311 vessels respectively. These three nations account for 1438 vessels or over 36% of the world's fleet.

Builders: Asian companies dominate the construction of tankers. Of the world's 4024 tankers, 2822 or over 70% were built in South Korea, Japan or China.

3 Approach and methodology

3.1 Source of information on large tankers accidents

The necessary information for this research was provided by National Technical University of Athens and Germanischer Lloyd. In particular:

1 NTUA-SDL database was the main source of information. In the database are included 146 NASF cases and 417 machinery cases that meet the criteria of particular research. A screenshot of the used database is given in the following.

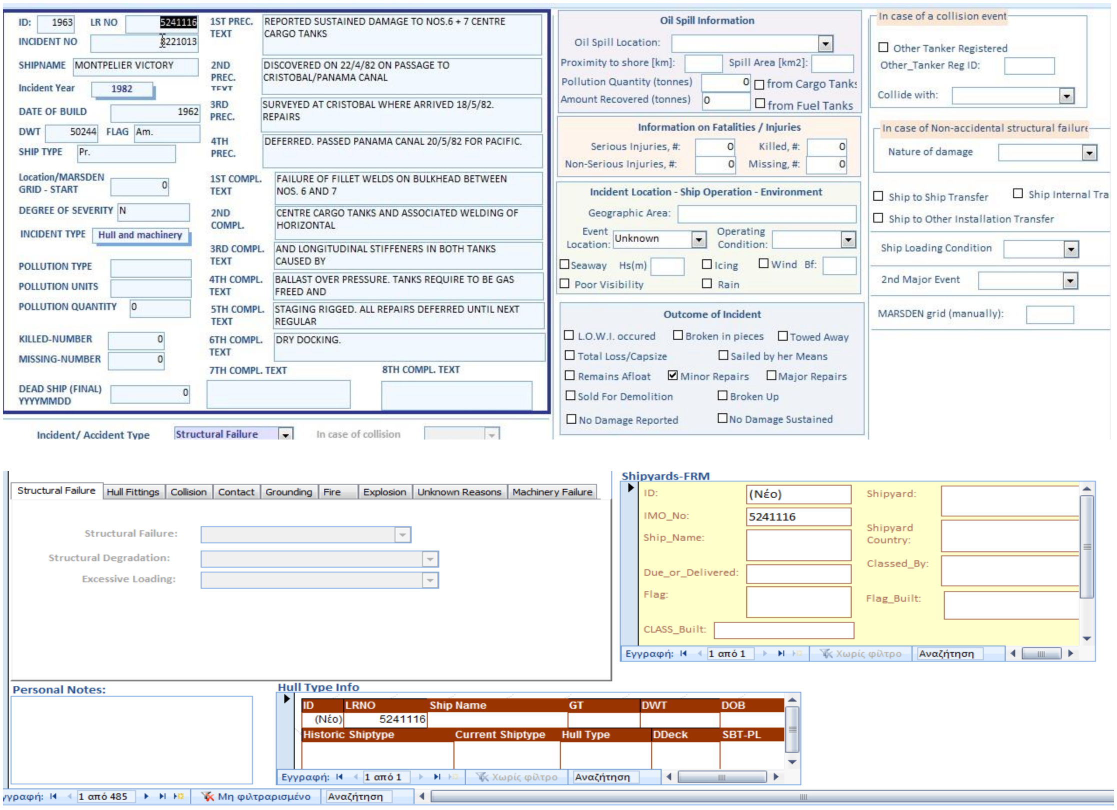


Figure 3.1. Screenshot of NTUA-SDL database

There is plenty of data for every single case:

a) name, ID, LR Nr., incident year, date of built, DWT, FLAG, location, degree of severity, ship type¸ incident type, text that gives details for the incident, complementary texts.

b) oil spill information: oil spill location, proximity to shore, spill area, pollution quantity, amount recovered, source of pollution.

c) information on fatalities/ injuries: serious injuries, non serious injuries, killed#, missing #.

d) incident location-ship operation-environment: geographic area, event location, operating condition, seaway, wind, visibility, icing.

e) outcome of incident: Loss Of Watertight Integrity(LOWI), broken in pieces, towed away, total loss/capsize, sailed by her means, remains afloat, extent of repairs, sold for demolition, broken up, no damage reported, no damage sustained,

f) shipyards, flag, classification societies: date, when the ship was delivered, where it was built, class when it was built, flag when it was built.

In some cases the quality of information within the complementary text is poor without any technical information.

In some cases it is stated that there was an oil release, resulting from the accident, but there is no description as far as the amount of oil spilled is concerned. Therefore, an amount of oil spill had to be assumed.

These boxes are not filled completely, mostly because it was not possible to have access to every piece of information needed in order to fill out these boxes.

2 The database was partly enriched with personal effort. Information concerns mainly shipyards, flags and classes and was found on:
   - GISIS (Global Integrated Shipping Information System)database by IMO (International Maritime Organisation)
   - www.maritime-connector.com
   - www.aukevisser.nl
   - IRS(International Register of Shipping)

3 Germanischer Lloyd provided very useful data: Annual Fleet at risk by age, size and hull type.

Table 3.1. Fleet at risk (in shipyears) independently of year of built. Time period 1990-2011. Focusing on basic hull type (DH, non DH) and ship's size.

year	Panamax		AFRAMAX		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
1990	23,3	173,2	31,6	362,1	11,2	229,6	0,0	385,2	0,0	54,0
1991	26,4	175,1	46,2	369,2	17,7	227,5	1,7	392,6	0,0	54,0
1992	28,7	168,1	72,0	366,4	36,6	229,6	5,3	400,5	0,0	54,0
1993	38,2	160,0	103,9	348,7	48,7	220,9	18,0	394,9	0,0	54,0
1994	42,9	155,9	125,7	335,0	57,5	212,3	28,2	390,0	0,0	53,9
1995	45,7	149,6	139,2	323,8	65,9	200,9	35,9	368,5	0,0	53,0
1996	46,8	147,8	154,2	318,9	74,7	188,9	55,3	354,2	0,0	53,0

1997	48,3	146,0	172,3	311,0	82,8	179,4	70,6	341,9	0,0	52,3
1998	49,2	144,7	198,7	303,9	100,0	172,9	80,7	332,0	0,0	52,0
1999	54,7	140,8	241,6	292,3	119,3	157,8	104,9	310,0	0,0	50,5
2000	69,1	137,1	275,3	263,6	139,6	129,4	141,0	269,6	0,0	43,7
2001	78,5	133,4	292,0	252,5	158,4	114,6	173,5	250,5	0,0	40,7
2002	85,7	127,0	314,6	230,0	177,2	88,0	203,5	209,5	1,6	29,4
2003	102,7	113,2	377,3	203,8	202,1	74,0	244,3	178,1	3,8	17,6
2004	136,8	95,6	444,0	166,2	229,2	58,2	275,3	154,8	4,2	7,0
2005	175,2	83,6	500,0	140,7	254,2	51,6	305,4	146,6	6,3	3,7
2006	216,7	78,8	556,6	124,3	279,1	51,0	327,2	142,8	7,9	2,9
2007	258,7	67,5	608,5	111,4	305,2	49,0	354,2	135,8	8,3	1,2
2008	296,1	54,7	664,1	97,8	319,7	41,1	387,0	118,7	10,6	0,8
2009	339,5	42,9	753,5	72,8	346,7	31,2	440,1	89,9	14,5	0,0
2010	364,9	29,8	825,7	46,6	389,6	18,3	492,1	57,2	16,4	0,0
2011	391,6	13,6	880,3	30,4	422,0	7,9	550,2	35,1	24,1	0,0

NOTE: In the table above one can notice decimal places. That can be better explained through an example: A ship travels/ has a contract for 9 months during a year. That will count for 9 months/12 months per year= 0,75 shipyears.

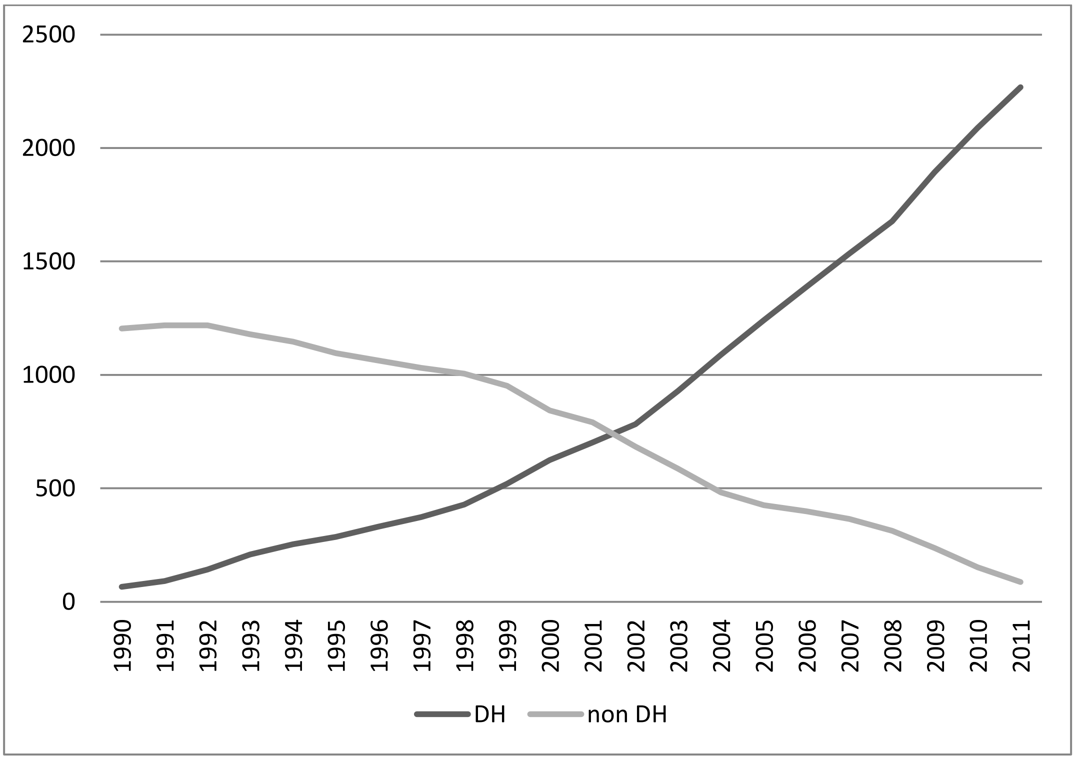


Figure 3.2. Annual change of fleet at risk for DH and non DH ships

Table 3.2. Fleet at risk (in shipyears) by age. Ships due or delivered after 1981. Time period 1990-2012. Focusing on basic hull type (DH, non DH) and ship's size.

age	Panamax		AFRAMAX		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
1	416,0	67,0	929,5	113,0	452,0	50,0	582,0	136,0	31,0	41,0
2	390,0	67,0	869,8	113,0	408,0	50,0	517,0	136,0	21,0	41,0
3	359,0	67,0	798,0	113,0	370,5	50,0	459,3	136,0	16,0	41,0
4	321,0	67,0	702,0	113,0	325,0	50,0	406,0	136,0	12,0	41,0
5	278,0	67,0	634,0	113,0	311,0	50,0	366,0	136,0	9,0	41,0
6	236,0	67,0	577,7	113,0	286,0	50,0	337,0	135,2	8,0	41,0
7	192,0	67,0	528,0	113,0	260,0	50,0	319,0	135,0	7,0	41,0
8	147,0	67,0	464,0	113,0	235,0	50,0	287,6	135,0	4,6	41,0
9	111,0	67,0	410,0	113,0	208,0	50,0	257,0	134,1	2,0	41,0
10	88,0	67,0	333,0	113,0	184,0	50,0	220,0	134,0	1,0	41,0
11	78,0	67,0	296,9	112,2	160,0	49,7	184,0	134,0	0,0	41,0
12	74,0	67,0	282,0	112,0	143,7	48,7	157,0	134,0	0,0	41,0
13	59,0	67,0	261,0	110,5	121,0	48,0	117,0	134,0	0,0	41,0
14	49,0	67,0	211,6	108,0	105,3	48,0	86,8	132,3	0,0	40,2
15	48,0	67,0	179,0	105,3	83,4	47,5	72,0	127,8	0,0	40,0
16	47,0	67,0	159,6	104,3	70,5	45,5	62,7	119,8	0,0	40,0
17	45,0	66,1	141,9	101,4	60,0	43,7	41,5	101,2	0,0	39,4
18	41,6	63,2	127,8	99,6	51,0	39,3	30,0	83,7	0,0	38,3
19	38,0	61,3	105,1	93,4	41,1	35,7	24,6	63,6	0,0	35,7
20	29,7	57,2	78,0	83,9	28,7	29,9	6,6	44,6	0,0	31,6
21	21,0	56,4	45,5	72,6	15,8	23,3	1,2	29,3	0,0	28,8
22	17,8	53,2	32,9	65,4	6,0	15,5	0,0	21,4	0,0	26,0
23	14,3	48,4	20,4	53,9	6,0	10,5	0,0	15,1	0,0	23,3
24	12,3	42,6	13,1	36,5	2,0	8,0	0,0	9,1	0,0	14,8
25	10,1	36,7	8,0	23,6	1,0	7,3	0,0	6,8	0,0	8,6
26	7,8	24,4	5,0	15,5	0,0	6,0	0,0	3,3	0,0	6,2
27	4,3	8,6	2,0	7,1	0,0	5,9	0,0	3,0	0,0	1,5
28	4,0	5,1	0,0	2,0	0,0	3,2	0,0	2,0	0,0	0,0
29	0,0	2,2	0,0	1,0	0,0	0,2	0,0	1,4	0,0	0,0
30	0,0	1,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,0
31	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

NOTE:. It was not possible to find data for all large tankers regardless of year of built, as far as age is concerned.

3.2 Definitions-Explanations concerning NTUA-SDL database

Event
An event is defined as something that happens or takes place, especially one of importance.[1]

Accident
An accident is defined as a sudden, not intended, event that causes loss of human life, personal injury, damage to the environment, and/or loss of assets and financial interests.[2]

Event location
In the NTUA-SDL database, the registration of casualty's location is based on the IMO relevant description on event location, namely at Berth, Anchorage, Port, Port Approach, Inland waters, Canals, Rivers, Archipelagos, Coastal (<12 miles off) ,Open Sea, shipyards and drydocks.
Based on the above categorization, four different event locations were identified as the basic categorization for the risk analysis of different events. The four different states are further related to different type of sea areas with different conditions for rescue efforts and environmental pollution, namely:
• Terminal areas (Port, Anchorage, Port Approach and at Berth). The ship lies at berth/ port or is operating at low speed because of port or berth approaching or anchorage operations.
• Operation in congested waters (Coastal (<12 miles off) or restricted waters). Areas within congested waters are characterized by high density traffic.

• En route at sea (Open Sea (≥12 miles off) & Archipelagos). Ship has her full operational speed.

• Operation in limited waters (Rivers, Canals and Inland waters).

•Operation in shipyards and drydocks.

Weather
There are only few cases with enough data about the weather. Therefore, the weather was considered as "bad" in these cases: "heavy weather damage", "force 11 storm", "cyclone", "heavy seas".

LOWI (Loss Of Watertight Integrity)
The probability of hull breaching in case of an accident is considered essential for the sequence of events and consequences of the accident.

- LOWI was considered in these cases: "bottom damage", "broke in two and sank", "forepeak flooded, bow section broke off", "damage to hull structure", "shell plating damage", "oil spill-leakage", "cracks below waterline", "reported taking water", "bow damage and took water", "hull holed", "double bottom ballast tank fracture", "ingress of water", "cracks near sea chest".

[1] www.oxforddictionaries.com
[2] M. Rausand, "System Reliability Theory (2nd ed.)", Wiley, 2004

- No LOWI :"deck damage", "fractures on internal structural members", "heavy weather damage(without further details)", "minor crack in cargo tank", "damage to bulkhead", "crack in weld of a tank", "damage to a tank", "crack in weld of a tank", "tank's structural damage", "crack between cargo tank and the duct keel", "internal hull structure damage"

Degree of severity

NTUA-SDL database is based on IHS database. According to IHS database an accident is considered serious, if one of the following situations applies:

- Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilization of main engines, extensive damages etc.
- Breakdown
- Actual total loss
- Any other undefined situation resulting in damage or financial loss, which is considered to be serious

Attention must be paid to the "any other undefined situation resulting in damage or financial loss, which is considered to be serious". This definition is relative and it is clearly up to the user/analyst of the IHS-database to determine the severity degree. Furthermore, the term "financial loss" is not determined.

Ship other transfer-ship internal transfer

"Ship other transfer"-When cargo was transferred to another ship(lightering) in order to improve ship's stability as a result of an accident.
"Ship internal transfer"-When cargo had been transferred to another tank/tanks in an effort to improve a ship's stability as a result of an accident.

Ship's part damaged(Nature of damage)

This category indicates which part of the ship was damaged and concerns NASF. The goal is to clarify which database descriptions were categorized under each of the four categories, namely hull, deck, internal, unknown.

1. Hull:"broke in two and sank", "forepeak flooded, tanks open to sea", "crack in tank and oil spill (and/or water ingress) ,"damage to hull", "shell plating damage and cracks", "repairs to hull", "cracked hull", "2 cracks below the waterline", "starboard shell damage", "oil leakage from tank/tanks", "reported taking water"
2. Deck:"deck damage"," crack in main deck", "corrosion to main deck"
3. Internal: "crack in tank without oil spill(or water ingress) ", "bottom damage", "internal structural members damage", "crack between cargo hold and duct keel", "damage to bulkheads", "structural damage", "crack in a weld of a tank"
4. Unknown:"heavy weather damage"

Oil recovery

Indicates in an oil spill case which amount of spilled oil was eventually recovered from sea.

Hull type

In this research hull types are divided in two main categories.

1. Double hull: Here are included "double hull(13F)", "double hull(MARPOL)", "double hull"
2. Non double hull: Here are included "single hull", "double bottom entire compartment length", "double sides entire compartment length"
3. Unknown: When there is no data available concerning the hull type

<u>Flag:</u> NTUA-SDL database includes different abbreviations for flags, which do not correspond totally to a worldwide accepted abbreviation list. Thus, the following list contains all these abbreviations and their interpretation. Lastly, it should be noted, that in some cases the full flag's name is encountered in NTUA-SDL database.

Table 3.3. Interpretation for flags' abbreviations (encountered in NTUA-SDL database)

abbreviation	flag	abbreviation	flag
Pa	Panama	Qt.	Qatar
Am.	Autoridad maritima de Panama	Sg.	Singapore
Br.	Bermuda	Sw.	Sweden
Bs.	Bahamas	Tu.	Tuvalu
Cy.	Cyprus	Ve.	Venezuela
Gb.	Gibraltar	SL	Sri Lanka
Gr.	Greece	HK	Hong Kong
In.	India	DIS	Denmark International Register
IoM	Isle of Man	Rm.	Romania
It.	Italy	TAAF	French Southern and Antarctic Islands
Iq.	Iraq.	My	Malaysia
Ir.	Iran	Sv.	Saint Vincent
Ku.	Kuwait		
Li.	Liberia		
Ly.	Libya		
M.I.	Marshall Islands		
Ma.	Malta		
NIS	Norwegian International Register		
No.	Norway		
Ph.	Philippines		

4 Analysis of Non Accidental Structural Failures

4.1 Full sample

Non Accidental Structural Failure (NASF) events consist of scenarios where the hull presents cracks and fractures, which affect the vessel's seaworthiness or efficiency.

NASF will be studied focusing on basic hull types (DH and non-DH) and ship's size (Panamax, Aframax, Suezmax, VLCC, ULCC).

The full sample consists of 146 NASF cases.

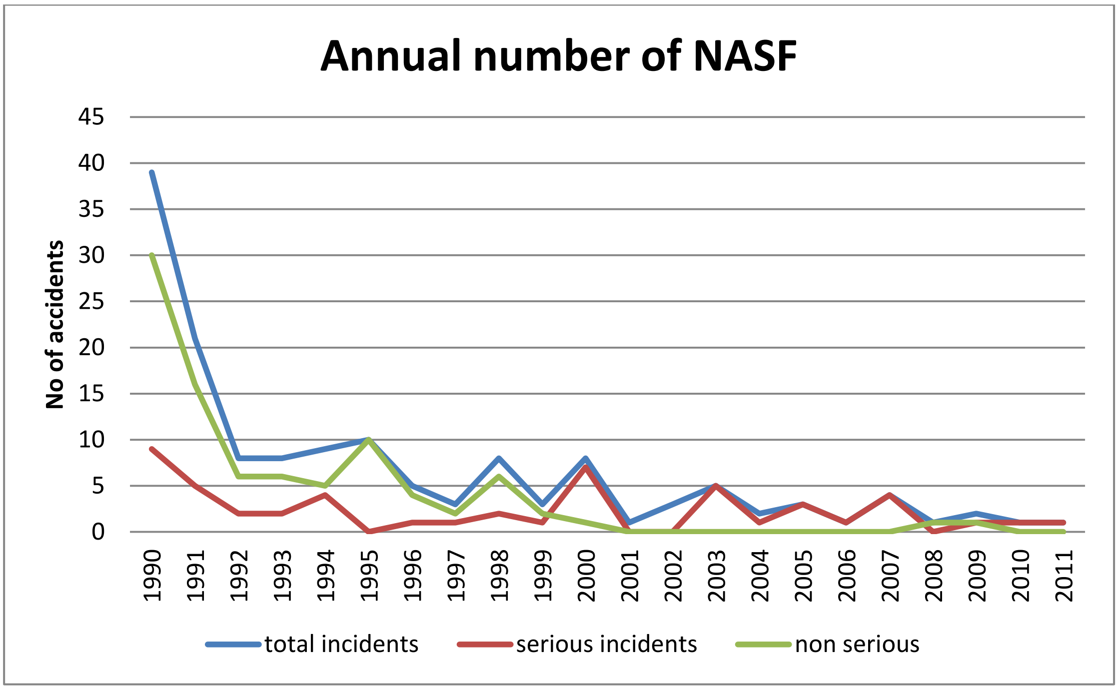


Figure 4.1. Annual number of NASF and severity level.

The figure above can be misleading, when focusing on the peaks. Subsequently, by studying frequencies safer conclusions could be drawn.

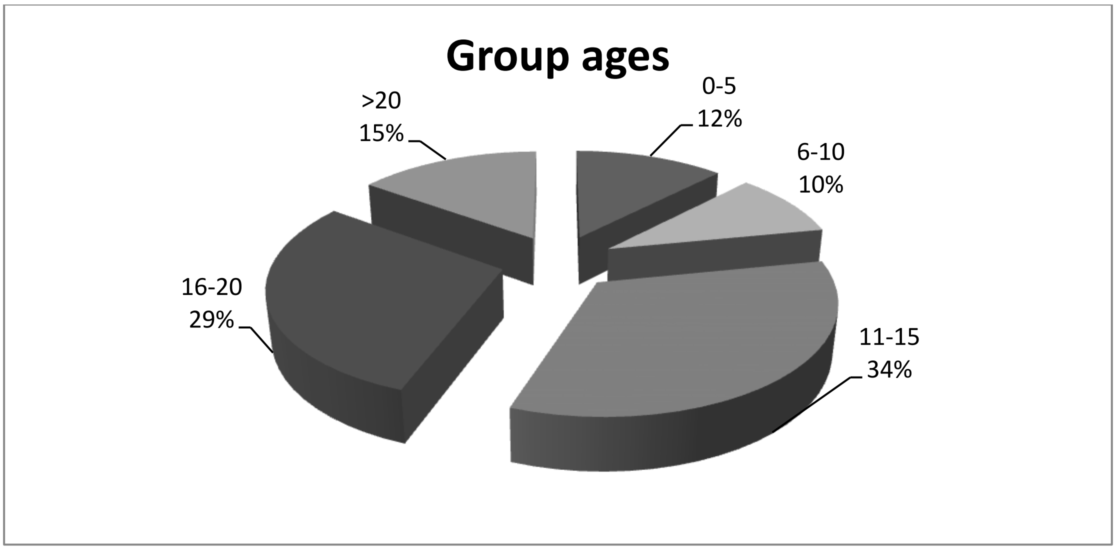


Figure 4.2. Group ages of large tankers involved in NASF.

It can be noticed that 44% of NASF regard relatively old tankers, that means tankers older than 15 years. A relation between age and structural problems seems logical, if we take into consideration that problems, such as corrosion and fatigue, affect increasingly ships, as they get older. The most important finding of this diagram is that 12% of NASF accidents concerns young ships (till 5 years old). This seems strange and implies that there were certain manufacturing (mainly bad building quality and incorrect processes followed) problems among others that mainly played a role in this negative development. (see 4.6-"NASF fault tree", for further causes of NASFs). Furthermore, there is not a straightforward relationship between ship's age and NASF.

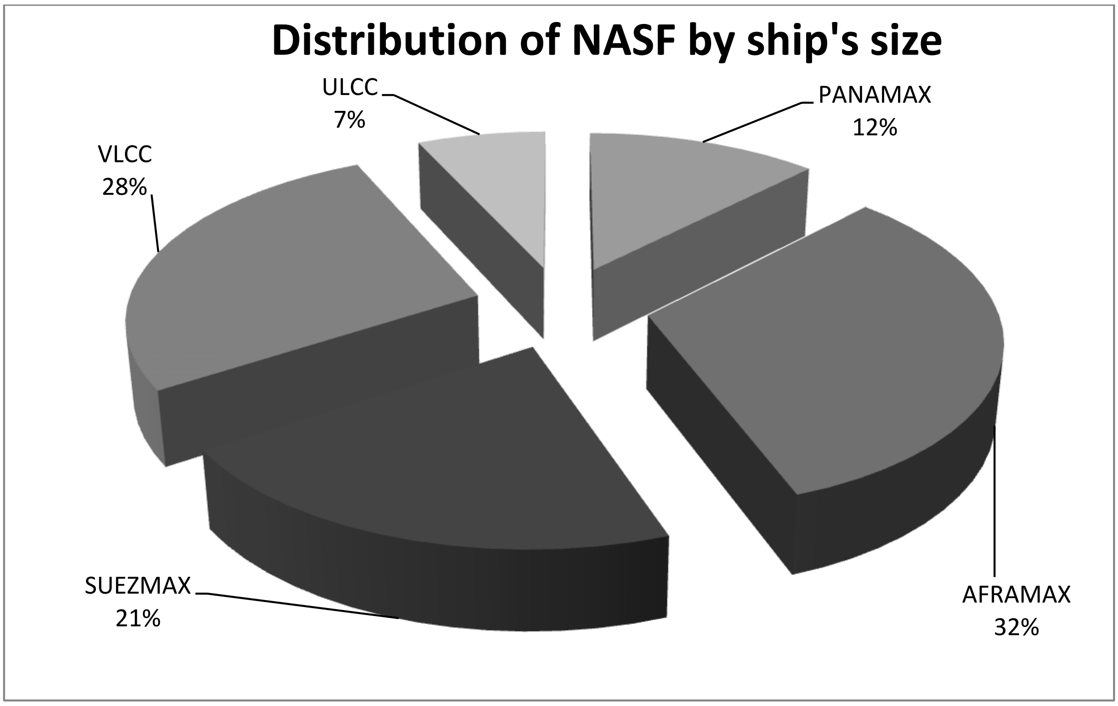


Figure 4.3. Distribution of NASF by ship's size.

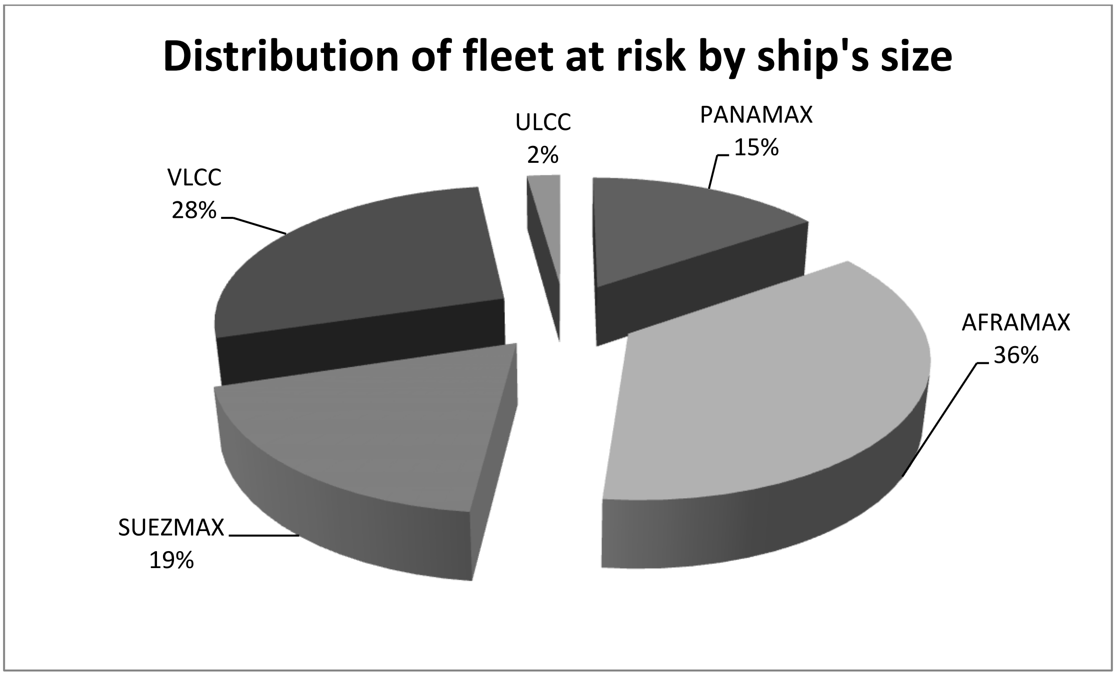


Figure 4.4. Distribution of fleet at risk by ship's size.

By comparing the above two diagrams we understand, that there is no obvious relation between ship's size and NASF, as the percentages are similar. There is one exception, that of ULCC. This seems logical, as ULCC are the largest of the large tankers and thus the developed stresses are greater in comparison to the other large tankers' categories. As a result it is more likely, that structural overstressing occurs. Nevertheless, that problem concerns ULCC and not VLCC. Contrariwise there is a great coincidence, that the percentage of VLCC that had a NASF, is same to the percentage of VLCC in the total fleet at risk (28%).

4.1.1 Event location, ship operation, environment

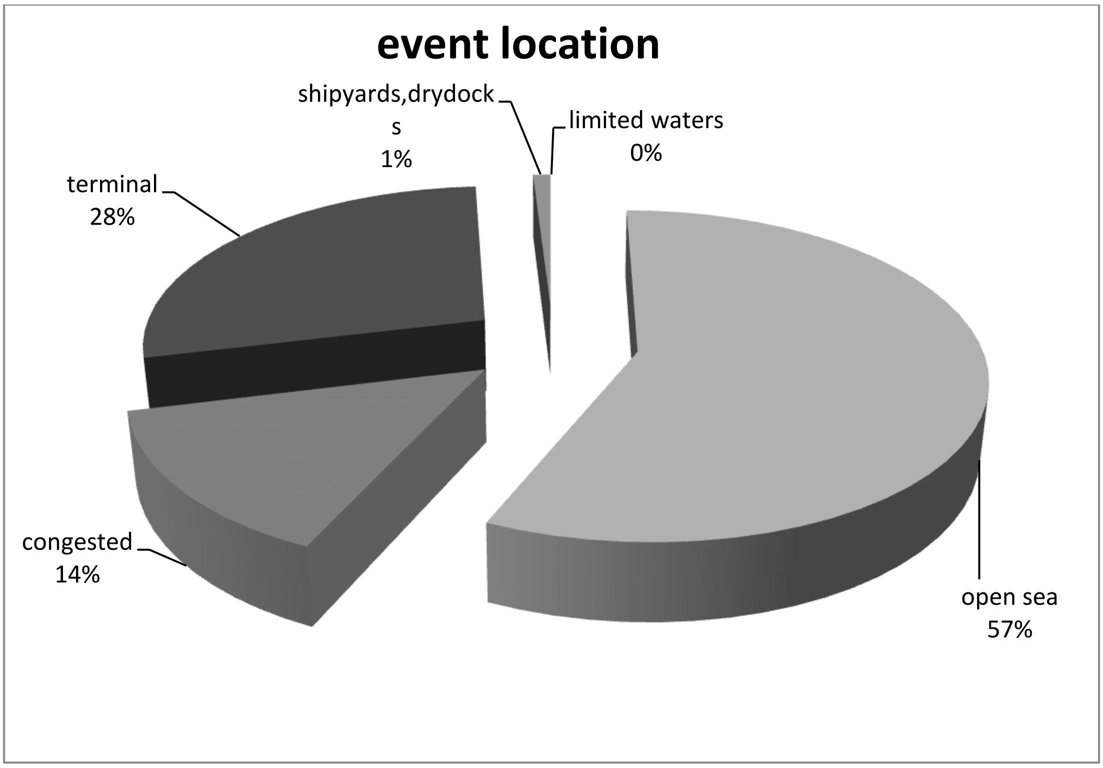


Figure 4.5. Event location. Unknown cases excluded.

Out of the146 NASF cases, we do not possess data for 42, that means 29%. In the above chart it is clear that event location plays a great role, as far as NASF are concerned. 57% took place in open sea and that can be attributed to two factors: 1) Large tankers spend a great percentage of their "operational" time in open sea. 2) Stresses developed in open sea are greater in contrast to more protected waters. Nevertheless it is worth noting, that large tankers are built to handle a wide range of weather conditions.

A great percentage of NASF took place in terminal waters, where the ships in theory operate at a low speed and are mostly protected by extreme weather conditions. This can attributed mainly to loading mistakes (ship overloaded or false loaded).

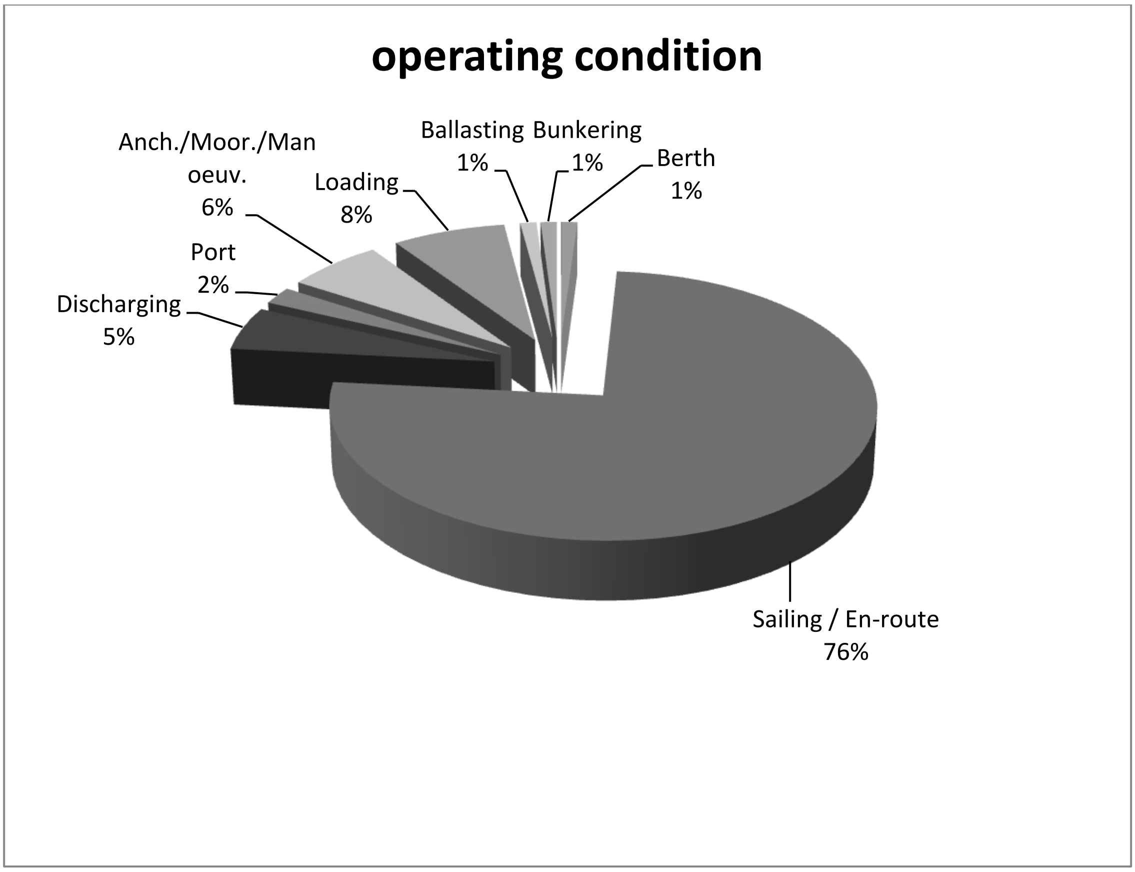


Figure 4.6. Operating condition. Unknown cases excluded.

With respect to operating condition, 36% of the cases are unknown. Apart from operating condition "sailing/en route", which is greatly represented in this category, the other ones, that stand apart, are operating conditions "loading" and " discharging". That seems reasonable, as loading mistakes could occur during loading/unloading processes. Possible loading mistakes during those procedures could lead to overstressing of the hull.

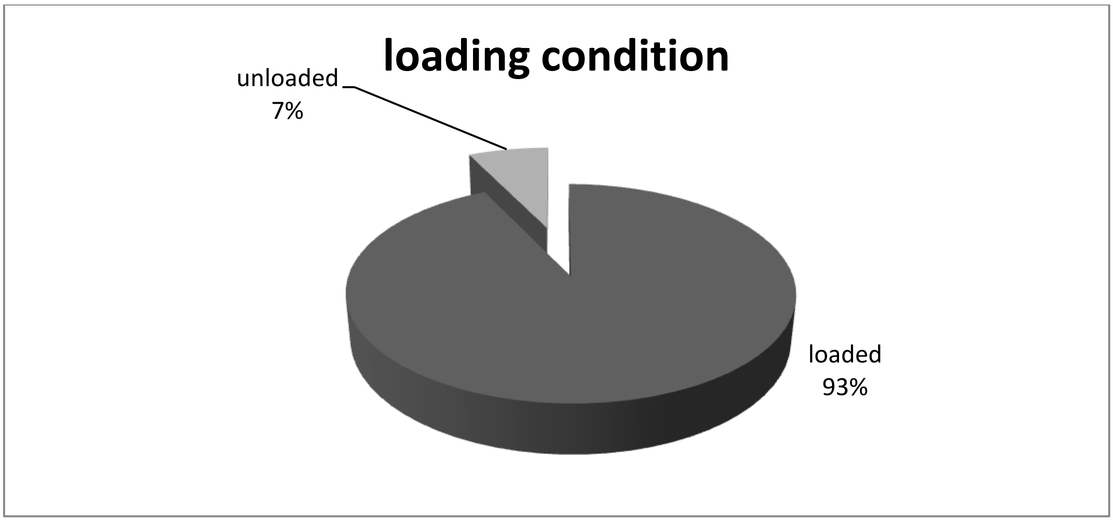


Figure 4.7. Loading condition. Unknown cases excluded**.**

Unfortunately, in this case we don't possess data for 71% of the accidents (104 out of 146). Nevertheless, it is clear, when examining the cases we possess data for, that loading condition plays an important role. To rephrase it, a loaded tanker is more likely to suffer a NASF in comparison to an unloaded tanker.

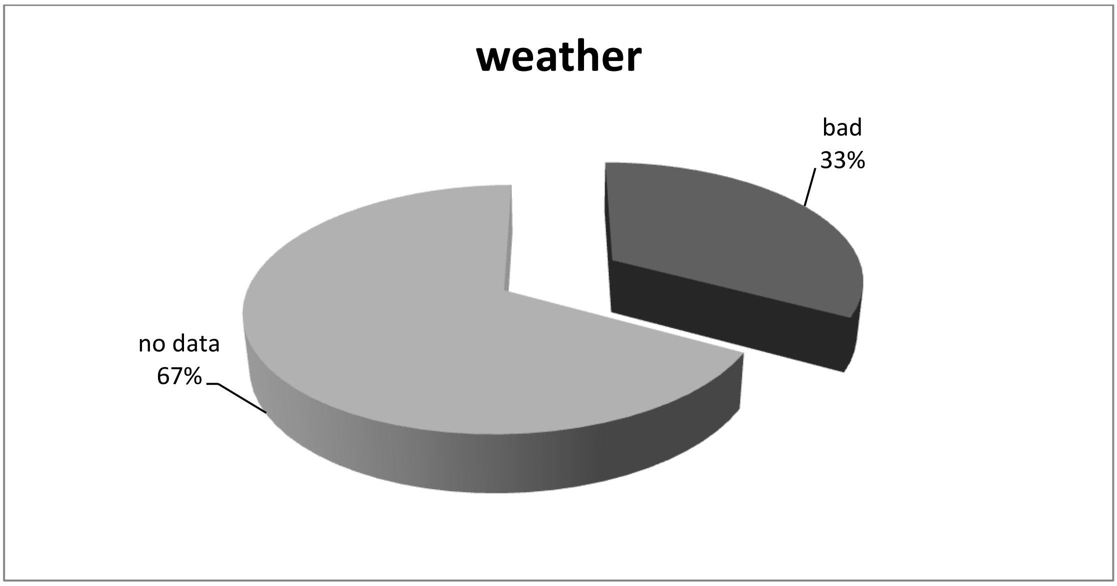


Figure 4.8. Weather

It was not possible to categorize further bad weather, to distinguish for example between "bad" and "very bad weather" or regarding to significant wave height. Unfortunately in the most cases the only comments, that could be found in the complementary texts of each accident, are phrases such as "heavy weather", "heavy seas"," typhoon"," heavy seas", "cyclone", tropical depression". There were no accidents, in which good weather was reported, probably because the one who compiled the report did not consider it important to write down the weather conditions, if they were not bad. As far as the 48 cases of bad weather conditions are concerned, they were to be found in these event locations:

Table 4.1. Event location, where bad weather was encountered

Open sea	36
terminal	1
congested	3
unknown	8
Bad weather condition cases	**48**

This table indicates that (obviously) it is far more likely that bad weather condition would be encountered in open sea, but that is not absolutely certain.

Last but not least, it should be again noted, that tankers are designed to handle a great range of weather condition. Despite that, weather conditions seem to play an important role. That can be possibly attributed to lots of reasons, including building quality and worker's skills (see 4.6-"NASF fault tree", for other reasons that could lead- independently or combined- to NASF)

4.1.2 Outcome of event

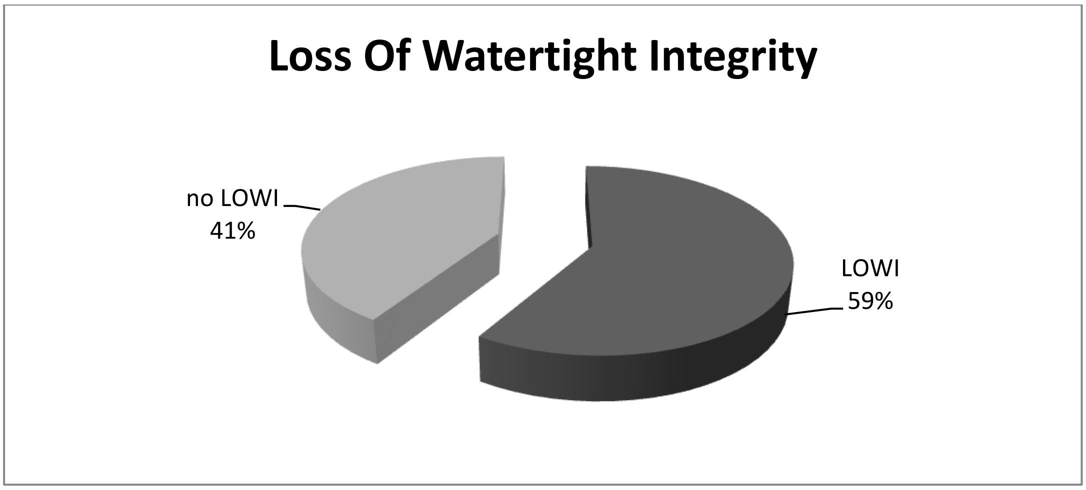


Figure 4.9. Percentage of NASF accidents, that led to LOWI.

This graph indicates one of the most important reasons, why NASF should be examined further and in details: they lead highly likely to Loss Of Watertight Integrity of the tanker. The consequences vary and in the worst case scenario are sinking of the ship, environmental pollution and loss of life. This is only rarely the case, but the impacts are enormous, taking past experience of such accidents into consideration (see 4.7- Characteristic NASF accidents)

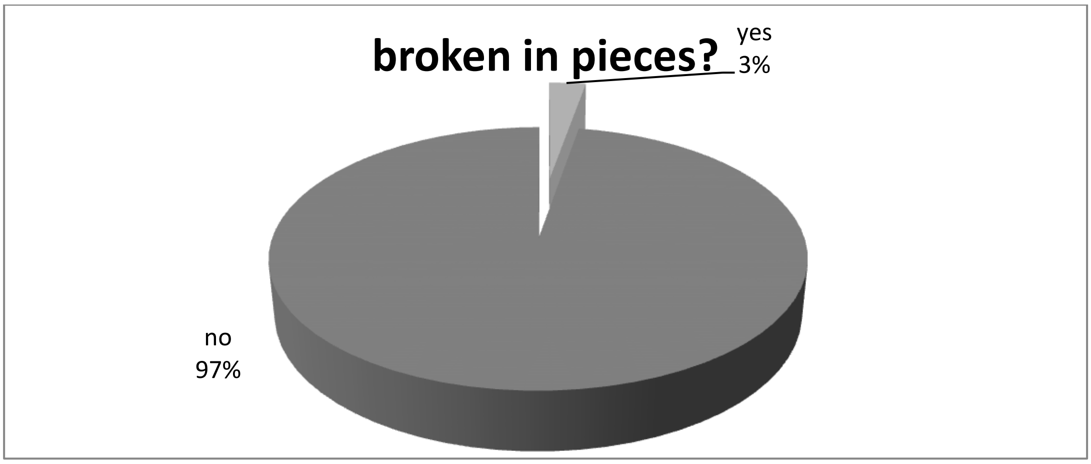


Figure 4.10. Percentage of NASF, in which the ship broke in pieces.

3 out of 4 cases, in which the tanker broke in pieces, were the ones responsible for 96% (166983 tons out of 174039 t in total) of the total environmental pollution caused by NASF during the studied period. The fourth case is one of an unloaded tanker and thus caused minor environmental pollution.

Table 4.2. Various outcomes

	yes	no
Towed away?	6%	94%
Sailed by her means?	91%	9%
Sold for demolition?	1%	99%
Broken up?	3%	97%
Ship other transfer?	1%	99%
Ship internal transfer?	1%	99%

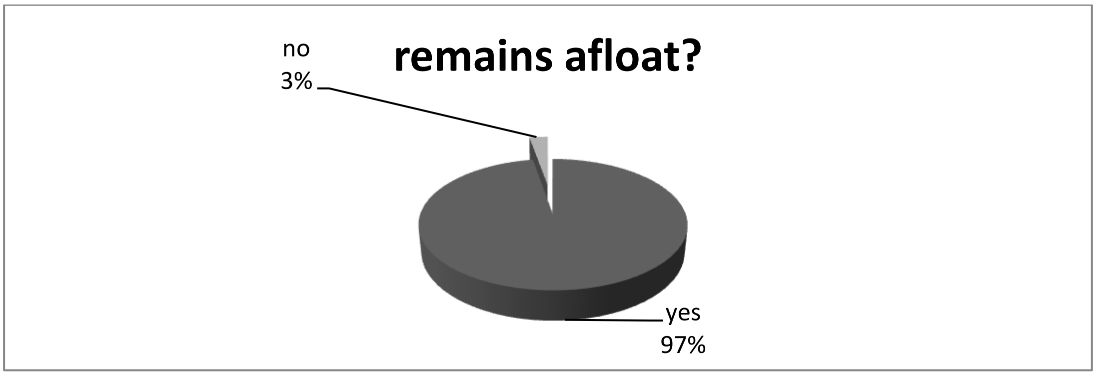


Figure 4.11. Percentage of NASF accidents, that affected ship's floatability**.**

LOWI could have occurred, but it was not that serious, in order to endanger ship's floatability.

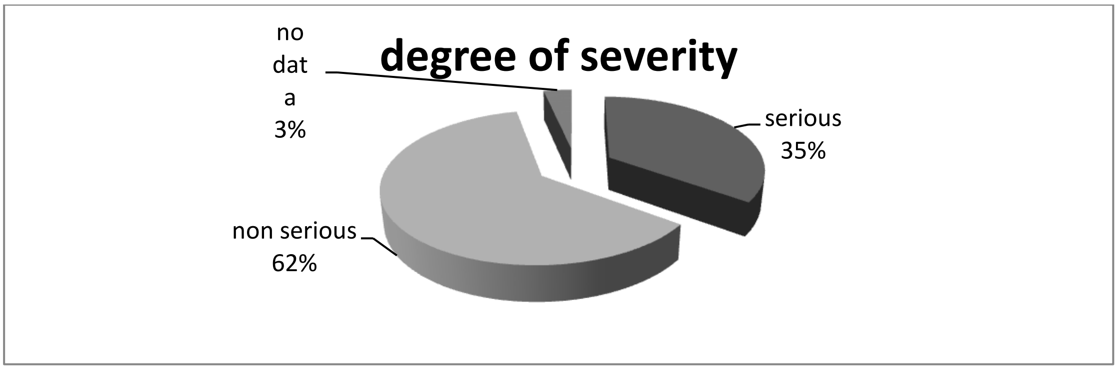


Figure 4.12. Distribution of NASF by degree of severity.

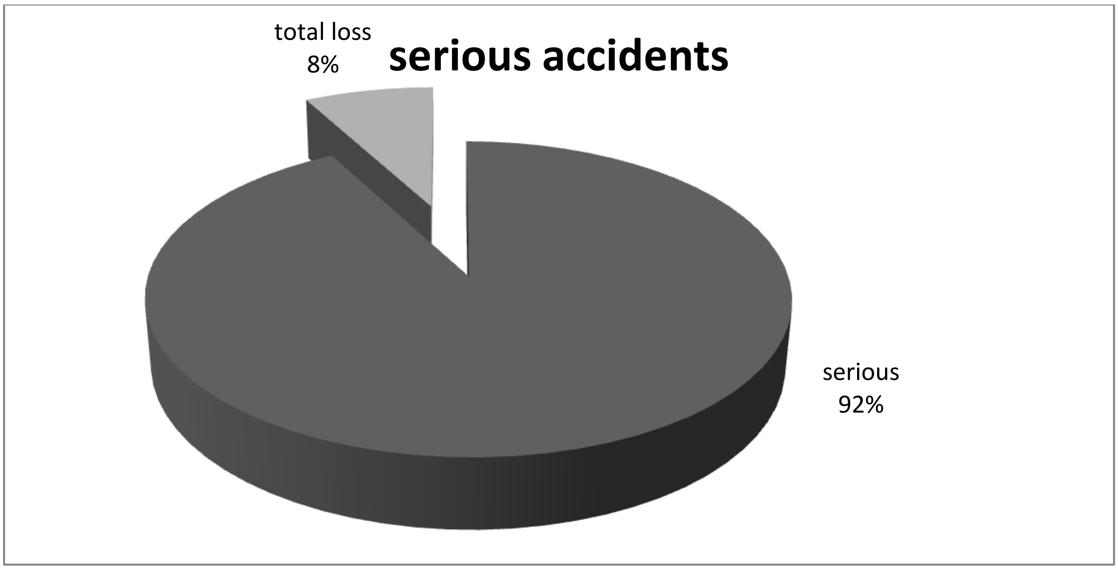


Figure 4.13. Distribution of serious NASF by degree of severity.

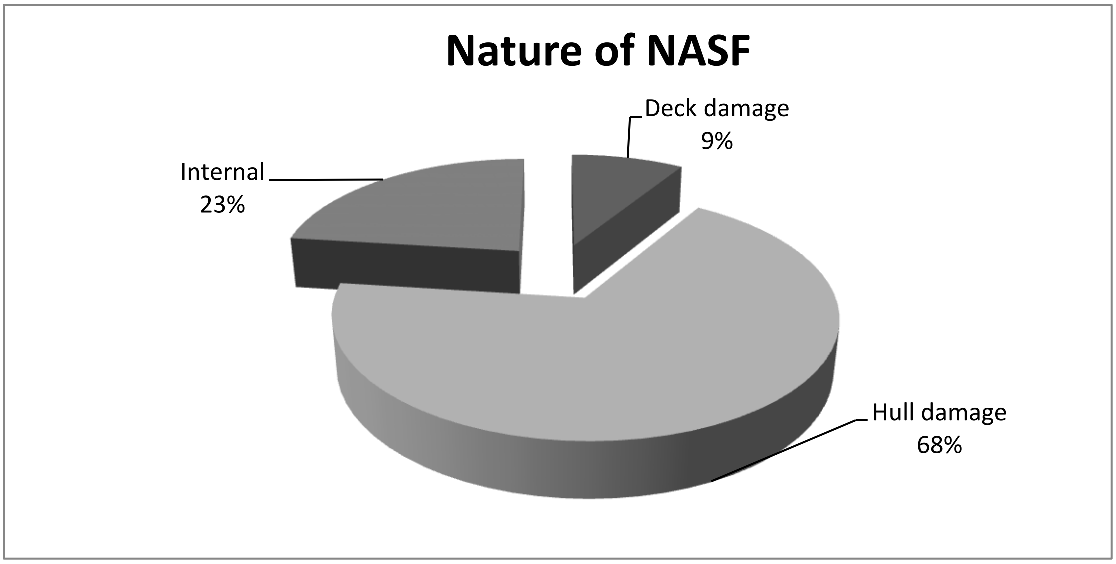


Figure 4.14. Nature of NASF. Ship's part damaged. Unknown cases excluded.

We don't possess data for 33 of the cases (23%). It is not easy to draw conclusions without distinguishing between different hull types. Therefore this category will be examined with more details subsequently.

Table 4.3. Various outcomes per decade of built.

	ship's part damaged				other outcomes			
decade of built	Hull	Deck	Internal	unknown cases	LOWI	serious	average age of NASF	total cases
1950's	0%	0%	100%	0	100%	0%	37	1
1960's	100%	0%	0%	0	100%	100%	24	2
1970's	74%	8%	18%	24	54%	27%	17,1	90
1980's	62%	4%	34%	2	71%	46%	12,9	28
1990's	50%	25%	25%	4	56%	40%	5,4	16

2000's	67%	16%	17%	3	56%	78%	3,9	9

The most striking finding of the analysis in Table 4.3 is the relationship between NASF and the average ship age. It gets smaller and smaller over the years, meaning that more young ships are engaged in NASF. Although the small average age in which NASF occurred is trivial for tankers built in 2000's (as they could not have a great average age), that is not the case for tankers built in 1990's. They present a really small average age of 5.4 years for the occurrence of NASF. Note that out of the 16 large tankers, that were built during the 1990's, 10 were built in South Korea,3 in Japan,1 in China and 2 in Spain.

Unfortunately, there is no data available for the distribution of fleet at risk by year of built, in order to calculate the frequencies of occurrence.

4.1.3 Fatalities, injuries

There were two fatalities in total resulting from NASF. In particular both fatalities happened in the same accident. 3 men were washed across deck (2 dead, 1 not seriously injured), while lashing survival rafts during a force 11 storm. Later cracks were discovered in deck plating. It could be said, that there is no real connection between the death of two members of the crew and the NASF, as it was not so, that the NASF led to the fatalities. It could be considered as an occupational accident.

The conclusion can be drawn, that NASF don't possess a big threat for life. The frequency is $5{,}65\text{x}10^{-5}$ fatalities per shipyear.

4.1.4 Oil spill information

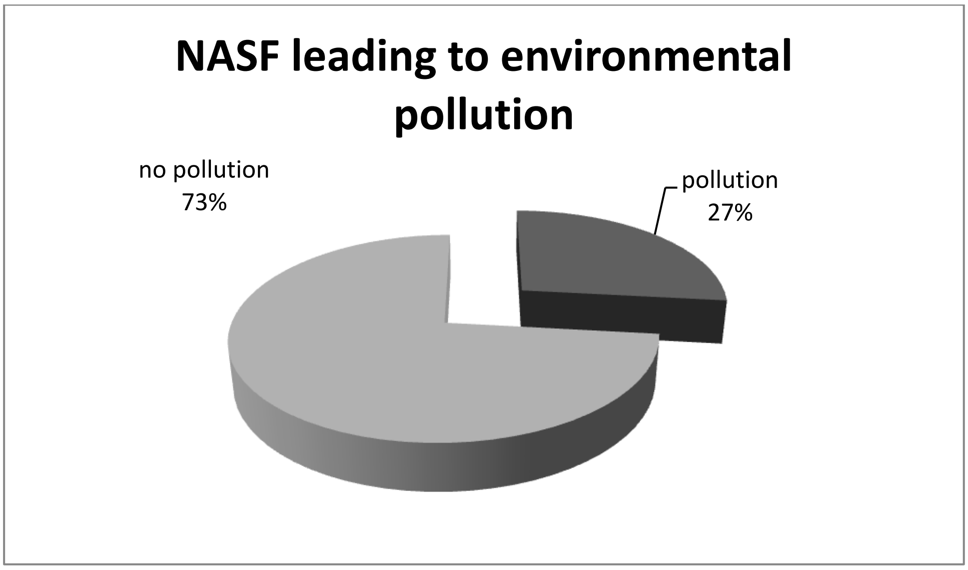


Figure 4.15. Percentage of NASF, that led to environmental pollution.

There are 39 cases of NASF which led to environmental pollution. Total oil spilled is 174039 tonnes.

The negative picture of NASF accidents is mainly formed by a few environmentally catastrophic accidents and not by many accidents, which caused minor pollution. 3 accidents are responsible for 96% of the total environmental pollution in tonnes caused by NASF.

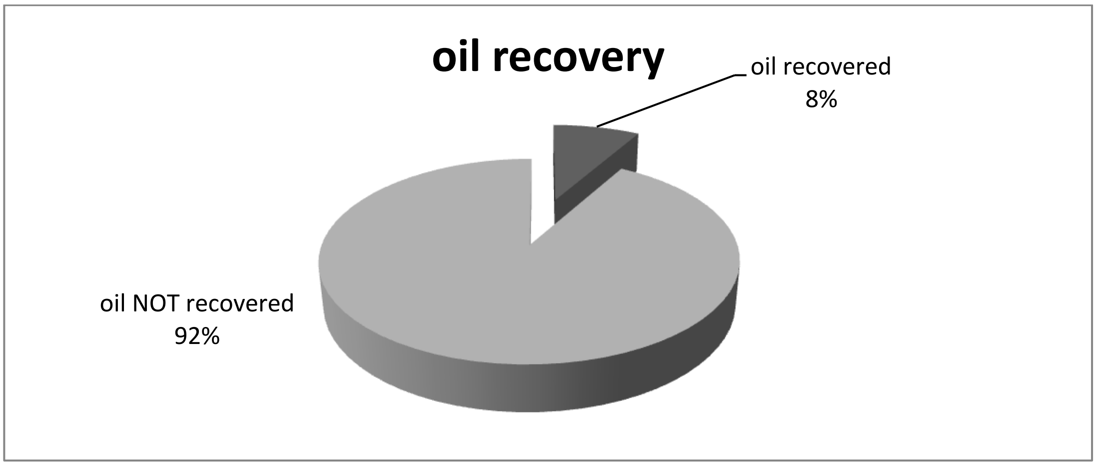


Figure 4.16. Percentage of spilled oil (in tonnes), that was recovered from sea.

In particular 14328 tonnes of oil were recovered.

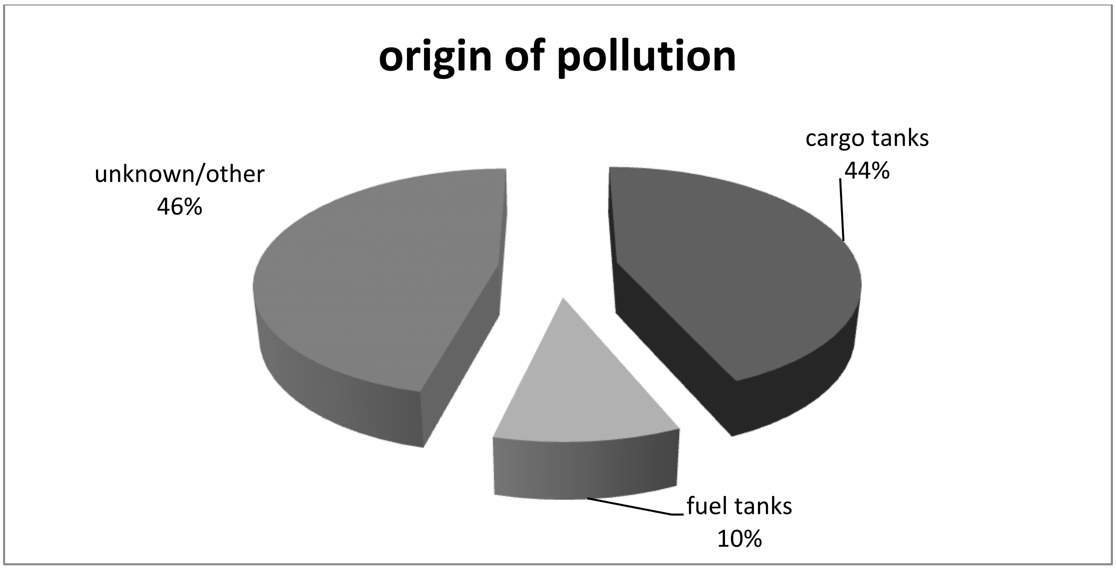


Figure 4.17. Origin of pollution among the ship**.**

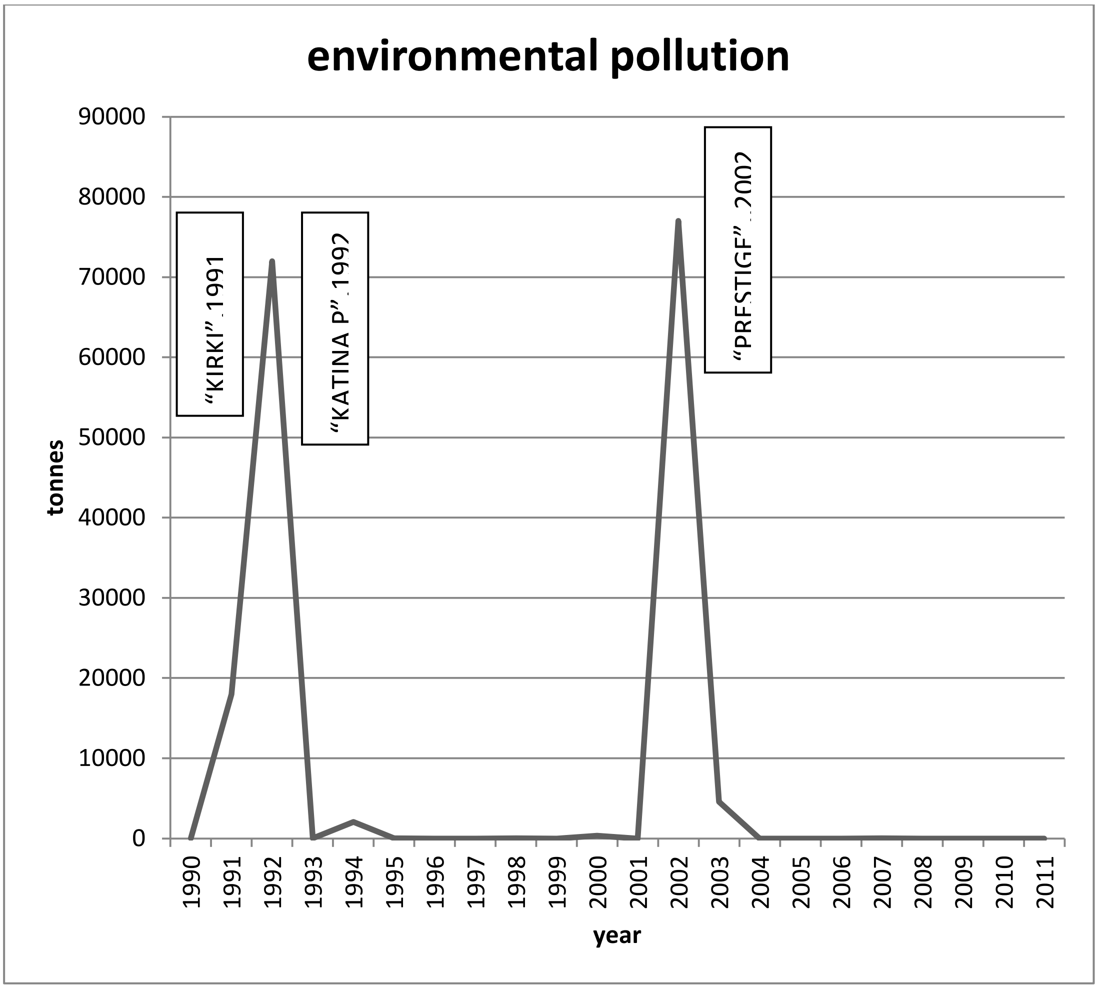


Figure 4.18. Environmental pollution. Yearly spill tone rate.

The 3 peaks represent the 3 worst accidents that led to significant environmental pollution.

4.1.5 Shipyards, flags, classes

Table 4.4. Class when accident occurred

class	cases
American Bureau of Shipping	13
Bureau Veritas	1
Det Norske Veritas	4
Lloyds Register	3
Hellenic Register of Shipping	1
Total cases	22

Table 4.5. Class when ship was built

class	cases
American Bureau of Shipping	4
Det Norske Veritas	2
Lloyds Register	2
Registro Italiano	0
Total cases	8

We possess data for very few cases and thus it is problematic to draw conclusions.

Table 4.6. Shipyard (country) of built for tankers, that presented NASF.

Shipyard (country)	cases
China	4
Croatia	1
Denmark	4
Sweden	19
Japan	48
Korea (South)	26
United States of America	22
Spain	11
Canada	1
Belgium	1
Poland	2
France	1
Italy	1
United Kingdom	2
Netherlands	1
Finland	1
Norway	1
Total cases	146

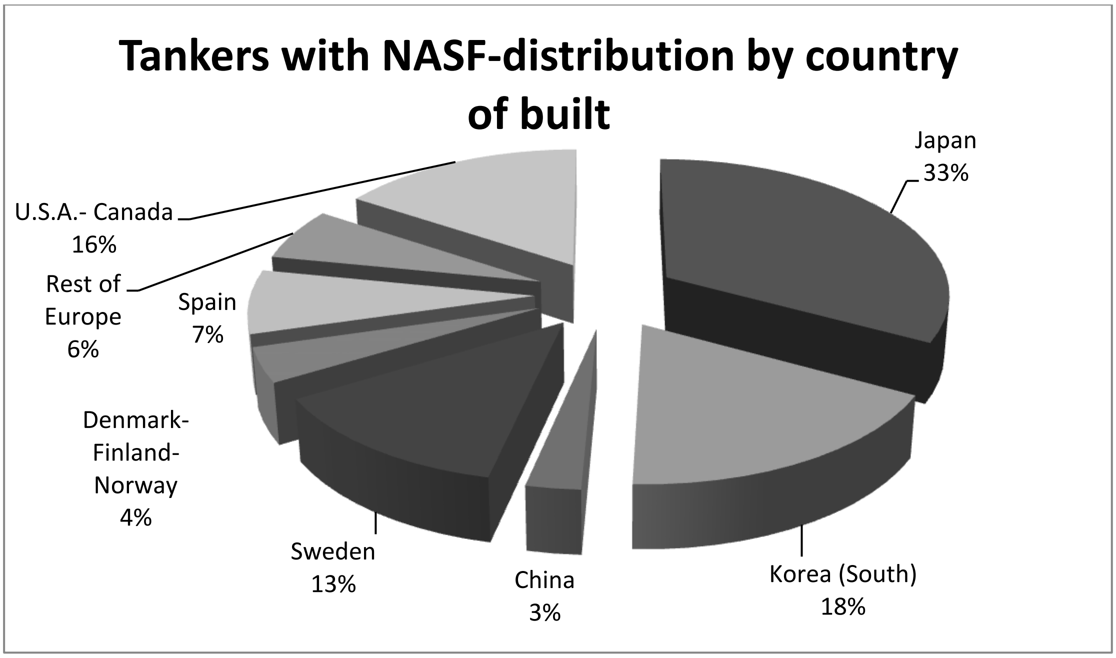


Figure 4.19. Distribution by shipyard (country) of built for tankers, that presented NASF.

Table 4.7. Information about mostly represented shipyards (countries), where tankers, that presented NASF, were built.

Shipyard (country)	cases	serious	Broken in pieces	LOWI	Deck damage	Hull damage	Internal damage	Average ship's age(when accident occurred)
Japan	48	31%	4,2%	62,5%	6,3%	62,5%	8,3%	15,8
Korea(South)	26	38,5%	3,8%	46,2%	11,5%	30,8%	26,9%	8,5
China	4	50%	0%	25%	0%	25%	0%	3,25
Sweden	19	31,6%	0%	68,4%	0%	63,2%	10,5%	16
Spain	11	54,5%	9,1%	63,6%	9,1%	45,5%	18,2%	14,5
U.S.A.-Canada	23	21,7%	0%	69,6%	8,7%	65,2%	21,7%	19,1
TOTAL	*146*	*35%*	*3%*	*59%*	*9%*	*68%*	*23%*	*14,4*

Large Tankers built in China and South Korea present a small average age, at which a NASF occurred. The sample for tankers built in China is really small, but indicative of probable problems. Surprisingly 2 of those tankers (built in China) were only 1 year old, when NASF occurred.

Table 4.8. Flag, when ship was built

Flag	cases
Bahamas	3
Bermuda	1
Cyprus	1
Greece	2

India	1
Italy	0
Liberia	10
Marshall Islands	1
Norway	1
Norway(NIS)	3
Panama	5
Qatar	1
Singapore	2
Sweden	1
U.S.A	3
USSR	1
Venezuela	1
Total cases	37

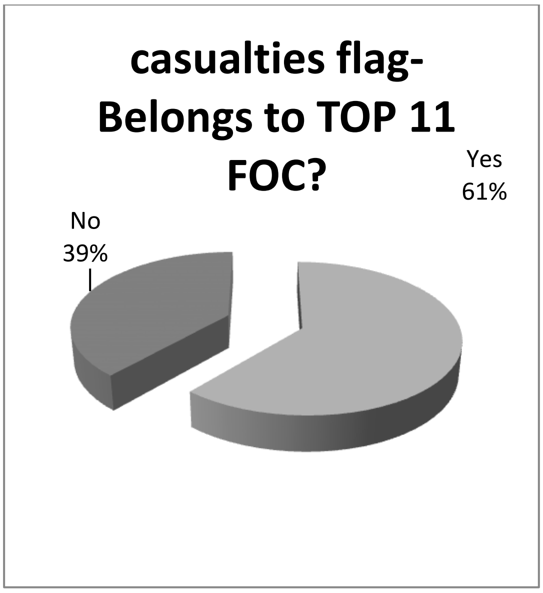
Table 4.9. Flag, when NASF occurred.

Flag	cases		
Panama	31	Gibraltar	2
Australia	3	Isle Of Man	1
Bahamas	10	Libya	3
Bermuda	2	Malaysia	1
Bermuda(British)	1	Norway(NIS)	7
Cyprus	5	Norway	2
France(FIS)	1	Philippines	1
Greece	16	Portugal(MAR)	2
Liberia	29	Qatar	1
Malta	6	Singapore	4
Marshall Islands	5	Sweden	1
Mauritius	1	TAAF	1
India	1	Tuvalu	1
Iran	2	U.S.A.	1
Iraq	1	Venezuela	1
Kuwait	2	*Total*	*145*

NOTE: No data for 1 case

Flags mostly represented are:1)Panama-21,2%,2)Liberia-19,9%,3)Greece-11%,4)Bahamas-6,8%,5)Norway(NIS),6)4,8%,7)Malta-4,1%,8)Marshall Islands-3,4%,9)Cyprus-3,4%

There are 6 cases with pollution over 50 t. Three of them had the flag of Malta, 1 of Iran, 1 of Greece and 1 of the Bahamas.



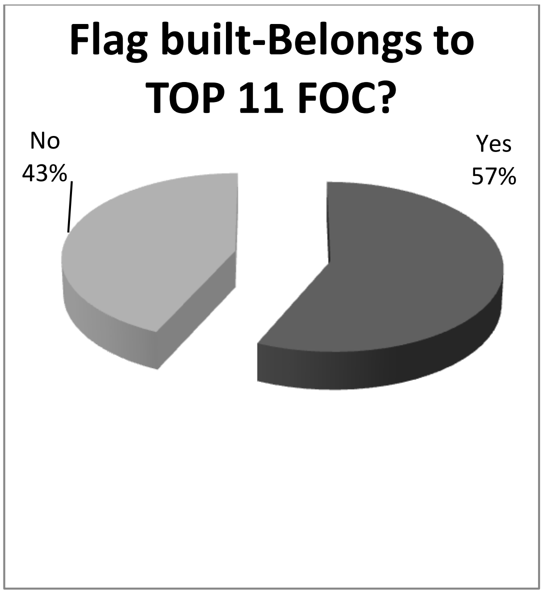


Figure 4.20. Flag, when NASF occurred and when the ship was built. Do they belong to TOP 11 FOC (Flags Of Convenience)?

TOP 11 Flags Of Convenience –according to world fleet in 2009 (merchant ships in general-not only large tankers) in DWT-are: Panama, Malta, St. Vincent, Liberia, Cyprus, France FIS, Marshall Is., Antigua, Cayman Islands, Bahamas, Bermuda. They account for almost 55% of the entire world fleet as of 2009(independently of ship type, DWT over 1000t) .It is worth noting that ships registered under flags of Panama, Malta, St. Vincent, Antigua, Cayman Islands, Bahamas are in US target list, as far as Port State targeting is concerned(as of 2009).

Definition of Flag Of Convenience: 1)the flag of such countries whose law allows - and indeed makes it easy - for ships owned by foreign nationals or companies to fly those flags in contrast to the practice in the maritime countries where the right to fly the national flag is subject to stringent conditions and involves far reaching obligations". 2) The business practice of registering a merchant ship in a sovereign state different from that of the ship's owners, and flying that state's civil ensign on the ship. Ships are registered under flags of convenience to reduce operating costs or avoid the regulations of the owner's country.

The most important reason, why so many ships operate under a FOC, is the reduction of crewing costs. The difference in crew cost between a traditional registered ship and an open registered ship(means: belonging to a FOC) is small but vital for competitiveness in the shipping market.

An example, that makes clear why FOC are so popular among shipowners could be seen by the operation of a modern VLCC-tanker under Swedish and Liberian flags. The difference in crew costs is estimated at 6-8 million SEK or 7-9 hundred thousand Euro per year. (Spruf, J., Ship Management, 1994). Another example of cost saving can be found comparing European, Indian and Chinese crews on a similar ship. On a vessel of 24 crew members where the crew consists of Northern Europeans, 10 officers and 14 unlicensed seafarers, the monthly cost is $80,000. Where the same ration crew is Indian, the monthly cost is $41,000.

Where the same ration crew is Chinese, the monthly cost is just $21,900. The difference between the Chinese crew and the Northern European crew is $58,000 per month and $698,400 per year.

There is growing concern, that crew employed under a FOC is insufficiently skilled and trained in a lot of cases, something that of course influences negatively a ship's operation, increasing the chances of an accident. That applies also for NASF. Possible crew errors that could lead to a NASF (not independently in most cases) include loading mistakes and voyage planning mistakes. In general, it seems logical, that an inadequately trained crew could not cope with an emergency situation as well as a skilled one.

4.1.6 Frequencies

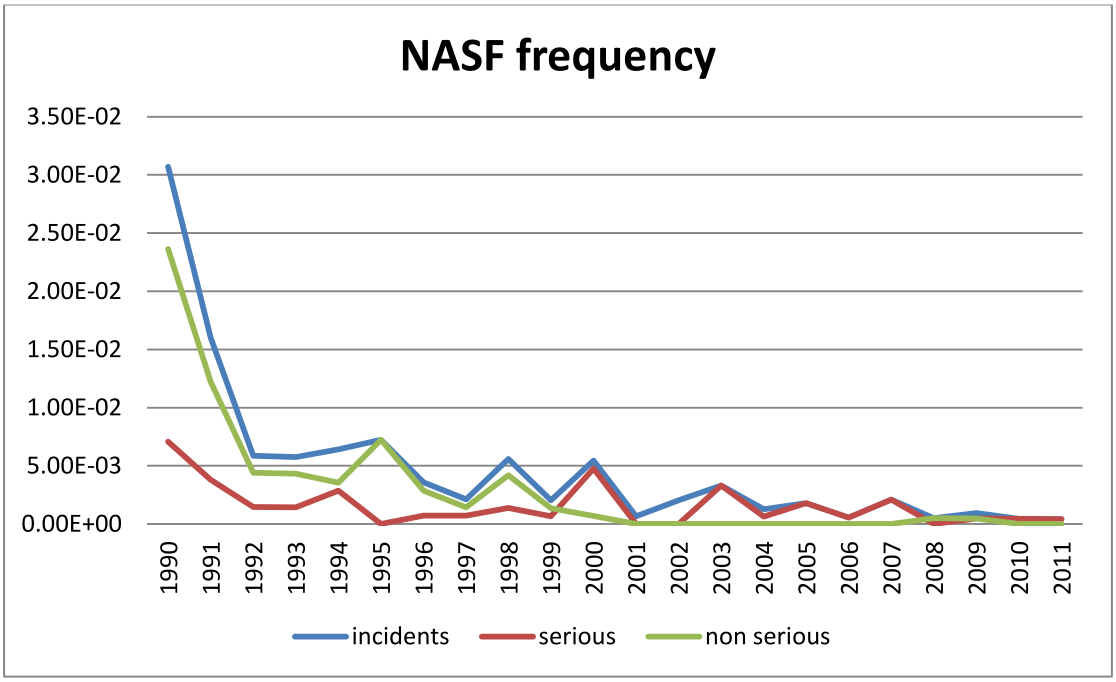


Figure 4.21. NASF frequency per shipyear.

According to this diagram there is an obvious tendency: NASF frequency has been significantly decreased during the last 23 years. <u>This can be attributed to the introduction of a series of regulatory measures, changes in ship design and technology and overall improvement of the safety culture of the maritime industry.</u>[3]

[3] A. Papanikolaou, E. Eliopoulou, "Impact of ship age on tanker accidents", Proceedings of the 2nd Int. Symposium on "Ship Operations, Management and Economics", Athens, Sep. 17-18, 2008

The eye-catching peak in 1990 could not be fully explained, but here is some data concerning these 39 cases:

- 16 out of 39 cases concern VLCC. 9 of them were built in Japan during 1973 and 1977. The average age of NASF for 14 out of these 16 accidents is 15 years.
- Hull type: 1 DH, 8 non DH and unknown for 30/39. Judging by the average age of NASF for these 30 cases (14,6 years) and the year of built (between 1971 and 1981), one could assume, that most of them are non DH.

Table 4.10. Annual number of NASF and degree of severity.

year	accidents	serious	non serious
1990	39	9	30
1991	21	5	16
1992	8	2	6
1993	8	2	6
1994	9	4	5
1995	10	0	10
1996	5	1	4
1997	3	1	2
1998	8	2	6
1999	3	1	2
2000	8	7	1
2001	1	0	0
2002	3	0	0
2003	5	5	0
2004	2	1	0
2005	3	3	0
2006	1	1	0
2007	4	4	0
2008	1	0	1
2009	2	1	1
2010	1	1	0
2011	1	1	0
	146	51	90

NOTE: 5 accidents are not characterized as serious or non serious

Table 4.11. Frequency of NASF in total, serious NASF and non serious NASF for studied period per shipyear.

	Frequency per shipyear
NASF	$4{,}124 \times 10^{-3}$
non serious NASF	$2{,}542 \times 10^{-3}$
serious NASF	$1{,}412 \times 10^{-3}$

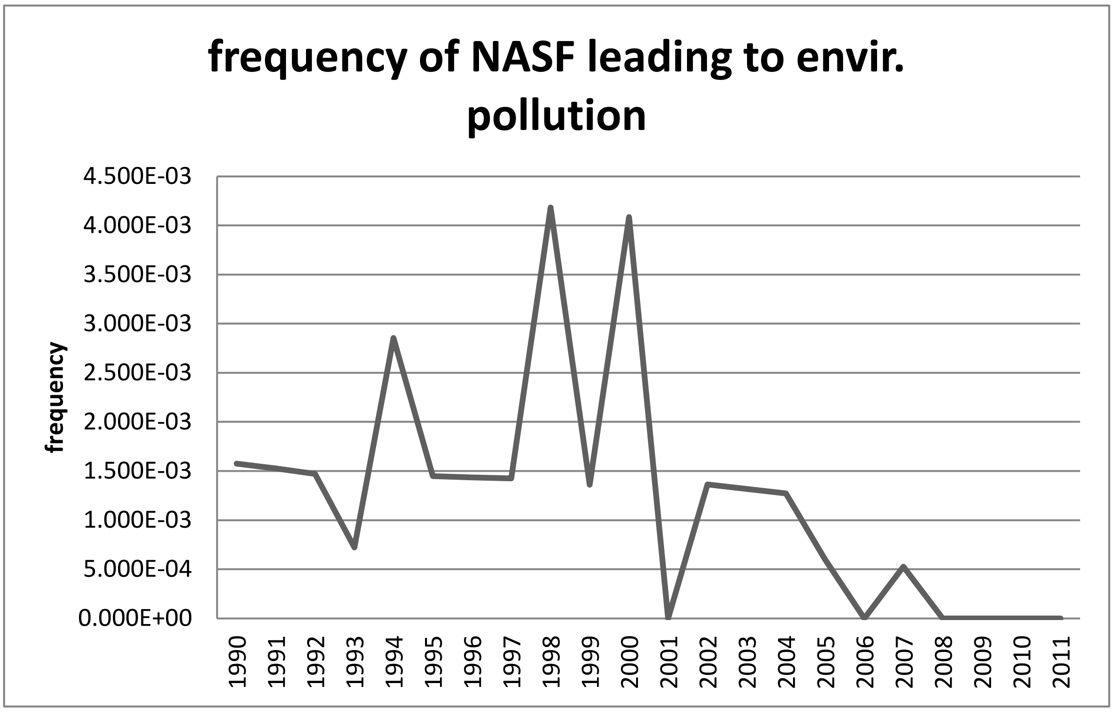


Figure 4.22. Frequency of NASF, that led to environmental pollution per shipyear.

1998 and 2000 are the years, that present peaks, as far as frequency and not amount of spilled oil is concerned. It is also worth noting, that there was no environmental pollution, caused by a NASF, from 2008 to 2011.

High frequency in the figure above does not necessarily mean that a big amount of oil was released to the sea. The negative picture of NASF accidents is mainly formed by a few environmentally catastrophic accidents and not by many accidents, which caused minor pollution. Figure 4.18 supports this statement.

Table 4.12. Frequency of NASF, that led to environmental pollution per shipyear. Tonnes of spilled oil annually.

year	cases	frequency	oil spilled(t)
1990	2	1,575E-03	34,134
1991	2	1,526E-03	17984
1992	2	1,469E-03	72001
1993	1	7,208E-04	5
1994	4	2,854E-03	2046,5
1995	2	1,447E-03	3,676
1996	2	1,435E-03	1,05
1997	2	1,424E-03	1,5
1998	6	4,183E-03	12,84

1999	2	1,359E-03	2
2000	6	4,087E-03	357,103
2001	0	0,000E+00	0
2002	2	1,364E-03	77000,1
2003	2	1,319E-03	4579
2004	2	1,273E-03	2
2005	1	5,998E-04	1
2006	0	0,000E+00	0
2007	1	5,263E-04	8,5
2008	0	0,000E+00	0
2009	0	0,000E+00	0
2010	0	0,000E+00	0
2011	0	0,000E+00	0
TOTAL	*39*	*1,101E-03*	*174039,403*

4.2 Focusing on the basic hull type

The sample consists of 22 double hull tankers and 39 non double hull tankers. Basic hull type is unknown for 85/146 NASF cases, reaching a percentage of 58,2%. Therefore, one should be really careful, when trying to generalize after studying this rather small sample.

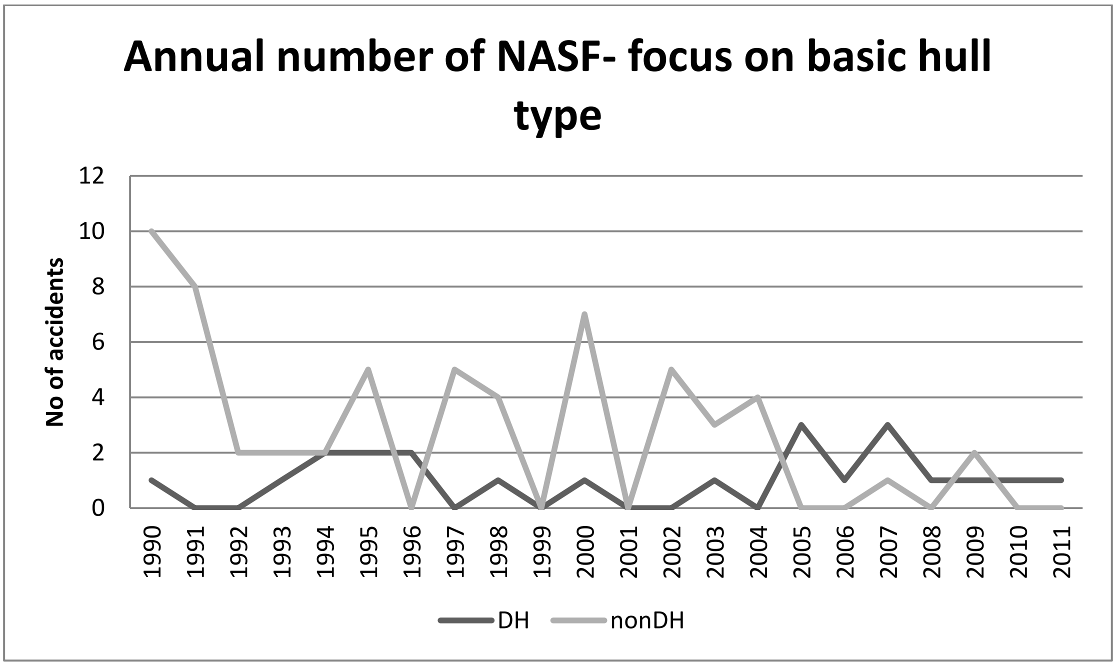


Figure 4.23. Annual number of NASF. Focus on basic hull type.

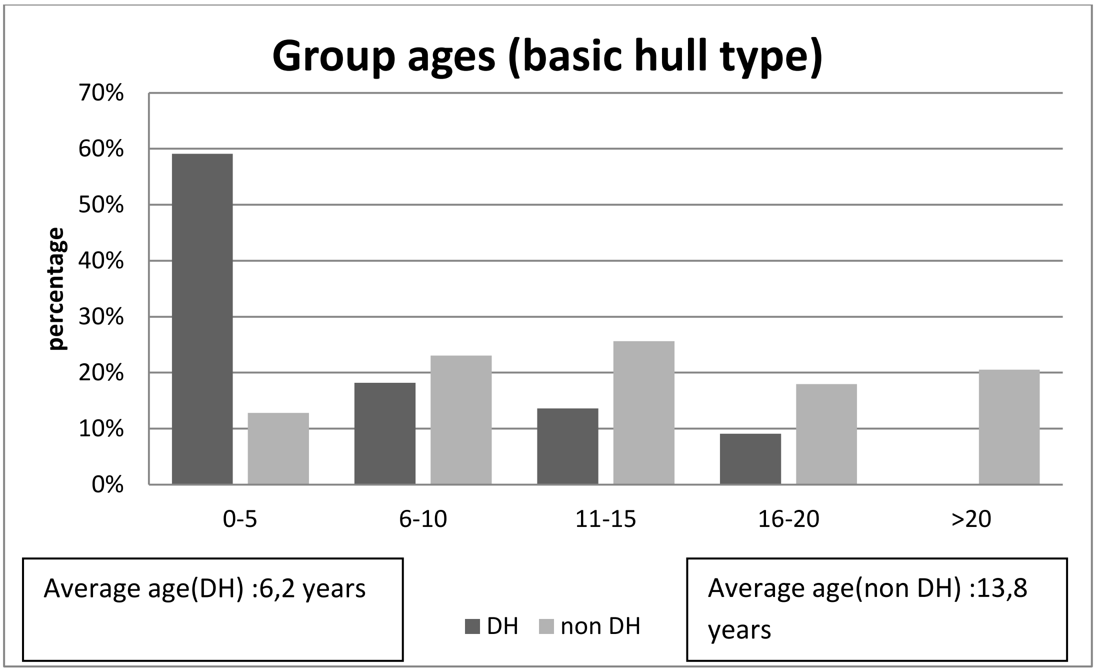


Figure 4.24. Group ages of large tankers involved in NASF. Focus on basic hull type

It is clear that double hull tankers are younger than non double hull ones. That does not mean, that DH are more likely to suffer a NASF (as frequencies are not taken into consideration in this part), but reflects mostly the gradual change from non DH designs to DH. At first glance it seems remarkable, that 56% of the DH tankers, that suffered a NASF, were 0 to 5 years old, but study of frequencies will help us draw more precise conclusions, although it seems quite problematic, that so young ships suffered a NASF. Furthermore, it should be noted that differences between DH and non DH designs should be studied carefully, as the ship types are of different average age. DH fleet is younger than non DH fleet. Older ships are more vulnerable to corrosion, fatigue etc. Once more it should be noted , that the sample is small, something that affects the results.

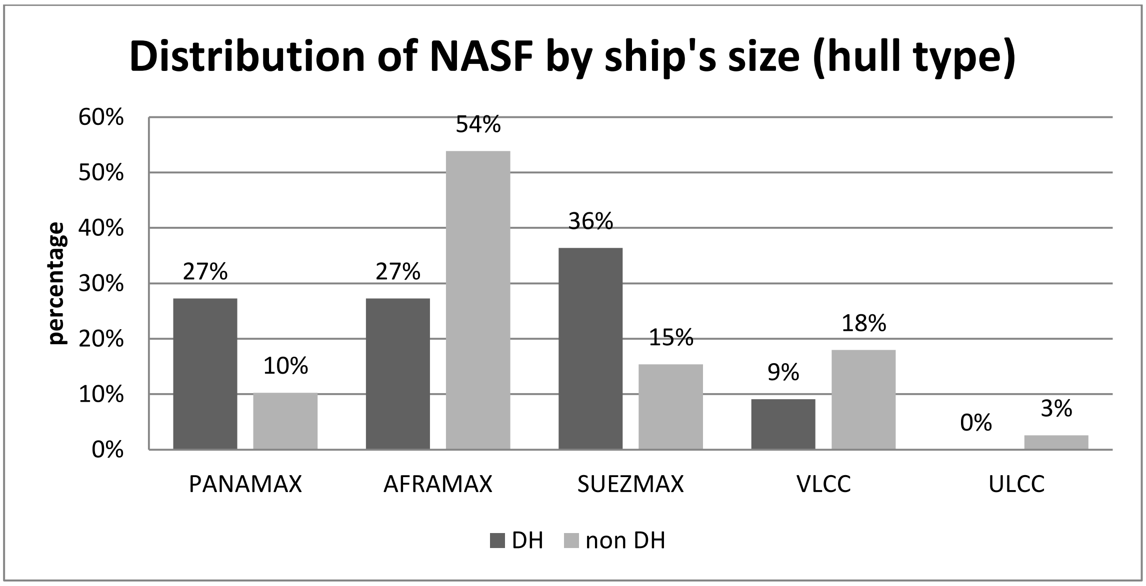


Figure 4.25. Distribution of NASF by ship’s size. Focus on hull type.

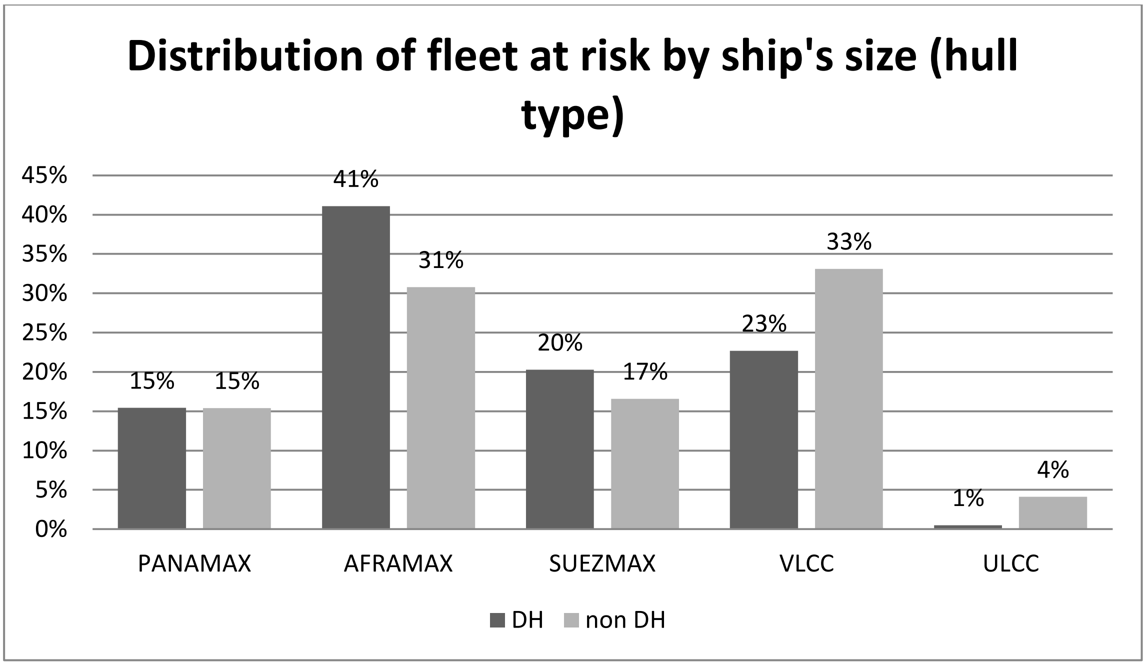


Figure 4.26. Distribution of fleet at risk by ship's size. Focus on basic hull type.

DH Panamax, non DH Aframax and DH Suezmax are represented more Figure 4.25 "Distribution of NASF by ship's size" than in Figure 4.26 "Distribution of fleet at risk by ship's size". That could indicate, that they have a higher risk of suffering a NASF, but frequencies will let us draw more precise conclusions.

Some statistics regarding them:1)DH Panamax, that suffered a NASF (6 cases)-3 built in China, 2 in South Korea, 1 in Croatia with an average age of 4,5 years.2) non DH Aframax (21 cases)- 9 built in Japan with an average age of 13,1 years, 5 in USA with an average age of 21,6, 6 in South Korea with an average age of 12,8 and 1 in Poland , 3)DH Suezmax (8 cases)- 5 built in South Korea with an average age of 3,2 years, 3 built elsewhere(USA, Spain) with an average age of 13 years.

Each ship size will be examined independently in chapter 4.3.

Once more frequencies are of greater significance in compared to just percentages. The point here is to just draw a general picture.

4.2.1 Event location, ship operation, environment

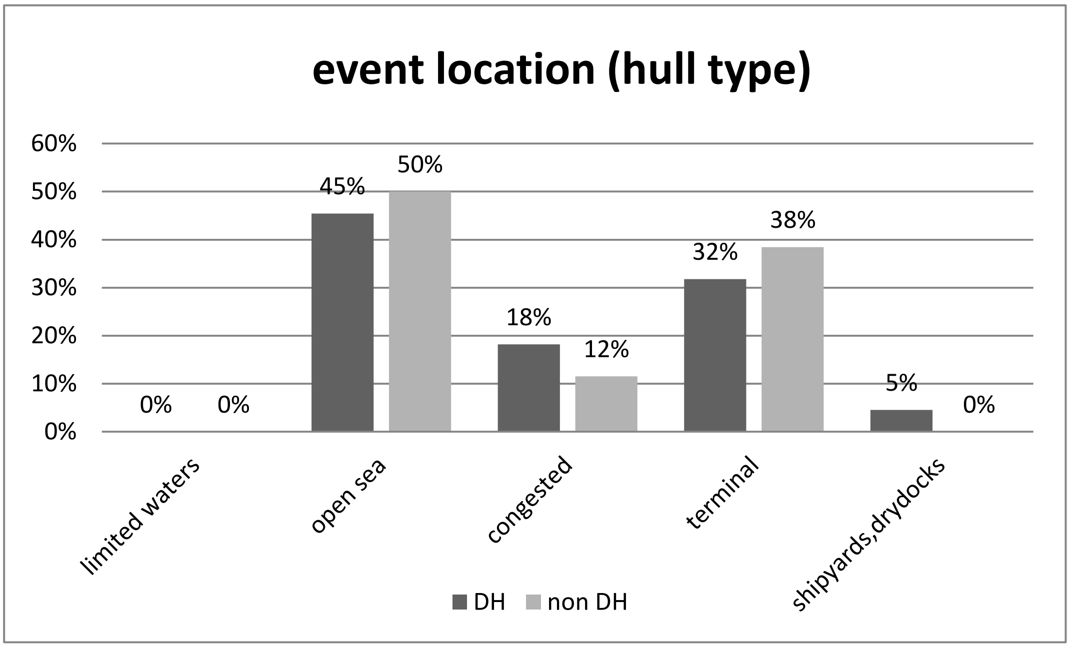


Figure 4.27. Event location (unknown cases excluded). Focus on hull type.

Unknown cases : 0 out of 22(9%,DH), 13/39(33,3% non DH)

As expected perhaps, results for event location are similar for both hull types and thus the only conclusion that can be drawn is that large tankers are most likely to suffer a NASF, while in open sea or terminal waters.(possible reasons already discussed)

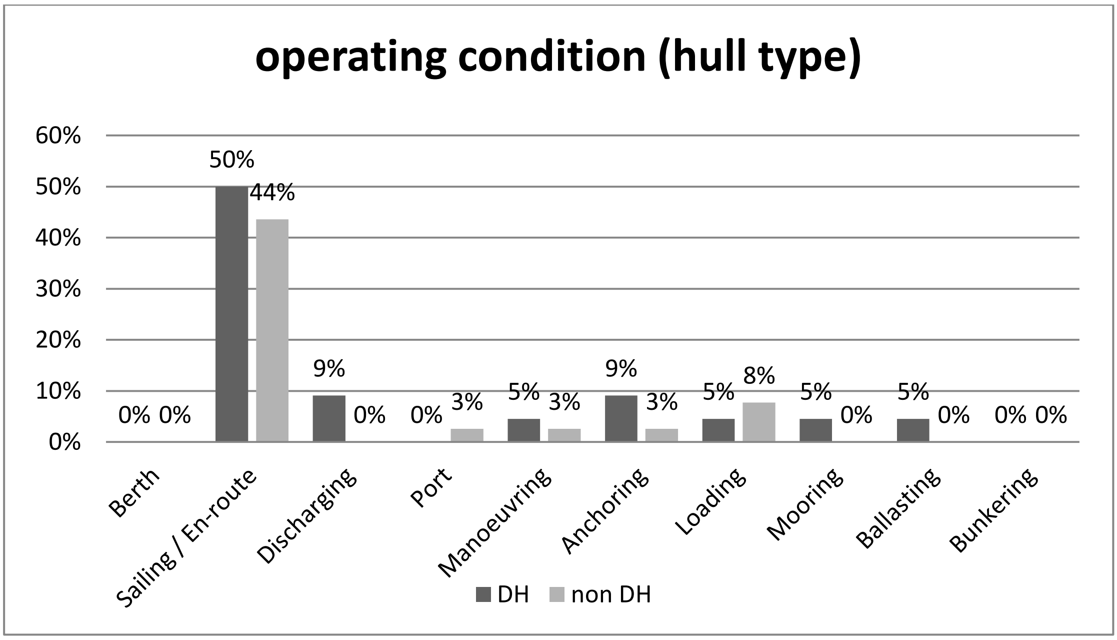
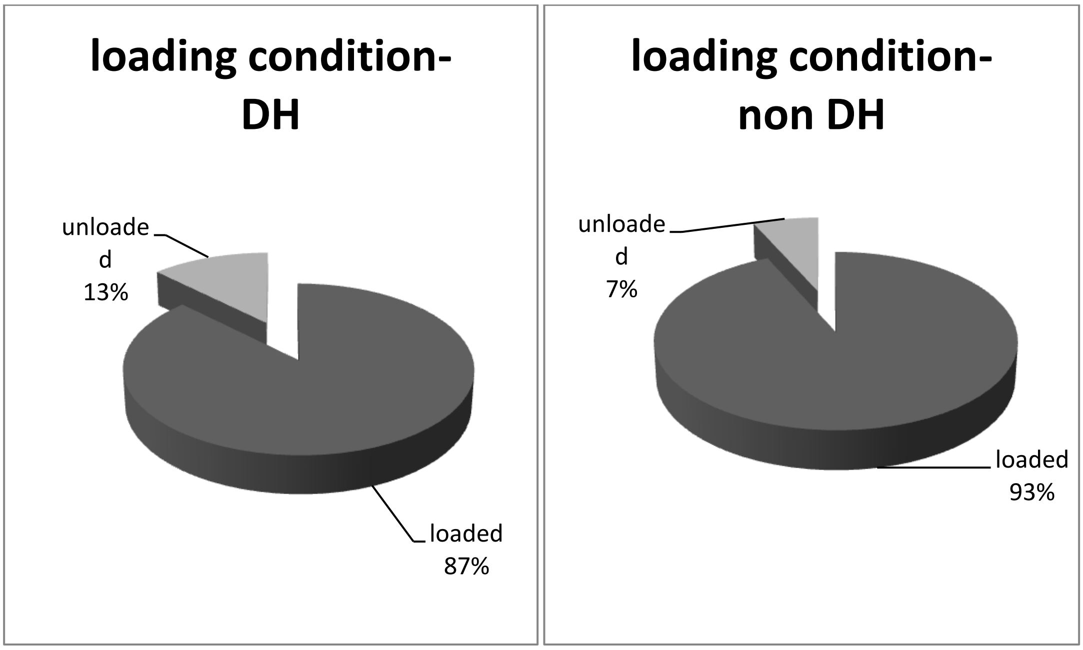


Figure 4.28. Operating condition (unknown cases excluded). Focus on basic hull type and ship's size.

Unknown cases: a)DH-3/22(13,6%), b)non DH 16/39(41%).



Unknown cases:14/22(63,6%) Unknown cases:24/39(61,5%)

Figure 4.29. Loading condition. Unknown cases excluded. Focus on basic hull type.

As far as loading condition is concerned, it seems clear, that loading condition can be a contributing factor for NASF, although ships are theoretically designed to be safe and stable independently of loading condition.

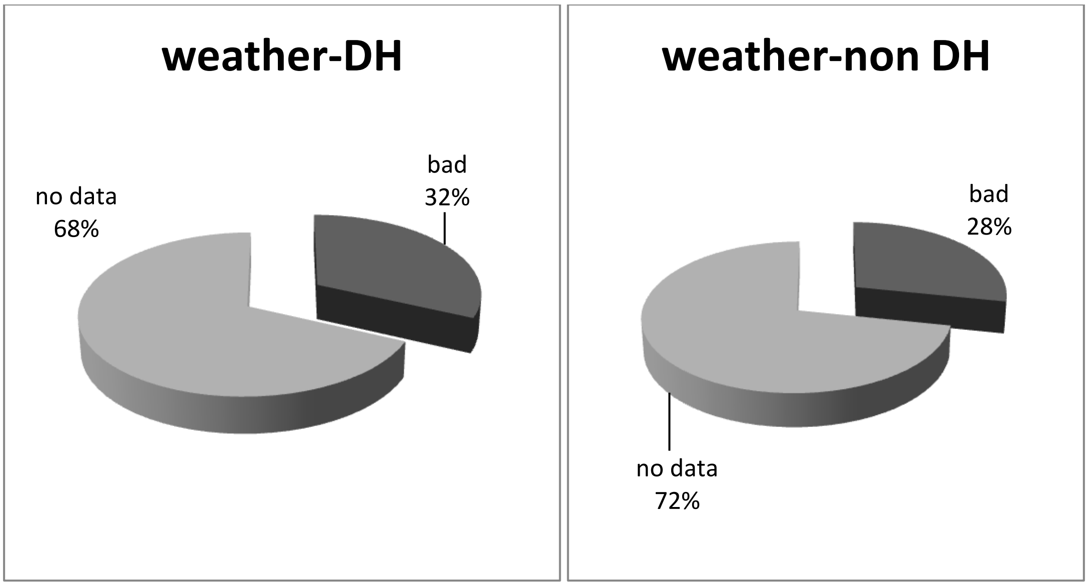


Figure 4.30. Weather. Focus on basic hull type.

Table 4.13. Event location, where bad weather was encountered. Focus on basic hull type.

Event location	DH	non DH
Open sea	5	8
terminal	0	0
congested	2	0
unknown	0	3
Bad weather condition cases	**7**	**11**

4.2.2 Outcome of event

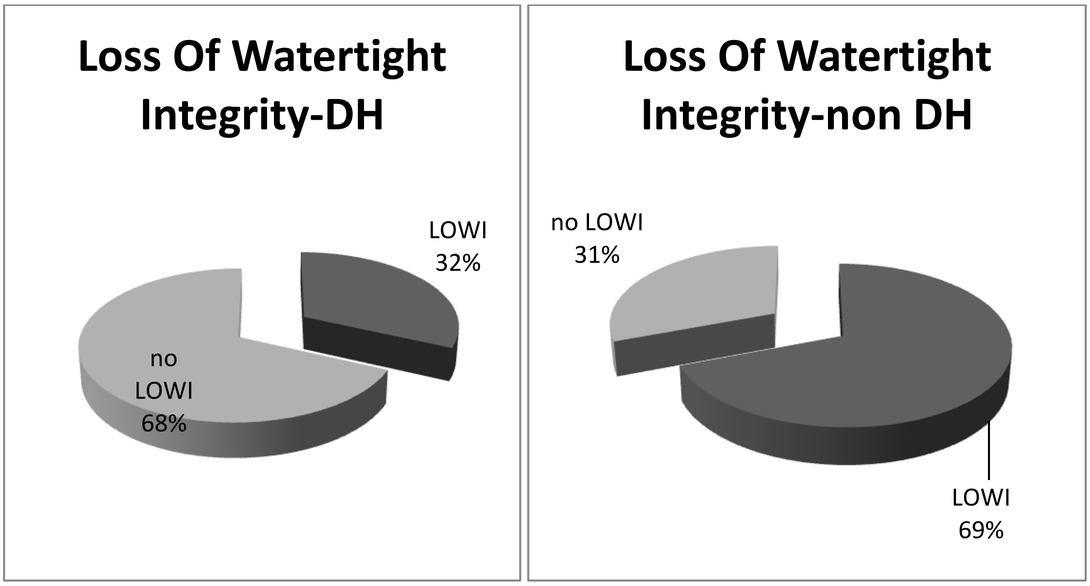


Figure 4.31. Percentage of NASF accidents, that led to LOWI. Focus on basic hull type.

Although the sample is not big , non DH ships seem to be more vulnerable to LOWI than DH.

The fact, that non DH ships present LOWI at such a large percentage could be justified by the fact, that non DH ships are older and thus for a larger period of time subjected to corrosion, fatigue etc. Average age, at which non DH ships presented LOWI is 14,3 years. The previous argument should not be that strong, taking into account the fact, that ships are (theoretically) designed for a greater economic lifecycle than that, at which non DH tankers suffered LOWI.

DH tankers present a smaller percentage of LOWI occurrence. However, the average age of the DH tankers, that presented LOWI is really small (4 years!!), something indicative of poor quality of structure. Some statistics regarding these 7 cases (DH tankers, that presented LOWI): built between 1992 and 2006, 4 in South Korea, 1 in Japan, in China and in Croatia.

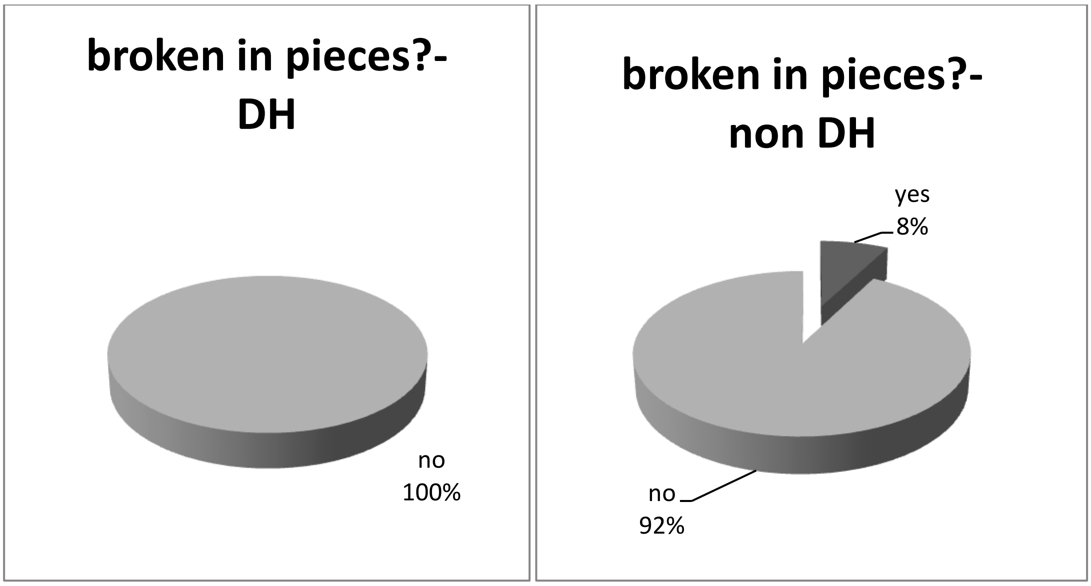


Figure 4.32. Percentage of NASF, in which the ship broke in pieces. Focus on basic hull type.

The two out of 3 cases in total, in which a non DH large tanker broke in pieces, are the infamous accidents of Prestige and Katina P (see chapter 4.7 for more details regarding these accidents). The 3rd tanker was not loaded.

Table 4.14. Various outcomes. Focus on basic hull type.

	Double Hull		Non Double Hull	
	yes	no	yes	no
Towed away?	9%	91%	5%	95%
Sailed by her means?	86%	14%	90%	10%
Remains afloat?	100%	0%	92%	8%
Sold for demolition?	0%	100%	0%	100%
Broken up?	0%	100%	3%	97%
Ship other transfer?	5%	95%	0%	100%
Ship internal transfer?	0%	100%	3%	97%

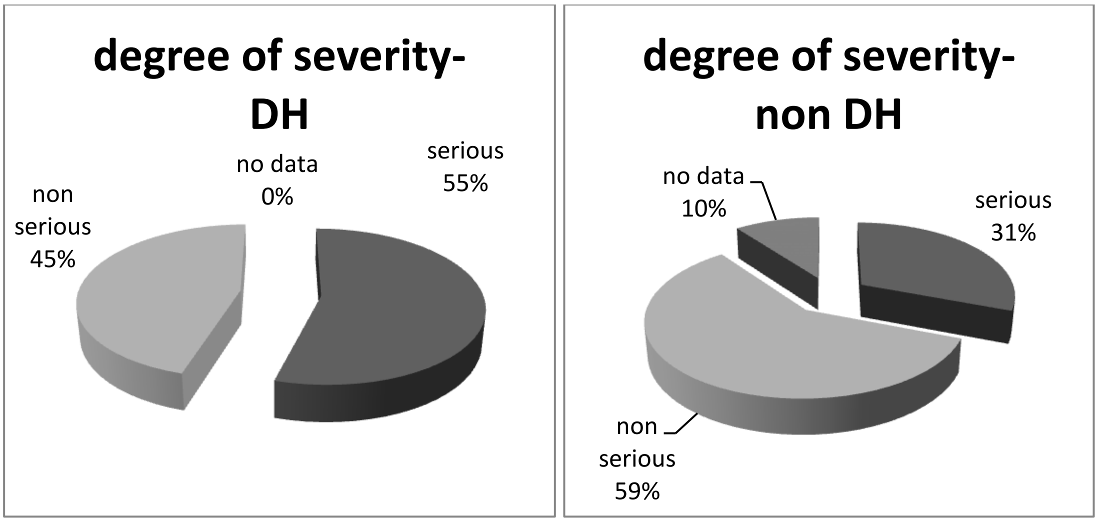


Figure 4.33. Distribution of NASF by degree of severity. Focus on basic hull type.

The chart above could be misleading. The frequencies at which DH and non DH NASF are characterized as serious are comparable. Remarkably that is not the case for accidents being characterized as non serious. There a growing tension of characterizing more easily an accident as serious over time or-to rephrase it- more rarely is an accident characterized as non serious nowadays. In the period 2001-2011 only two NASF have been considered as non serious.(out of 24 in total during the same period). To summarize, two similar accidents could be characterized with different degrees of severity only because they happened in different decades (for example) and not because the one had worst consequences than the other.

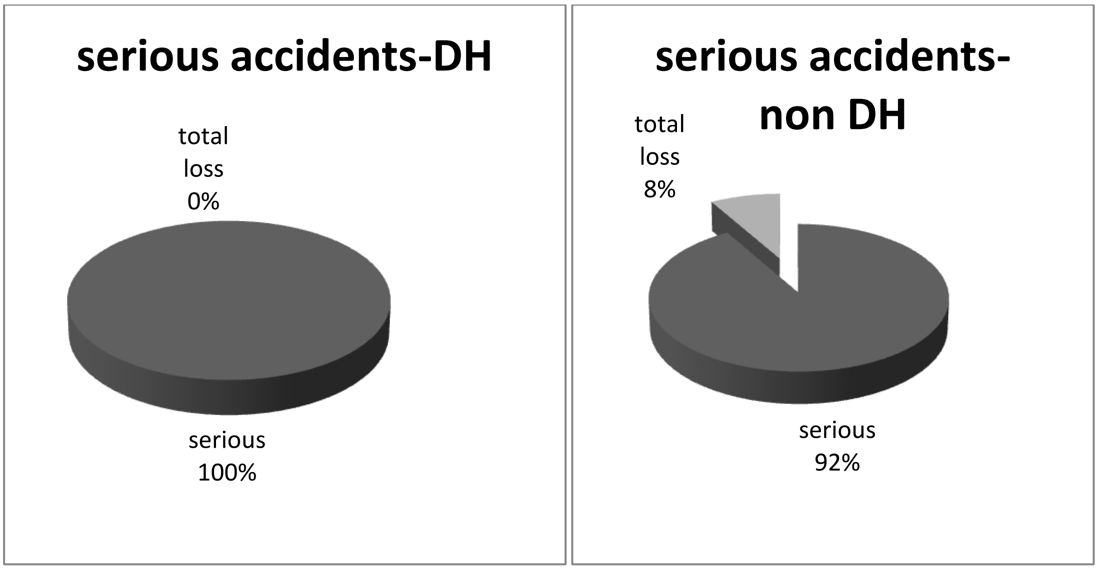


Figure 4.34. Distribution of serious NASF by severity level. Focus on basic hull type.

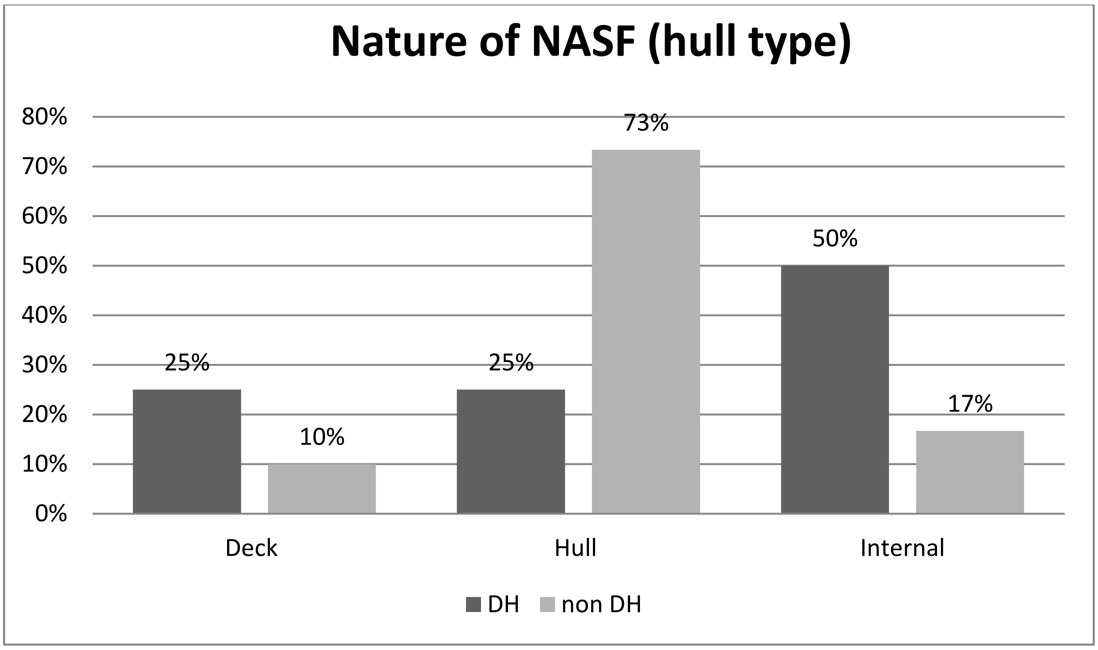


Figure 4.35. Nature of NASF. Ship's part damaged. Unknown cases excluded. Focus on basic hull type.

Unknown cases: a) DH-6/22 (27,3%), b) non DH- 9/39 (23,1%).

It is worth noting, that DH tankers present mostly internal structural problems, while non DH tankers present mostly hull problems. Arguments that justify this are:

1) Double hull tankers operate with global stress levels some 30% higher than those with single hulls, because of the uniform distribution of cargo and ballast over the length of the ship. In a single hull tanker, the ballast tanks can be positioned to minimize longitudinal bending and shear stresses, resulting in values well below the acceptable maximum.

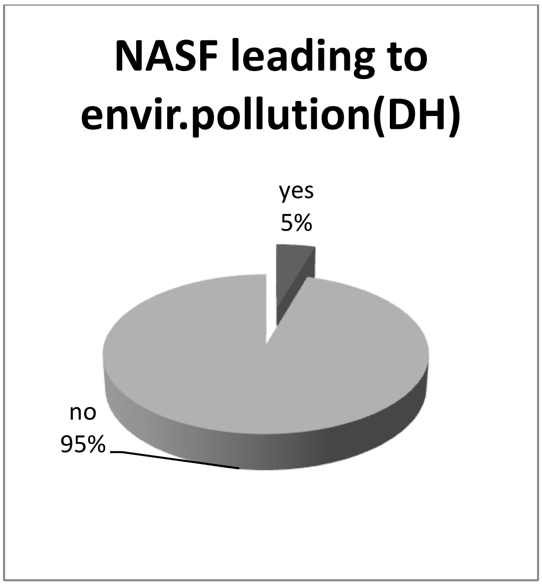
2) Structures of ballast spaces in double hull tankers are more susceptible to fractures and minor failures as compared to single hull tankers .Corrosion is considered one of the main reasons for failure of hull structures in tankers. Improper maintenance of ballast tank structures and failure to maintain the integrity of protective coating and cathodic protection in ballast tanks have lead to structural failure in the past. In double hull tankers, the surface area of the tanks is more than double than that of single hull tanks. Thus they require more maintenance during the operating life.

3) Non DH tankers are older and so subjected to corrosion, fatigue, (possibly to)poor maintenance, etc. to a greater extent than non DH tankers. They have also "simpler" internal designs and thus they present more often structural problems in their outer part, that means their hull.

4.2.3 Fatalities, injuries

As already discussed, there were two deaths and 1 non serious injury, resulting from a NASF (although it could be considered as an occupational accident). These happened on board of the same ship-and same accident- , whose hull type in unknown. Practically the frequency of fatalities, because of NASF-DH and non DH-, is 0, although it is not really so. It is obvious though, that fortunately NASF possess only very rarely danger for human life.

4.2.4 Oil spill information



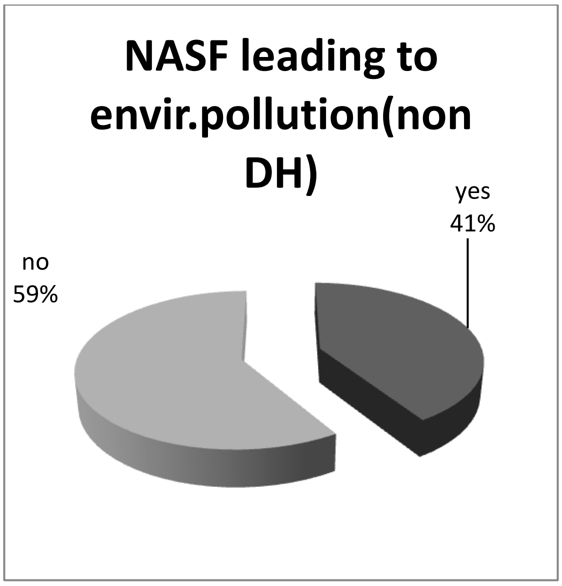


Figure 4.36. Percentage of NASF, that led to environmental pollution. Focus on basic hull type.

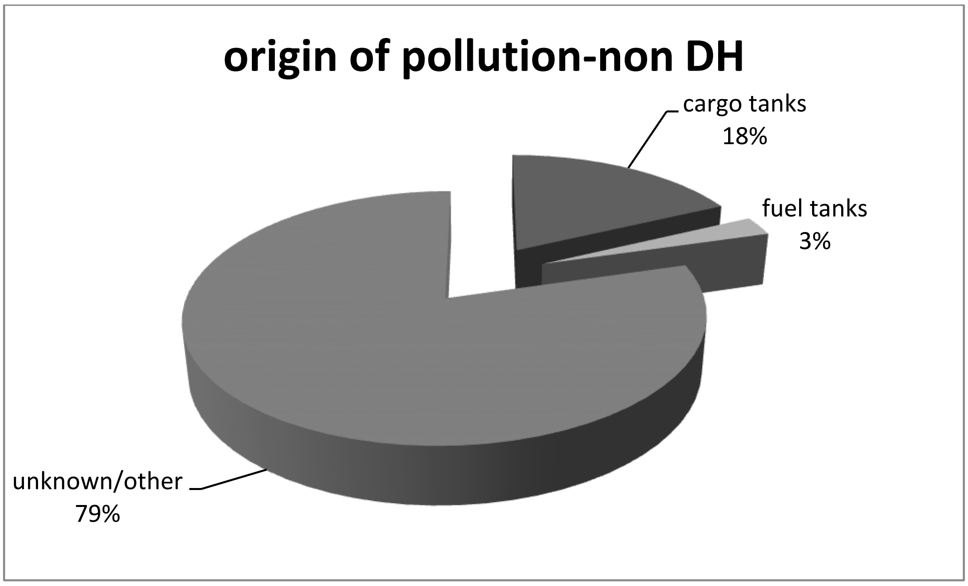


Figure 4.37. Origin of pollution among the ship for non DH tankers.

This seems logical, as cargo tanks cover a greater part of ship than fuel tanks. Additionally, this chart implies the need for change and evolution, as far as hull designs are concerned. Penetration of cargo tanks could cause enormous environmental pollution and thus non DH designs are insufficient. DH designs are not necessarily the solution, but are one step forward towards environmentally friendly transportation of oil across the sea.

4.2.5 Shipyards, flags, classes

Table 4.15. Class, when NASF occurred. Focus on basic hull type.

Class	DH	Non DH
American Bureau of Shipping	9	3
Bureau Veritas	1	0
Det Norske Veritas	4	0
Lloyds Register	1	2
Hellenic Register of Shipping	0	1
TOTAL	15	6

Table 4.16. Class, when ship was built. Focus on basic hull type.

Class	DH	Non DH
American Bureau of Shipping	4	0
Det Norske Veritas	2	0
Lloyds Register	1	1
Registro Italiano	0	0
TOTAL	7	1

The sample is unfortunately small and so it is difficult to draw safe conclusions. However, there are some facts worth noting.

The two more catastrophic NASF, that led to the greatest environmental pollution (accidents of tankers PRESTIGE and KATINA P) were single hull tankers. The first was classed by ABS and the second by Hellenic Register of Shipping, by the time the accident occurred.

A key issue raised by the PRESTIGE accident was whether classification societies can be held responsible for the consequences of accidents, that lead to environmental pollution. After a series of trials the court decided that there was no existing precedent to assign a duty on behalf of the coastal state. ABS was free of any sanctions.ABS had certified the Prestige as "in class" for its final voyage. The "in class" status states that the vessel is in compliance with all applicable rules and laws, not that it is or is not safe. Anyway it would be problematic to assume that classification societies have nothing to do with structural deficiencies of ships, as classification societies by definition are the ones responsible for establishing and maintaining technical standards for the construction and operation of ships and offshore structures and also for carrying out regular surveys to ensure compliance with the standards. Somebody should be responsible for structural deficiencies and for the consequences, that result from them…

Table 4.17. Shipyard (country) of built for tankers, that presented NASF. Focus on basic hull type.

Shipyard (country)	DH	Non DH
China	4	0
Croatia	1	0
Denmark	1	0
Sweden	0	3
Japan	1	14
Korea (South)	11	12
United States of America	2	7
Spain	1	1
Canada	0	0
Belgium	0	0
Poland	1	1
TOTAL	*22*	*39*

Table 4.18. Information about mostly represented shipyards (countries), where tankers, that presented NASF, were built. DH tankers.

DH	cases	serious	Broken in pieces	LOWI	Deck damage	Hull damage	Internal damage	Average ship's age(when accident occurred)
Japan	1	100%	0%	100%	0%	100%	0%	4
Korea(South)	11	45,5%	0%	36,4%	27,3%	9,1%	36,4%	4,2
China	4	50%	0%	25%	0%	25%	0%	3,25
Sweden	0							
Spain	1	100%	0%	0%	100%	0%	0%	7
U.S.A.-Canada	2	0%	0%	0%	0%	0%	100%	16
*TOTAL**	*22*	*55%*	*0%*	*32%*	*25%*	*25%*	*50%*	*6,2*

*all shipyards included, not only the ones in this table

As already mentioned, the average age of large DH tankers, that suffered a NASF, is small (6,2 years old). After studying the table above, it becomes obvious, that most ships ,that suffered a NASF, were built in Japan, China and South Korea. That is not a surprising fact, as the vast majority of merchant is built in these 3 countries. Unfortunately, we possess no data, as far as fleet at risk by shipyard of built, is concerned. Nevertheless, structural failure at such a young age indicate problems, omissions and mistakes.

Table 4.19. Information about mostly represented shipyards (countries), where tankers, that presented NASF, were built. Non DH tankers.

Non DH	cases	serious	Broken in pieces	LOWI	Deck damage	Hull damage	Internal damage	Average ship's age(when accident occurred)
Japan	14	28,6%	14,3%	78,6%	7,1%	64,3%	7,1%	14,1
Korea(South)	12	41,7%	8,3%	66,7%	0%	58,3%	25%	10,7
China	0							
Sweden	3	33,3%	0%	33,3%	0%	0%	0%	17
Spain	1	0%	0%	0%	0%	100%	0%	7
U.S.A.-Canada	7	28,6%	0%	71,4%	28,6%	71,4%	0%	19,4
*TOTAL**	*39*	*31%*	*8%*	*69%*	*10%*	*73%*	*17%*	*13,8*

*all shipyards included, not only the ones in this table

Table 4.20. Flag when ship was built. Focus on basic hull type.

Flag	DH	nonDH
Bahamas	2	0
Bermuda	1	0
Cyprus	1	0
Greece	1	1
India	1	0
Italy	0	0
Liberia	9	1
Marshall Islands	1	0
Norway	1	0
Norway(NIS)	1	2
Panama	0	5
Qatar	0	1
Singapore	1	1
Sweden	0	1
U.S.A	2	0
USSR	0	0
Venezuela	0	1
Total cases	21	13

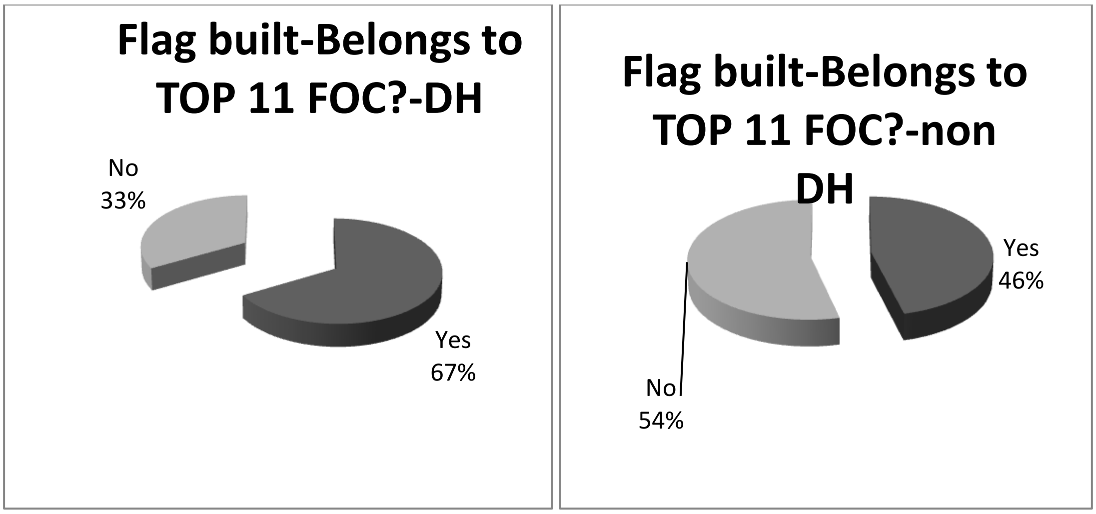


Figure 4.38. Flag when ship was built. Belongs to TOP 11 FOC? Focus on basic hull type.

Table 4.21. Flag when NASF occurred. Focus on basic hull type.

Flag	*DH*	*Non DH*
Panama	2	11
Australia	0	3
Bahamas	1	1
Bermuda	1	0
Bermuda(British)	1	0
Cyprus	0	2
France(FIS)	1	0
Greece	1	4
Liberia	5	5
Malta	0	2
Marshall Islands	3	0
Mauritius	0	0
India	1	0
Iran	0	0
Iraq	0	0
Kuwait	0	1
Gibraltar	0	0
Isle Of Man	0	0
Libya	0	1
Malaysia	0	1
Norway(NIS)	2	1
Norway	1	1
Philippines	0	0
Portugal (MAR)	0	0
Qatar	0	1
Singapore	2	2
Sweden	0	1

TAAF	1	0
Tuvalu	0	0
U.S.A.	0	0
Venezuela	0	1
TOTAL	22	38

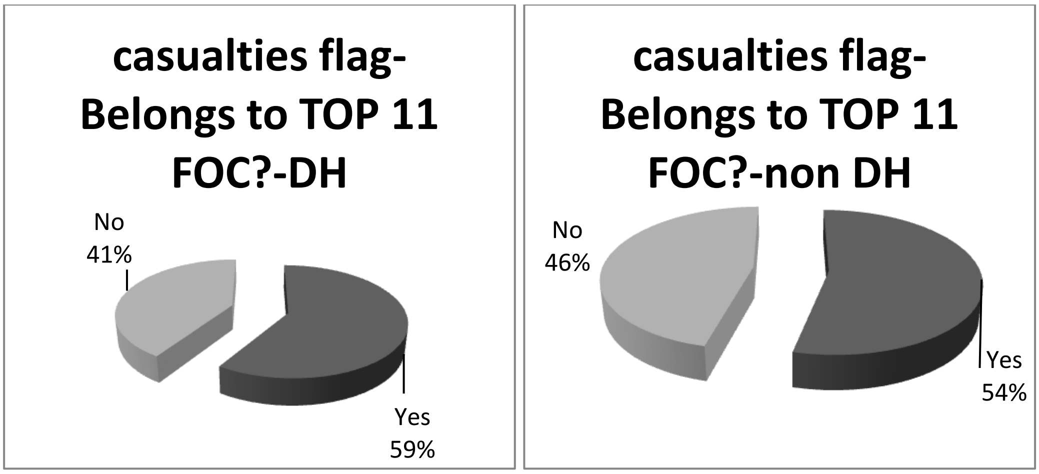


Figure 4.39. Flag when NASF occurred. Belongs to TOP 11 FOC? Focus on basic hull type.

4.2.6 Frequencies

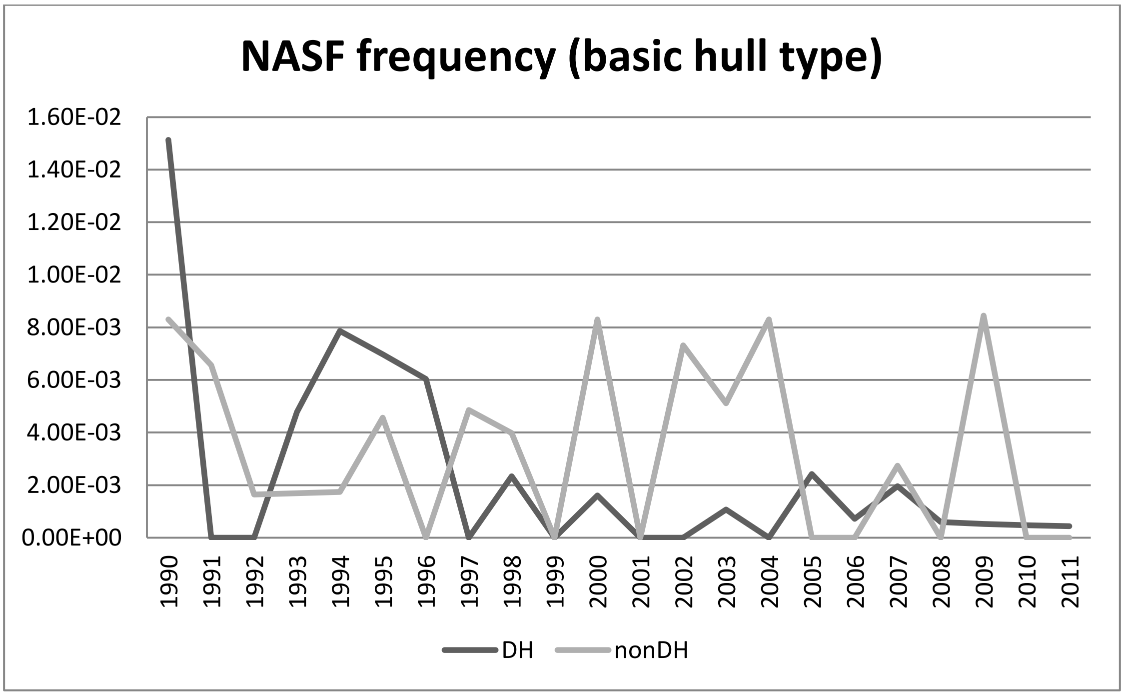


Figure 4.40. NASF frequency per shipyear. Focus on basic hull type.

In order to understand the above chart, one should always keep in mind the annual change of DH and non DH fleet. For example in1990 DH NASF frequency is twice compared to the non DH NASF frequency. This great difference could be justified by the fact, that in 1990 there was 1 DH NASF (fleet at risk: 66,1 shipyears), that means that the sample is very small and such sharp changes of values are expected. As DH fleet grows, no such sharp changes are noted.

Furthermore the sudden peaks could also be justified by the small sample.

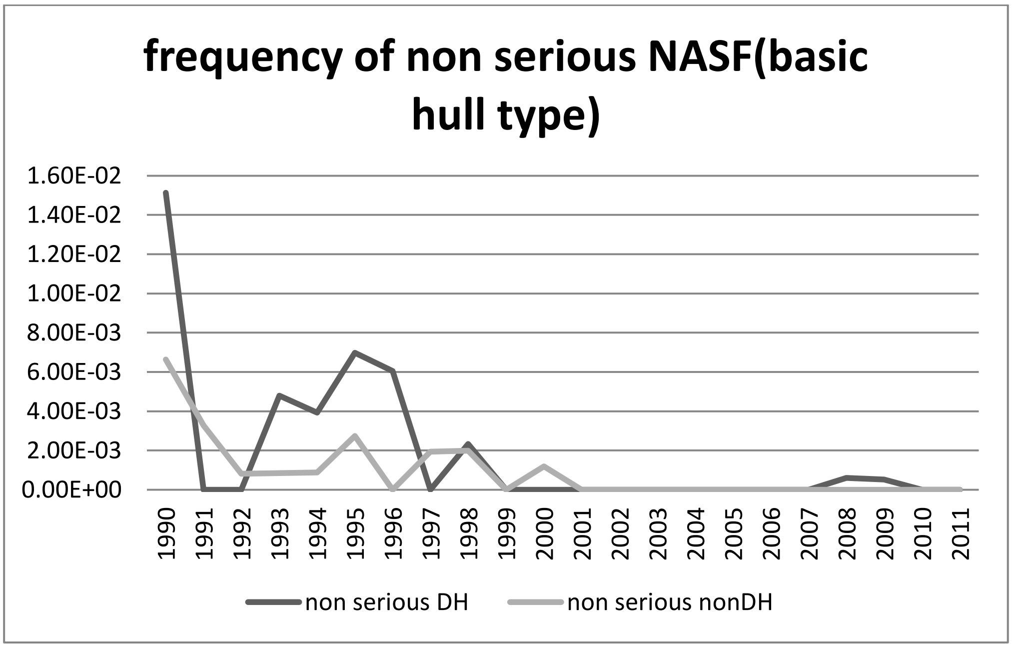


Figure 4.41. Frequency of non serious NASF per shipyear. Focus on basic hull type.

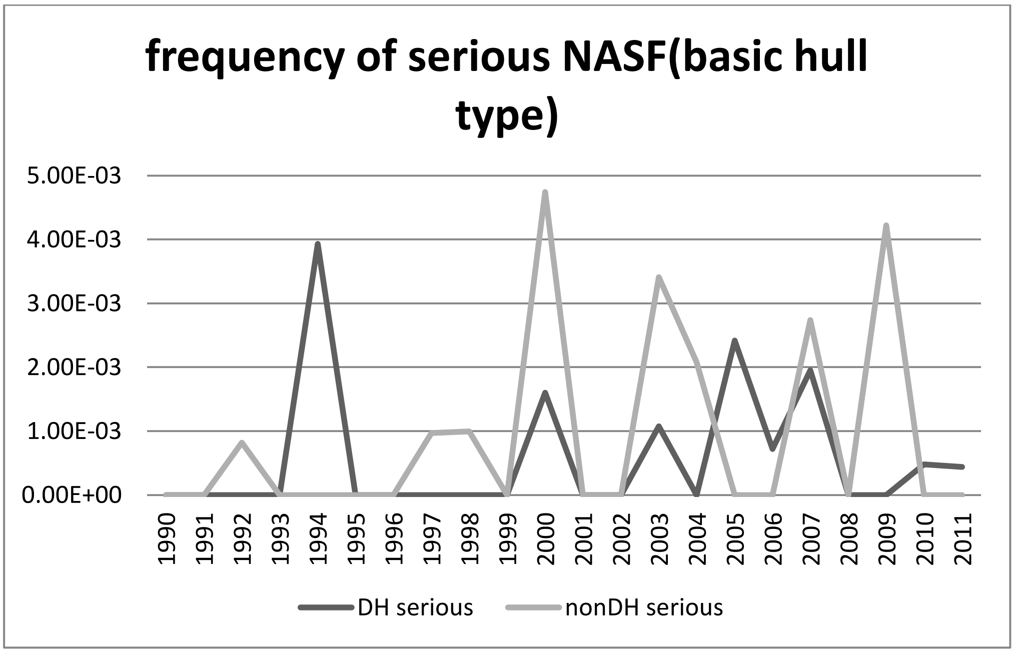


Figure 4.42. Frequency of serious NASF per shipyear. Focus on basic hull type.

The trend is that more accidents are characterized as serious over time. In the period 2001-2011 only two NASF are characterized as non serious.(out of 24 in total during the same period)

Table 4.22. Annual number of NASF and degree of severity. Focus on basic hull type.

	DH	DH	DH	Non DH	Non DH	Non DH
year	accidents	serious	non serious	accidents	serious	non serious
1990	1	0	1	8	0	8
1991	0	0	0	4	0	4
1992	0	0	0	2	1	1
1993	1	0	1	1	0	1
1994	2	1	1	1	0	1
1995	2	0	2	3	0	3
1996	2	0	2	0	0	0
1997	0	0	0	3	1	2
1998	1	0	1	3	1	2
1999	0	0	0	0	0	0
2000	1	1	0	5	4	1
2001	0	0	0	0	0	0
2002	0	0	0	3	0	0
2003	1	1	0	2	2	0
2004	0	0	0	2	1	0
2005	3	3	0	0	0	0
2006	1	1	0	0	0	0
2007	3	3	0	1	1	0
2008	1	0	1	0	0	0
2009	1	0	1	1	1	0
2010	1	1	0	0	0	0
2011	1	1	0	0	0	0
TOTAL	*22*	*12*	*10*	*39*	*12*	*23*

Table 4.23. Frequency of NASF in total, serious NASF and non serious NASF for studied period per shipyear. Focus on basic hull type.

	DH	Non DH
NASF frequency per shipyear	$1,16x10^{-3}$	$2,37x10^{-3}$
Frequency of non serious NASF per shipyear	$5,28x10^{-4}$	$1,4x10^{-3}$
Frequency of serious NASF per shipyear	$6.34x10^{-4}$	$7,28x10^{-4}$

It should be again noted, that it is quite problematic to draw conclusions only by the frequencies above. The reason is that we have data for only 61 of the146 NASF cases, far as hull type is concerned. It is more “secure” and meaningful to observe the trends and not the values.

Table 4.24. Frequency of NASF leading to environmental pollution. Tonnes of spilled oil in total. Focus on basic hull type.

	cases	Oil spilled (tones)	frequency
DH tankers	1	1 (assumed)	$5{,}28x10^{-5}$
Non DH tankers	16	149371	$9{,}71x10^{-4}$

According to these statistics non DH tankers are almost 20 times more likely to spill oil into the sea following a NASF. One should be really careful, because 1 DH tanker NASF leading to a great oil spillage could change this picture dramatically. Nevertheless, it does not go unnoticed, that tankers in general seem to become gradually environmentally friendlier with the introduction of DH design, although the problem is only partly solved (for example DH designs reduce environmental risk for low energy collision and groundings, but not for high energy ones. That extends beyond the limits of this thesis and will not be discussed further)

Out of the 16 non DH tankers NASF oil spillage cases:

- 2 are responsible for 86% of total 174039 tonnes of oil spilled (as result of NASF, including tankers with unknown hull type).
- in 11 cases pollution was smaller than 1 t or assumed so.

There are 22 cases of oil spillage, resulting in an environmental pollution of almost 24668 tonnes, for which we possess no data regarding the hull type.

Table 4.25. Frequency of NASF that led to environmental pollution per shipyear. Non DH tankers.

year	pollution cases	fleet at risk	Frequency per shipyear
1990	0	1204,12	0,000E+00
1991	0	1218,44	0,000E+00
1992	1	1218,56	8,206E-04
1993	0	1178,52	0,000E+00
1994	0	1147,09	0,000E+00
1995	0	1095,71	0,000E+00
1996	0	1062,78	0,000E+00
1997	2	1030,72	1,940E-03
1998	3	1005,51	2,984E-03
1999	0	951,42	0,000E+00

2000	4	843,29	4,743E-03
2001	0	791,61	0,000E+00
2002	2	683,93	2,924E-03
2003	1	586,68	1,705E-03
2004	2	481,76	4,151E-03
2005	0	426,24	0,000E+00
2006	0	399,76	0,000E+00
2007	1	364,89	2,741E-03
2008	0	313,12	0,000E+00
2009	0	236,86	0,000E+00
2010	0	151,87	0,000E+00
2011	0	87,16	0,000E+00
TOTAL	16	16480,05	9,709E-04

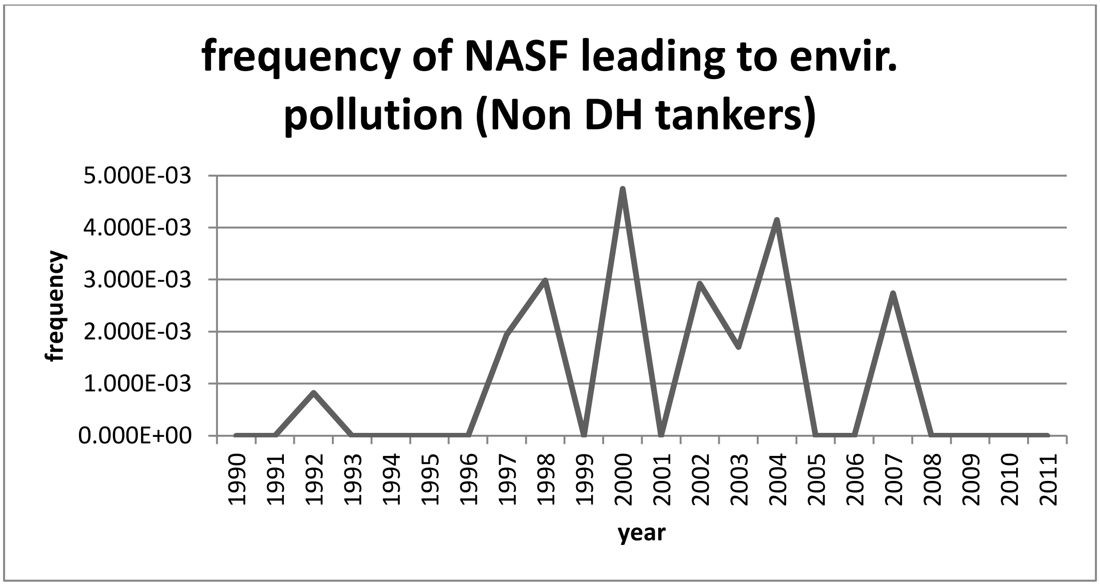


Figure 4.43. Frequency of NASF, that led to environmental pollution per shipyear. Non DH tankers.

4.3. Focusing on ship's size

Table 4.26. Sample examined

	Panamax	Aframax	Suezmax	VLCC	ULCC
DH	6	6	8	2	0
Non DH	4	21	6	7	1
Unknown hulltype	8	20	17	31	9
Tota lcases	*18*	*47*	*31*	*40*	*10*

Table 4.27. Group ages of large tankers involved in NASF. Focus on ship's size.

Ship's age, when NASF occurred	Panamax	Aframax	Suezmax	VLCC	ULCC
0-5	16,7%	17%	16,1%	5%	0%
6-10	27,7%	6,4%	6,4%	10%	0%
11-15	11,1%	31,9%	32,3%	47,5%	30%
16-20	27,7%	21,3%	35,5%	27,5%	60%
>20	16,7%	23,4%	9,7%	10%	10%
Total cases	18	47	31	40	10
Average age	13,4	14,7	13,7	14,7	16,2

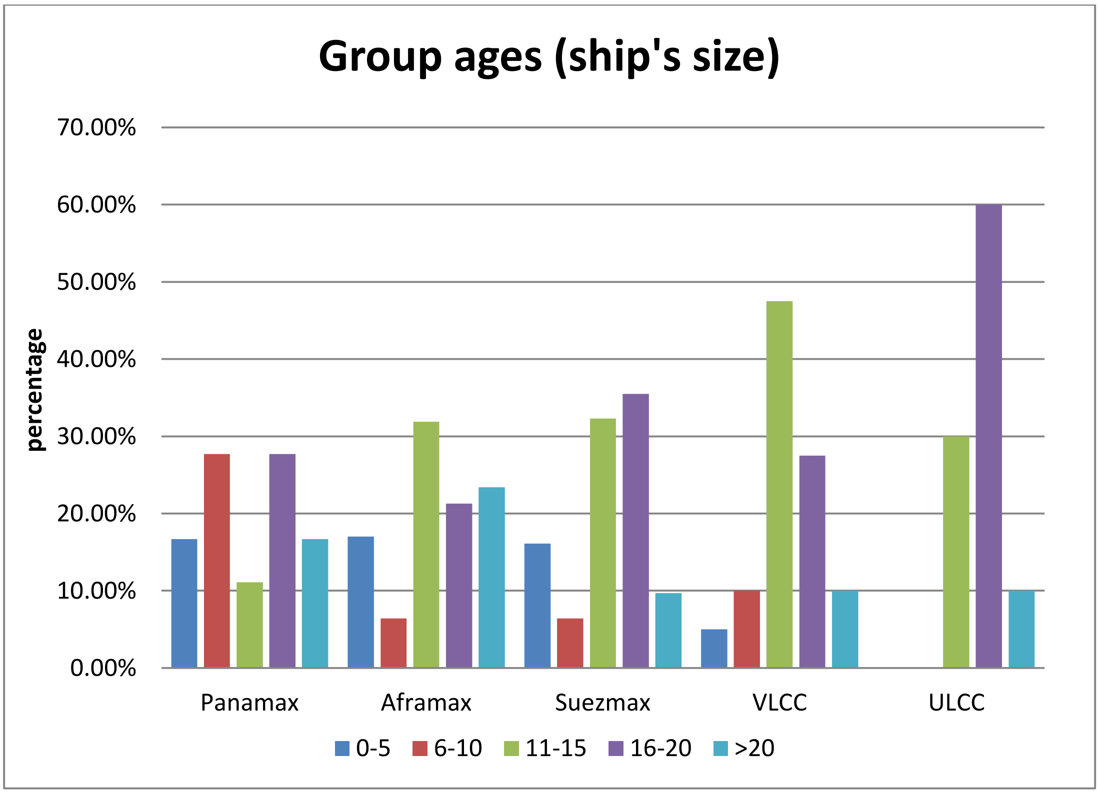


Figure 4.44. Group ages of large tankers involved in NASF. Focus on ship's size.

Only 5% of VLCC and no ULCC failed at an age less than 5 years. Contrariwise 16-17% of Panamax, Aframax and Suezmax, that presented a NASF, failed at an age 0-5 years. Furthermore, 44% of Panamax with NASF, were younger than 11 years. Some further statistics regarding those 3 ship's sizes:

-Panamax(0-5 years old):

- 2/3 built in China
- 2/3 classed by ABS, when NASF occurred

-Panamax(6-10 years old)

- 2/5 built in South Korea, 2/5 in Japan, 1/5 in China
- 2/5 classed by ABS, when NASF occurred
- 2/5 flagged by Marshall Islands, when NASF occurred

-Aframax(0-5 years old)

- 5/8 built in South Korea
- 2/8 classed by DNV, when NASF occurred
- 2/8 flagged by Australia, when NASF occurred

-Suezmax(0-5years old)

- 5/5 built in South Korea
- 2/5 classed by ABS, when NASF occurred
- 4/5 flagged by Liberia, when NASF occurred

ULCC NASF occur at a higher average age compared to the other large tanker's types (sizes).

Size relationship: As already mentioned in chapter 4.1, there is-maybe surprisingly- no obvious relation between ship's size and NASF. There is one exception, that of ULCC.

4.3.1. Event location, ship operation, environment

Table 4.28. Event location (unknown cases excluded). Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
open sea	40,0%	41,2%	61,9%	74,1%	85,7%
congested	20,0%	11,8%	19,0%	14,8%	0,0%
terminal	33,3%	47,1%	19,0%	11,1%	14,3%
limited waters	0,0%	0,0%	0,0%	0,0%	0,0%
shipyards,drydocks	6,7%	0,0%	0	0,0	0,0
Total cases(unknown cases excluded)	15	34	21	27	7
unknown cases	3	13	10	13	3

Open sea is the event location mostly represented in all large tankers sizes. Points to emphasize on after studying the above table:

-Open sea is more frequently the event location of a NASF, as the ship's size gets bigger. 74% of VLCC and 86% of ULCC NASF took place in open sea compared to 40% for Panamax and Aframax

-The bigger the ship, the greater dimensional limitations of the port, river, canal etc it faces. In a lot of cases the largest of the large tanker unload their cargo far from the port. It seems logical, that no ULCC NASF event took place in congested waters. That's not the case for example for a Panamax, which can operate without facing dimensional restrictions in the most cases in congested or limited waters.

-NASF in terminal waters could be attributed mostly to loading/unloading mistakes.

Table 4.29. Operating condition (unknown cases excluded). Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
Sailing / En-route	57,1%	53,6%	88,2%	92,9%	100,0%
Loading	7,1%	14,3%	11,8%	0,0%	0,0%
Discharging	0,0%	14,3%	0,0%	3,6%	0,0%
Berth	0,0%	3,6%	0,0%	0,0%	0,0%
Port	0,0%	3,6%	0,0%	3,6%	0,0%
Anch./Moor./Manoeuv.	28,6%	7,2%	0,0%	0,0%	0,0%
Ballasting	0,0%	3,6%	0,0%	0,0%	0,0%
Bunkering	7,1%	0,0%	0,0%	0,0%	0,0%
Unknown cases	4	19	14	12	3
Total cases (unknown excluded)	14	28	17	28	7

Table 4.30. Loading condition (unknown cases excluded)

	Panamax	Aframax	Suezmax	VLCC	ULCC
loaded	100,0%	88,2%	100,0%	91,7%	100,0%
unloaded	0,0%	11,8%	0,0%	8,3%	0,0%
Unknown cases	12	30	25	28	9
Total cases (unknown excluded)	6	17	6	12	1

It is obvious as a general comment, that a loaded tanker is more likely to suffer a NASF, than an unloaded one..

Table 4.33 Weather. Focus on ship's size

	Panamax	Aframax	Suezmax	VLCC	ULCC
bad	22,2%	17,0%	35,5%	50,0%	50,0%
no data	77,8%	83,0%	64,5%	50,0%	50,0%
total cases	18	47	31	40	10

4.3.2. Outcome of event

Table 4.31. Percentage of NASF accidents, that led to LOWI. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
Yes	83,3%	57,4%	58,1%	52,5%	50,0%
No	16,7%	42,6%	41,9%	47,5%	50,0%
Total cases	18	47	31	40	10

Panamax present LOWI at 83,3%, a percentage significantly greater, than those of the other large tanker's sizes. The causes are not clear.

Table 4.32. Percentage of NASF, in which the ship broke in pieces. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
yes	5,6%	6,4%	0,0%	0,0%	0,0%
no	94,4%	93,6%	100,0%	100,0%	100,0%
total cases	18	47	31	40	10

Table 4.33. Various outcomes. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
Towed away	11,1%	6,4%	3,2%	5,0%	10,0%
Sailed by her means	83,3%	91,5%	90,3%	95,0%	90,0%
Remains afloat	94,4%	95,7%	100,0%	97,5%	100,0%
Sold for demolition	0,0%	2,1%	0,0%	0,0%	0,0%

Broken up	0,0%	4,3%	0,0%	5,0%	0,0%
Ship other transfer	0,0%	2,1%	0,0%	2,5%	0,0%
Ship internal transfer	0,0%	2,1%	0,0%	0,0%	0,0%
Total cases	18	47	31	40	10

There are no points to emphasize on after studying the table above. The outcomes of the accidents seem similar at least for these categories.

Table 4.34. Distribution of NASF by degree of severity. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
serious	50,0%	42,6%	19,4%	32,5%	30,0%
non serious	50,0%	51,1%	74,2%	67,5%	70,0%
Unknown	0,0%	6,4%	6,5%	0,0%	0,0%
total	18	47	31	40	10

Table 4.35. Distribution of serious NASF by degree of severity. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
serious	88,9%	95,0%	100,0%	84,6%	100,0%
total loss	11,1%	5,0%	0,0%	15,4%	0,0%
Total serious cases	9	20	6	13	3

Table 4.36. Nature of NASF. Ship's part damaged. Focus on ship's size**.**

	Panamax	Aframax	Suezmax	VLCC	ULCC
Deck damage	5,6%	10,6%	9,7%	0,0%	10,0%
Hull damage	66,7%	51,1%	45,2%	55,0%	50,0%
Internal	11,1%	21,3%	25,8%	12,5%	10,0%
Unknown damage	16,7%	17,0%	19,4%	32,5%	30,0%
Total cases	18	47	31	40	10

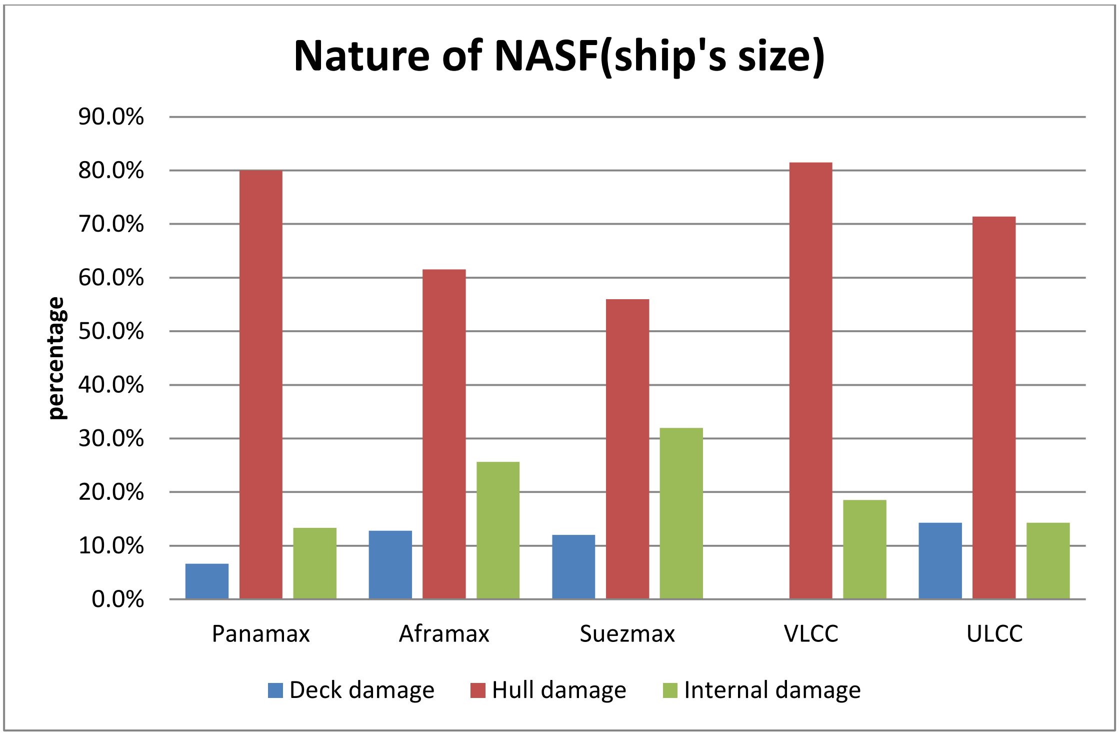


Figure 4.45. Nature of NASF. Ship's part damaged. Unknown cases excluded. Focus on ship's size.

It could be misleading to draw conclusions according to the chart above although it provides us with a first overview. As already discussed, DH designs present mostly internal damages, whereas non DH designs mostly hull damages. Also it should be noted, that we do not possess data, as far as hull type is concerned, for 58% of NASF. The sample is not homogenous, even if unknown cases are excluded, as there are different percentages of DH, non DH and unknown hull types for each large tanker's size.

Nevertheless, some findings of the charts above are:

-If we take for granted that non DH designs present mostly hull damages and DH designs internal damages, then we could assume that the ships with unknown hull type are mostly non DH designs. That's because hull damages are greatly represented in the above chart. Also 75/104 large tankers with NASF and unknown hull type were built in the 1970's, something that indicates, that we have to do mainly with non DH designs.

-Hull damages are the category mostly represented for all ship sizes. Suezmax is the ship size with the greatest percentage, as far as internal damages are concerned.

4.3.3. Fatalities, injuries

As mentioned, there were two fatalities in total, which resulted from NASF. It could be considered as an occupational accident. The accident happened on a 24 year old Panamax tanker.

4.3.4. Oil spill information

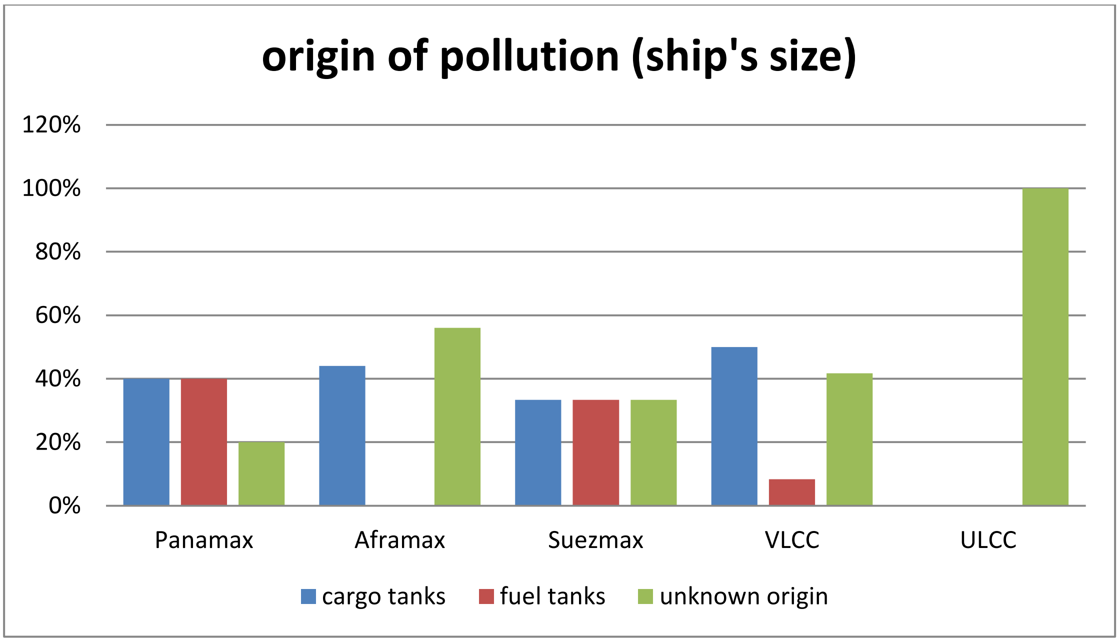


Figure 4.46. Origin of pollution among the ship. Focus on ship's size.

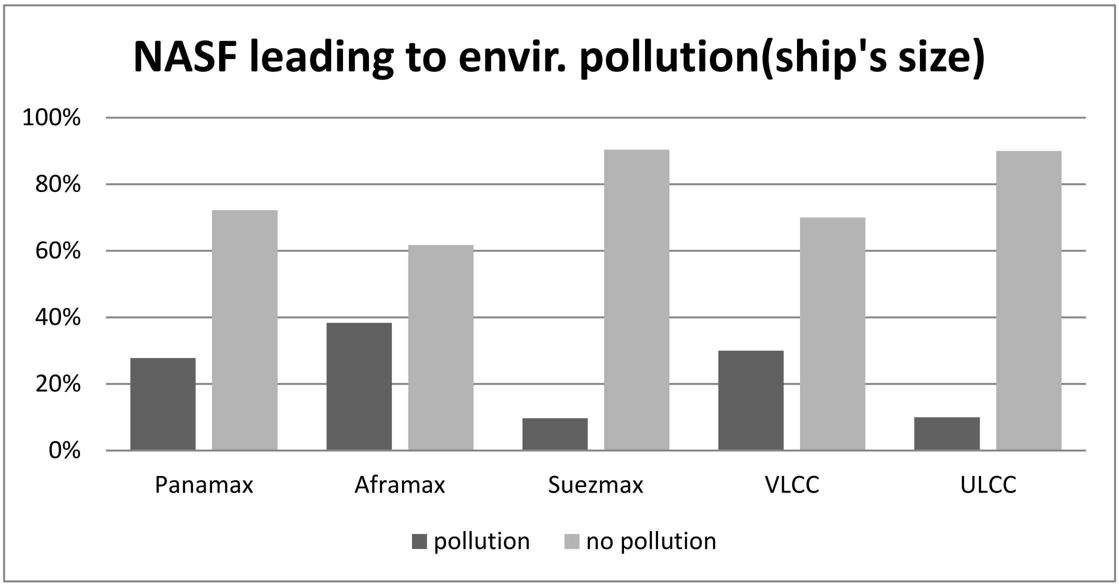


Figure 4.47. Percentage of NASF, that led to environmental pollution. Focus on ship's size.

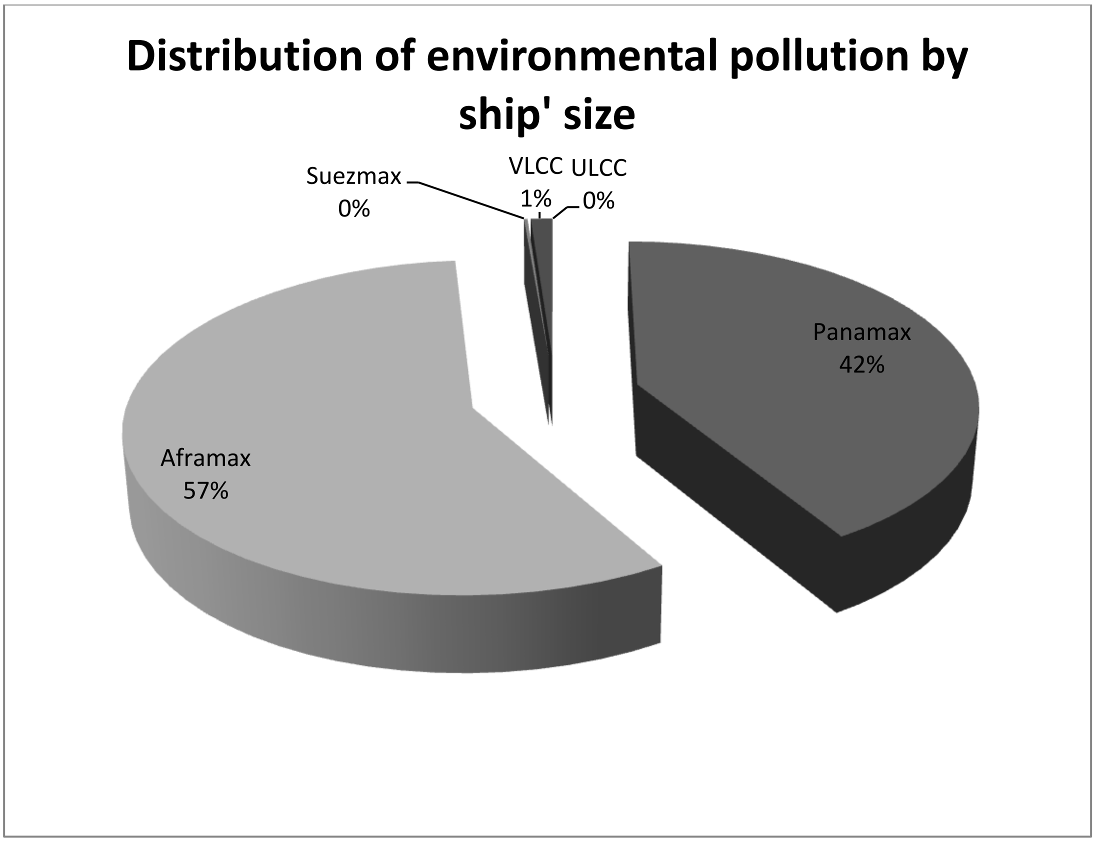


Figure 4.48. Distribution of total environmental pollution (percentage of spilled oil in tonnes) by ship's size.

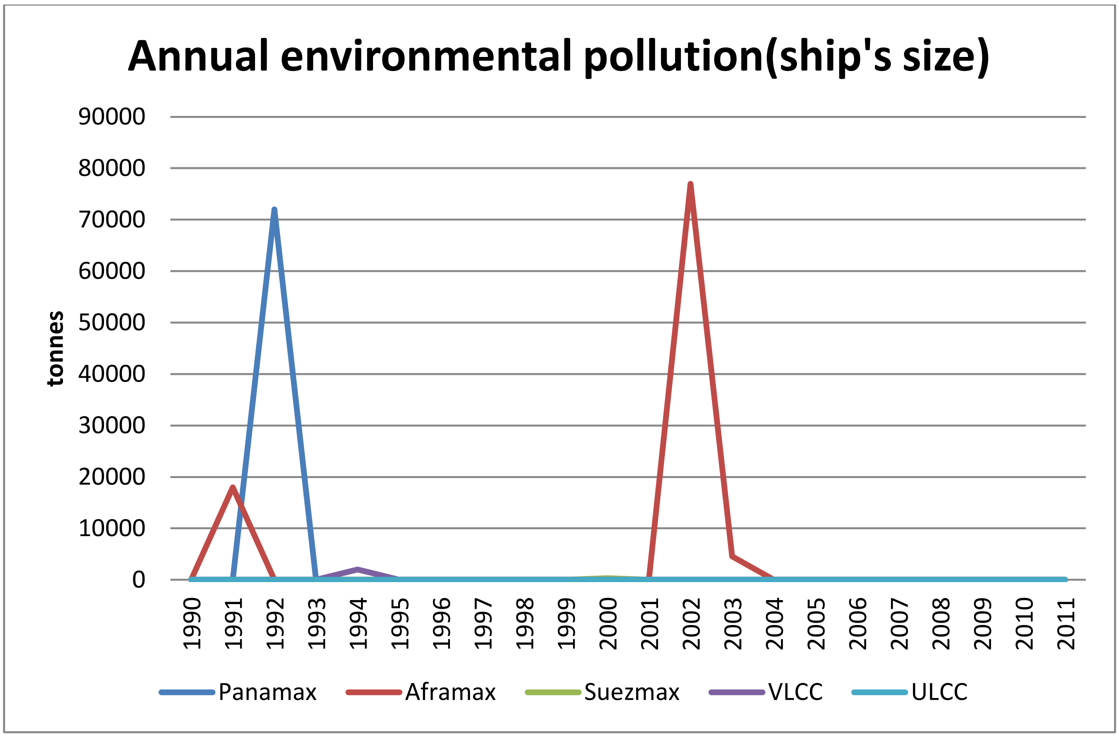


Figure 4.49. Environmental pollution. Yearly spill tone rate. Focus on ship's size.

4.3.5. Shipyards, flags, classes

Table 4.37. Class ,when accident occurred. Focus on ship's size.

class	Panamax	Aframax	Suezmax	VLCC	ULCC
American Bureau of Shipping	4	2	4	3	
Bureau Veritas				1	
Det Norske Veritas	1	2	1		
Lloyds Register	1		1	1	
Hellenic Register of Shipping	1				

Table 4.38. Class, when ship was built. Focus on ship's size.

class	Panamax	Aframax	Suezmax	VLCC	ULCC
American Bureau of Shipping	2		1	1	
Det Norske Veritas	1	1			
Lloyds Register	1			1	

The sample in the tables above is very small and thus no logical conclusions can be drawn.

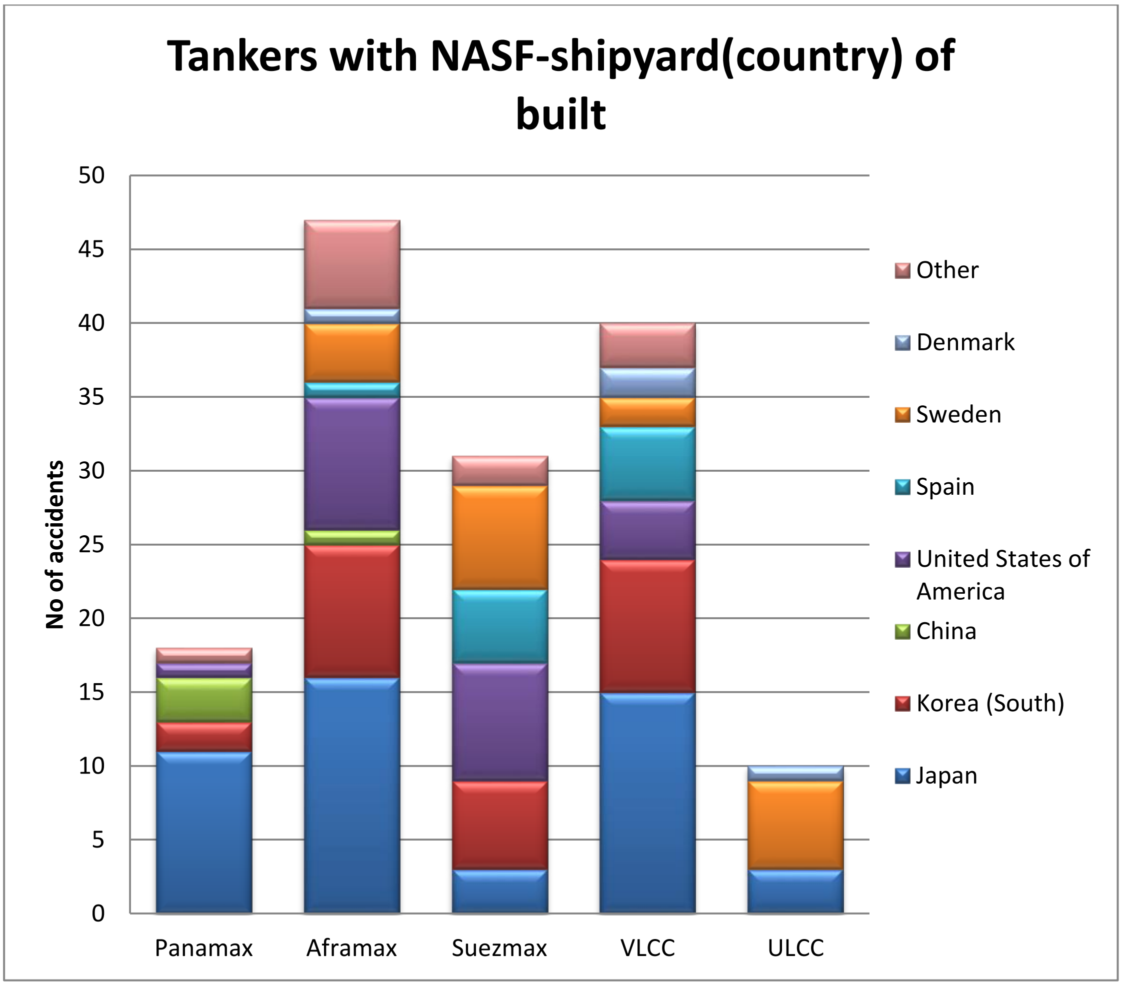


Figure 4.50. Shipyard (country) of built for tankers, that presented NASF. Focus on ship's size.

NOTE: In "OTHER" are included countries, where no more than 2 large tankers, that suffered a NASF, were built (Croatia, Canada, Belgium, Poland, Finland, Netherlands, France, Italy, Norway, United Kingdom).

Table 4.39. Shipyard (country) of built for tankers, that presented NASF. Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
China	3	1			
Croatia	1				
Denmark		1		2	1
Sweden		4	7	2	6
Japan	11	16	3	15	3
Korea (South)	2	9	6	9	
United States of America	1	9	8	4	
Spain		1	5	5	
Canada		1			
Belgium		1			
Poland		2			
Finland			1		
Netherlands				1	
France		1			
Italy		1			
Norway			1		
United Kingdom				2	
Total	*18*	*47*	*31*	*40*	*10*

The charts above show a general picture. Subsequently will every shipyard- country be examined independently regarding its possible relation to NASF by ship's size.

Table 4.40.a. Information about mostly represented shipyards (countries), where PANAMAX, that presented NASF, were built. Focus on ship's size.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	11	45,4%	9,1%	90,9%	81,8%	9,1%	9,1%	16
Korea (South)	2	50,0%	0,0%	100,0%	50,0%	0,0%	0,0%	6
China	3	66,7%	0,0%	33,3%	33,3%	0,0%	0,0%	4
USA	1	0,0%	0,0%	100,0%	0,0%	0,0%	100,0%	37
Croatia	1	100,0%	0,0%	100,0%	100,0%	0,0%	0,0%	3

TOTAL	*18*	*50,0%*	*5,6%*	*83,3%*	*66,7%*	*5,6%*	*11,1%*	*13,4*

The sample for Panamax tankers built in China, which presented NASF, is not big, but the average age, at which NASF occurred, is pretty small (4 years). Such a small average age could not be attributed to corrosion, which needs time to affect ship's seaworthiness, but mostly to construction-manufacturing mistakes. To rephrase it, the ship was deficient, by the time it was built.

Panamax built in Japan present mostly hull damage.

Table 4.40.b. Information about mostly represented shipyards (countries), where AFRAMAX, that presented NASF, were built. Focus on ship's size.

					ship's part damaged			average age	
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)	
Japan	16	31,3%	6,3%	68,8%	62,5%	6,3%	6,3%	14,9	
Korea(South)	9	55,6%	11,1%	33,3%	22,2%	11,1%	55,6%	9,1	
China	1	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1	
USA	9	22,2%	0,0%	66,7%	66,7%	22,2%	11,1%	20	
Spain	1	100,0%	100,0%	100,0%	100,0%	0,0%	0,0%	22	
Sweden	4	75,0%	0,0%	75,0%	75,0%	0,0%	0,0%	16,3	
Denmark	1	100,0%	0,0%	0,0%	0,0%	0,0%	100,0%	16	
Canada	1	100,0%	0,0%	100,0%	100,0%	0,0%	0,0%	17	
Belgium	1	100,0%	0,0%	0,0%	0,0%	100,0%	0,0%	14	
Poland	2	50,0%	0,0%	50,0%	0,0%	0,0%	100,0%	10	
France	1	0,0%	0,0%	100,0%	100,0%	0,0%	0,0%	15	
Italy	1	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	21	
TOTAL	*47*	*42,60%*	*6,40%*	*57,40%*	*51,10%*	*10,60%*	*21,30%*	*14,7*	

Aframax built in Japan present mostly hull damage, whereas those built in South Korea mainly internal damage.

Aframax built in USA present a great average age, approaching their economic lifecycle. We could not necessarily conclude, that USA built Aframax are of very good quality, as they presented a NASF, but we could assume, that the most possible reasons, why NASF in these occurred, has to do with wrong/inefficient surveys, inspections and maintenance. Ships are not built to last for 25 years or more without checking periodically and efficiently their seaworthiness and correcting deficiencies/omissions.

Worth noting is also the case of one built in China Aframax, which presented a NASF at the age of 1 year!

Table 4.40.c. Information about mostly represented shipyards (countries), where SUEZMAX, that presented NASF, were built. Focus on ship's size.

					ship's part damaged			average age	
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)	
Japan	3	0,0%	0,0%	66,7%	66,7%	0,0%	0,0%	16,7	
Korea (South)	6	0,0%	0,0%	50,0%	16,7%	33,3%	33,3%	5	
USA	8	12,5%	0,0%	62,5%	62,5%	0,0%	37,5%	17,3	
Spain	5	40,0%	0,0%	40,0%	20,0%	20,0%	20,0%	12,6	
Sweden	7	28,6%	0,0%	71,4%	57,1%	0,0%	14,3%	16,4	
Finland	1	100,0%	0,0%	0,0%	0,0%	0,0%	100,0%	12	
Norway	1	0,0%	0,0%	100,0 %	100,0%	0,0%	0,0%	17	
TOTAL	*31*	*19,40%*	*0%*	*58,10 %*	*45,20%*	*9,70%*	*25,80%*	*13,7*	

Suezmax built in South Korea present a small average age of failure, in contrast to USA built ones.

Japan built Suezmax present mostly hull damage. That is the case also for Panamax, Aframax and VLCC tankers.

USA built tankers have again the highest average age of NASF.

Table 4.40.d. Information about mostly represented shipyards (countries), where VLCC, that presented NASF, were built. Focus on ship's size.

					ship's part damaged			average age	
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)	
Japan	15	26,7%	0,0%	40,0%	60,0%	0,0%	6,7%	15,7	
Korea(South)	9	44,4%	0,0%	44,4%	44,4%	0,0%	0,0%	10,7	
USA	4	25,0%	0,0%	75,0%	75,0%	0,0%	0,0%	16,3	
Spain	5	60,0%	0,0%	80,0%	60,0%	0,0%	20,0%	14,8	
Sweden	2	0,0%	0,0%	100,0%	50,0%	0,0%	50,0%	16,5	
Denmark	2	0,0%	0,0%	50,0%	50,0%	0,0%	50,0%	17,5	
Netherlands	1	100,0%	0,0%	100,0%	100,0 %	0,0%	0,0%	13	
United Kingdom	2	0,0%	0,0%	0,0%	0,0%	0,0%	50,0%	18,5	
TOTAL	*40*	*32,50%*	*0%*	*52,50%*	*55%*	*0%*	*12,50%*	*14,7*	

Table 4.40.e. Information about mostly represented shipyards (countries), where ULCC, that presented NASF, were built. Focus on ship's size.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	3	33,3%	0,0%	33,3%	0,0%	33,3%	33,3%	18,7
Sweden	6	16,7%	0,0%	50,0%	66,7%	0,0%	0,0%	15
Denmark	1	100,0%	0,0%	100,0%	100,0%	0,0%	0,0%	16
TOTAL	10	30%	0%	50%	50%	10%	10%	16,2

Although the frequency failure for ULCC is the greatest the average age of failure is the biggest. All ULCC that failed were built between 1974 and 1978 and none of them failed at an age smaller than 13.

Table 4.41. Flag, when ship was built. Does it belong to TOP 11 FOC? Focus on ship's size.

Flag	Panamax	Aframax	Suezmax	VLCC	ULCC
Bahamas		2			1
Bermuda	1				
Cyprus	1				
Greece	1				1
India			1		
Italy					
Liberia	2	1	5	2	
Marshall Islands		1			
Norway			1		
Norway(NIS)		3			
Panama	1	2	1	1	
Qatar		1			
Singapore	1	1			
Sweden				1	
U.S.A			2	1	
USSR		1			
Venezuela	1				
TOTAL	*8*	*12*	*10*	*5*	*2*
belongs to top 11 FOC?*	*63%*	*50%*	*60%*	*60%*	*50%*

*TOP 11 Flags Of Convenience: Panama, Malta, St. Vincent, Liberia, Cyprus, France (FIS), Marshall Islands, Antigua, Cayman Islands, Bahamas, Bermuda.

Table 4.42. Flag, when NASF occurred. Does it belong to TOP 11 FOC? Focus on ship's size.

	Panamax	Aframax	Suezmax	VLCC	ULCC
Panama	3	12	8	7	1
Australia		3			
Bahamas		5		3	2
Bermuda	1			1	
Bermuda(British)	1				
Cyprus		4	1		
France(FIS)				1	
Greece	3	5	2	4	2
Liberia	4	3	9	11	2
Malta	2	3	1		
Marshall Islands	2	1		1	1
Mauritius		1			
India			1		
Iran				2	
Iraq			1		
Kuwait				1	1
Gibraltar				2	
Isle Of Man				1	
Libya			3		
Malaysia		1			
Norway(NIS)		5		1	1
Norway			2		
Philippines				1	
Portugal(MAR)			1	1	
Qatar		1			
Singapore	1	1		2	
Sweden				1	
TAAF		1			
Tuvalu			1		
U.S.A.			1		
Venezuela	1				
TOTAL	18	46	31	40	10
belongs to top 11 FOC?	66,70%	60,90%	58,10%	60%	60%

4.3.6 Frequencies

Table 4.43. Annual number and frequency of NASF (per shipyear). Focus on ship's size.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
year	cases	frequency	cases	frequency	cases	frequency	cases	frequency	cases	frequency
1990	4	2,03E-02	9	2,29E-02	7	2,91E-02	16	4,15E-02	3	5,56E-02
1991	1	4,96E-03	9	2,17E-02	4	1,63E-02	6	1,52E-02	1	1,85E-02
1992	3	1,52E-02	0	0,00E+00	2	7,51E-03	1	2,46E-03	2	3,70E-02
1993	0	0,00E+00	3	6,63E-03	2	7,42E-03	2	4,84E-03	1	1,85E-02
1994	0	0,00E+00	4	8,68E-03	1	3,71E-03	3	7,17E-03	1	1,85E-02
1995	0	0,00E+00	4	8,64E-03	5	1,87E-02	0	0,00E+00	1	1,89E-02
1996	0	0,00E+00	1	2,11E-03	2	7,59E-03	2	4,88E-03	0	0,00E+00
1997	0	0,00E+00	2	4,14E-03	0	0,00E+00	1	2,42E-03	0	0,00E+00
1998	2	1,03E-02	2	3,98E-03	2	7,33E-03	1	2,42E-03	1	1,92E-02
1999	0	0,00E+00	0	0,00E+00	1	3,61E-03	2	4,82E-03	0	0,00E+00
2000	0	0,00E+00	3	5,57E-03	2	7,44E-03	3	7,31E-03	0	0,00E+00
2001	0	0,00E+00	0	0,00E+00	1	3,66E-03	0	0,00E+00	0	0,00E+00
2002	0	0,00E+00	2	3,67E-03	1	3,77E-03	0	0,00E+00	0	0,00E+00
2003	1	4,63E-03	3	5,16E-03	0	0,00E+00	1	2,37E-03	0	0,00E+00
2004	0	0,00E+00	2	3,28E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
2005	0	0,00E+00	2	3,12E-03	1	3,27E-03	0	0,00E+00	0	0,00E+00
2006	0	0,00E+00	0	0,00E+00	0	0,00E+00	1	2,13E-03	0	0,00E+00
2007	3	9,19E-03	0	0,00E+00	0	0,00E+00	1	2,04E-03	0	0,00E+00
2008	1	2,85E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2009	1	2,61E-03	1	1,21E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
2010	1	2,53E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2011	1	2,47E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
TOTAL	*18*	*3,30E-03*	*47*	*3,66E-03*	*31*	*4,72E-03*	*40*	*4,10E-03*	*10*	*1,29E-02*

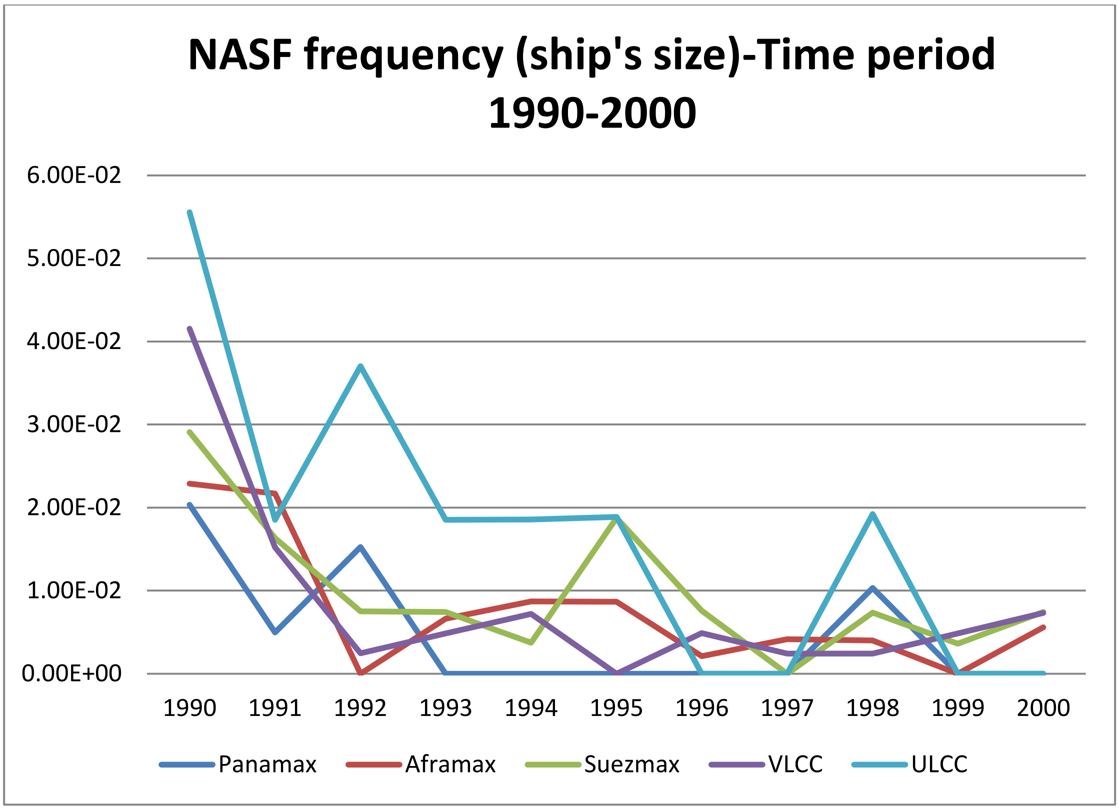


Figure 4.51.a. NASF frequency per shipyear for time period 1990-2000. Focus on ship's size.

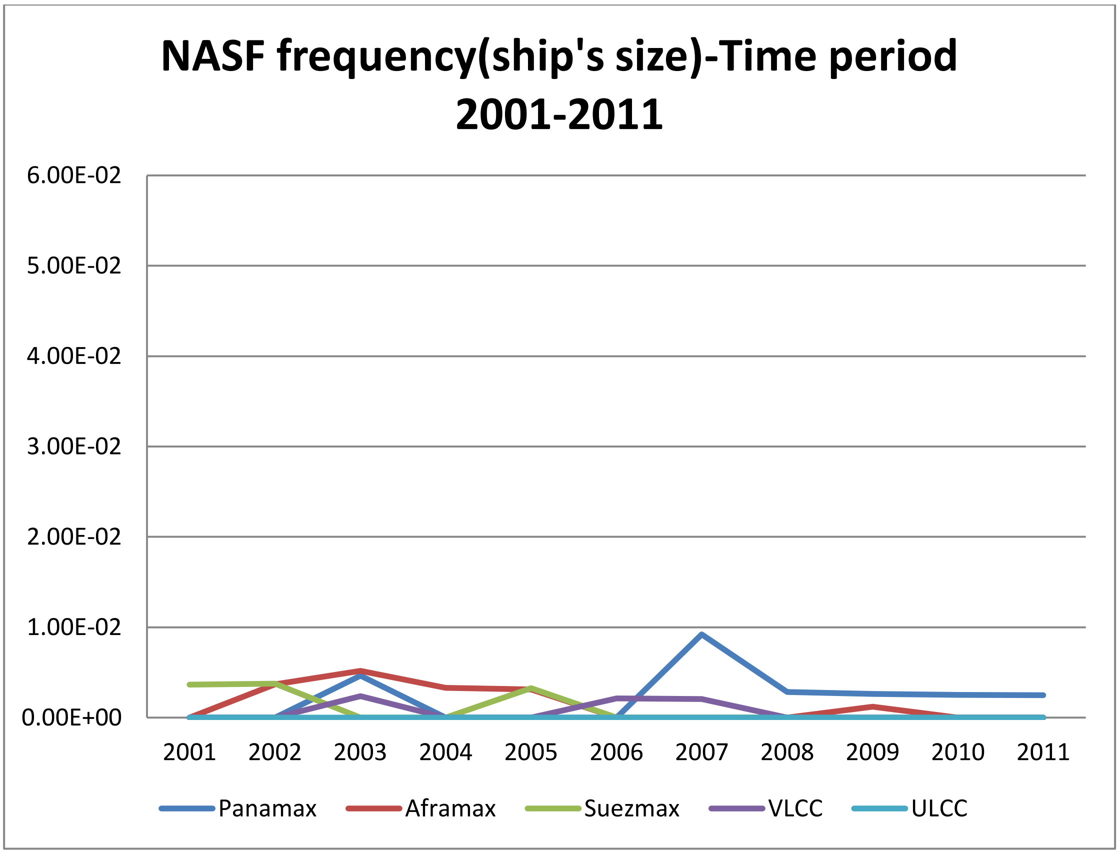


Figure 4.51.b. NASF frequency per shipyear for time period 2001-2011. Focus on ship's size.

The NASF frequency per shipyear for Panamax, Aframax, Suezmax, VLCC NASF frequency per shipyear ranges from 3,3 x10^{-3} to 4,72x10^{-3}. ULCC present a significantly higher NASF frequency per shipyear (1,29 x10^{-2}). That seems logical for reasons already discussed (ULCC are the largest of the large tankers and thus the developed stresses are greater in comparison to the other large tankers' categories. As a result it is more likely, that structural overstressing occurs).

Table 4.44. Annual number of NASF. Focus on ship's size and severity level.

	Panamax			Aframax			Suezmax		
year	cases	serious	non serious	cases	serious	non serious	cases	serious	non serious
1990	4	1	3	9	3	6	7	1	6
1991	1	0	1	9	3	6	4	1	3
1992	3	2	1	0	0	0	2	0	2
1993	0	0	0	3	1	2	2	1	1
1994	0	0	0	4	3	1	1	0	1
1995	0	0	0	4	0	4	5	0	5
1996	0	0	0	1	0	1	2	0	2
1997	0	0	0	2	0	2	0	0	0
1998	2	0	2	2	0	2	2	0	2
1999	0	0	0	0	0	0	1	0	1
2000	0	0	0	3	3	0	2	2	0
2001	0	0	0	0	0	0	1	0	0
2002	0	0	0	2	0	0	1	0	0
2003	1	1	0	3	3	0	0	0	0
2004	0	0	0	2	1	0	0	0	0
2005	0	0	0	2	2	0	1	1	0
2006	0	0	0	0	0	0	0	0	0
2007	3	3	0	0	0	0	0	0	0
2008	1	0	1	0	0	0	0	0	0
2009	1	0	1	1	1	0	0	0	0
2010	1	1	0	0	0	0	0	0	0
2011	1	1	0	0	0	0	0	0	0
TOTAL	*18*	*9*	*9*	*47*	*20*	*24*	*31*	*6*	*23*

	VLCC			ULCC		
year	cases	serious	non serious	cases	serious	non serious
1990	16	2	14	3	2	1
1991	6	1	5	1	0	1
1992	1	0	1	2	0	2
1993	2	0	2	1	0	1
1994	3	1	2	1	0	1

1995	0	0	0	1	0	1
1996	2	1	1	0	0	0
1997	1	1	0	0	0	0
1998	1	1	0	1	1	0
1999	2	1	1	0	0	0
2000	3	2	1	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	1	1	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	1	1	0	0	0	0
2007	1	1	0	0	0	0
2008	0	0	0	0	0	0
2009	0	0	0	0	0	0
2010	0	0	0	0	0	0
2011	0	0	0	0	0	0
TOTAL	*40*	*13*	*27*	*10*	*3*	*7*

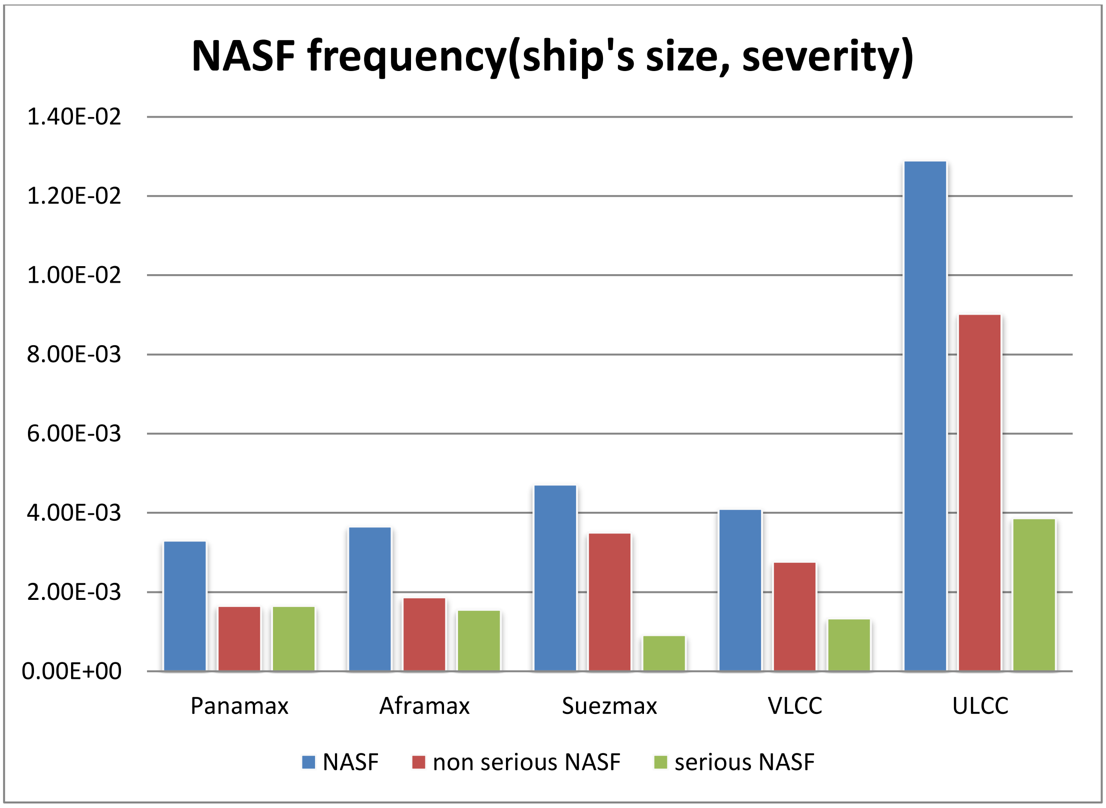


Figure 4.52. Frequency of NASF per shipyear. Focus on ship's size and severity level.

ULCC present by far the highest severity per shipyear, although most of them are characterized as non serious. All ULCC failures took place till 1998.

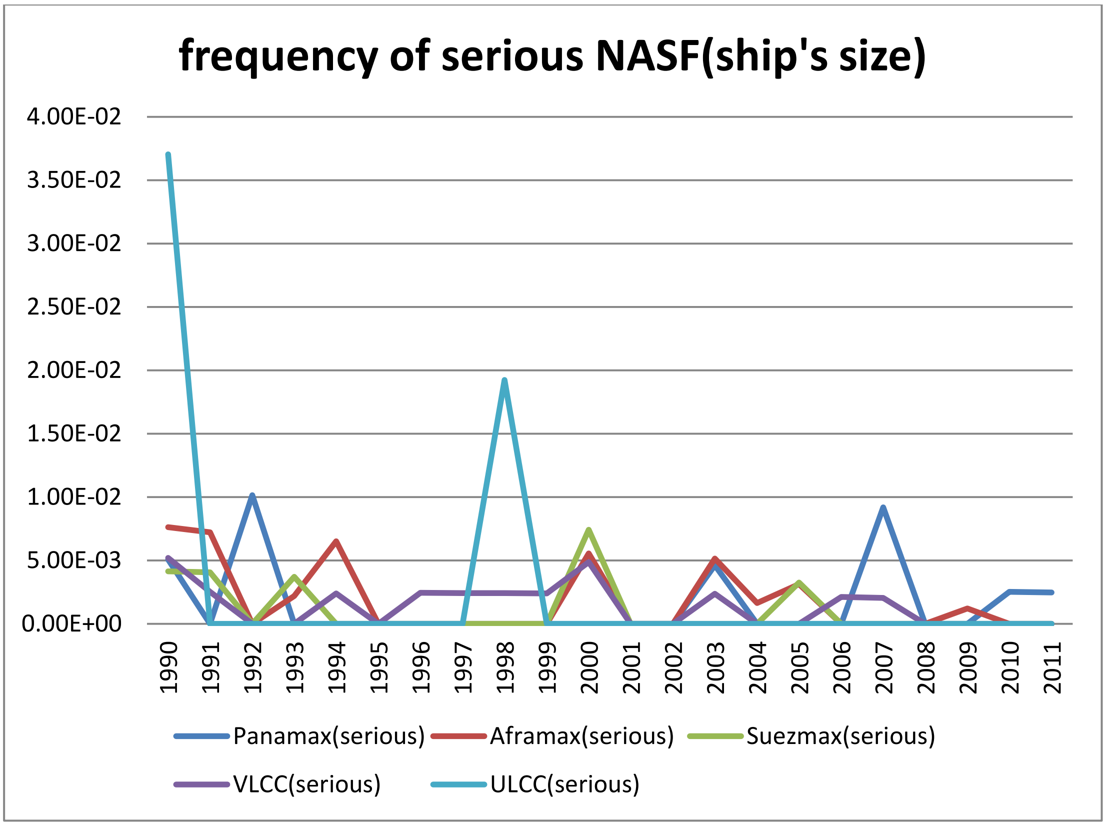


Figure 4.53. Frequency of serious NASF per shipyear. Focus on ship's size.

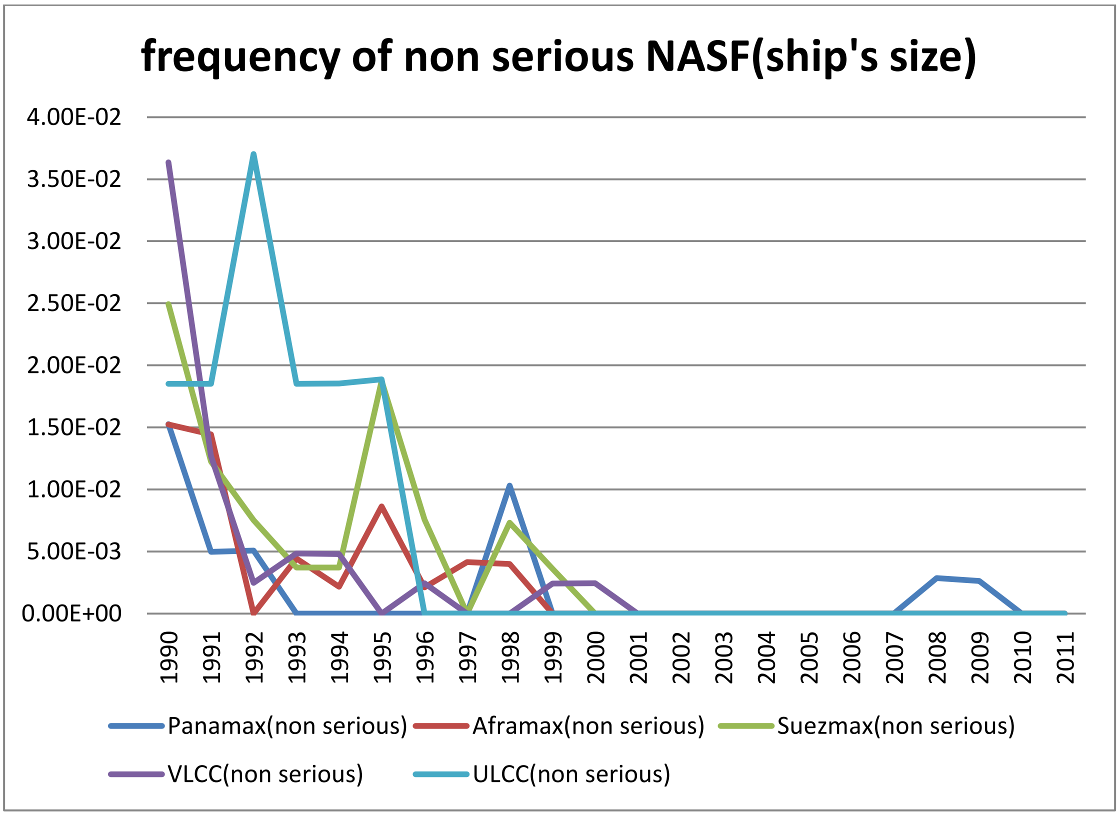


Figure 4.54. Frequency of non serious NASF per shipyear. Focus on ship's size.

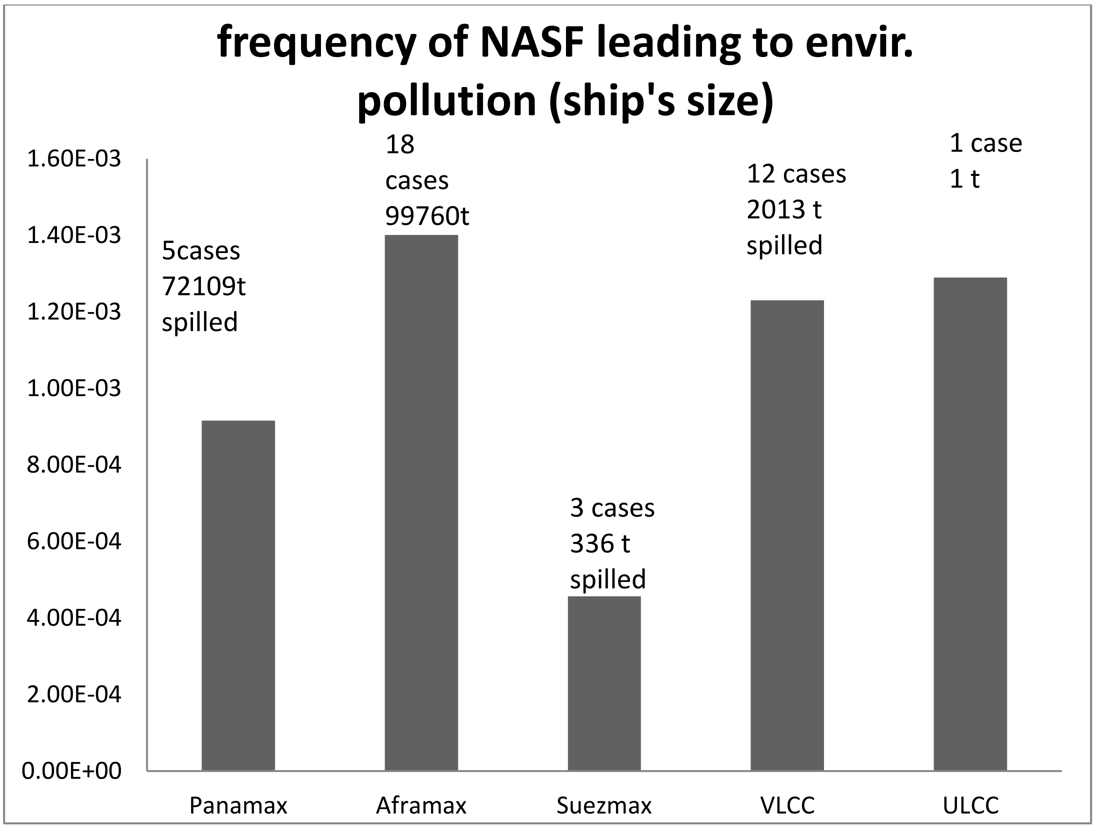


Figure 4.55.a. Frequency of NASF, that led to environmental pollution per shipyear for studied period. Focus on ship’s size.

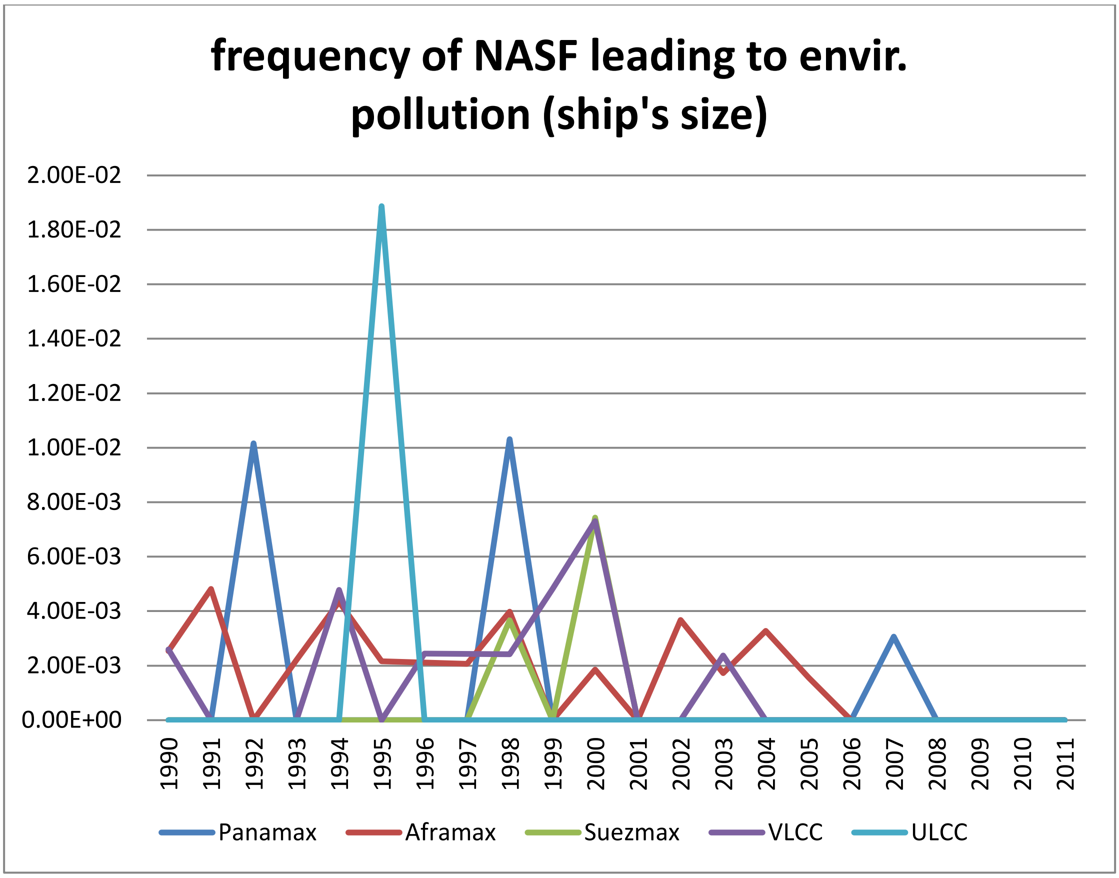


Figure 4.55.b. Frequency of NASF, that led to environmental pollution per shipyear. Focus on ship's size.

This distribution could easily change, if only one big NASF occurred. Suezmax seem to be the most environmentally friendly tanker's type, having the smallest pollution frequency and leading to "only" 336 t of oil spillage. ULCC are responsible for almost no oil spillage (1t , which was assumed) although their frequency is similar to these of the other tankers sizes. That is really encouraging, as the environmental consequences of a NASF of a loaded ULCC would be enormous. On the other side Aframax seem to be the least environmentally friendly ship's size having the biggest frequency and leading to 99760t out of 174039t of total oil spillage caused by NASF, that means 57%. It should be noted though, that 95000t out of these 99760t were caused by only two NASF.

Table 4.45. Annual number and frequency of NASF, that led to environment pollution. Focus on ship's size.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
year	cases	frequency	cases	frequency	cases	frequency	cases	frequency	cases	frequency
1990	0	0,00E+00	1	2,54E-03	0	0,00E+00	1	2,60E-03	0	0,00E+00
1991	0	0,00E+00	2	4,81E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
1992	2	1,02E-02	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
1993	0	0,00E+00	1	2,21E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
1994	0	0,00E+00	2	4,34E-03	0	0,00E+00	2	4,78E-03	0	0,00E+00
1995	0	0,00E+00	1	2,16E-03	0	0,00E+00	0	0,00E+00	1	1,89E-02

1996	0	0,00E+00	1	2,11E-03	0	0,00E+00	1	2,44E-03	0	0,00E+00
1997	0	0,00E+00	1	2,07E-03	0	0,00E+00	1	2,42E-03	0	0,00E+00
1998	2	1,03E-02	2	3,98E-03	1	3,66E-03	1	2,42E-03	0	0,00E+00
1999	0	0,00E+00	0	0,00E+00	0	0,00E+00	2	4,82E-03	0	0,00E+00
2000	0	0,00E+00	1	1,86E-03	2	7,44E-03	3	7,31E-03	0	0,00E+00
2001	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2002	0	0,00E+00	2	3,67E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
2003	0	0,00E+00	1	1,72E-03	0	0,00E+00	1	2,37E-03	0	0,00E+00
2004	0	0,00E+00	2	3,28E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
2005	0	0,00E+00	1	1,56E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00
2006	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2007	1	3,06E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2008	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2009	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2010	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
2011	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00
TOTAL	*5*	*9,16E-04*	*18*	*1,40E-03*	*3*	*4,57E-04*	*12*	*1,23E-03*	*1*	*1,29E-03*

4.4.Focusing on ship's size and basic hull type

Table 4.46. Sample examined

	Panamax	Aframax	Suezmax	VLCC	ULCC
DH	6	6	8	2	0
nonDH	4	21	6	7	1
Total(hull type known)	10	27	14	9	1
Total(independently of hull type)	18	47	31	40	10

NOTE:As seen above, the examined sample , when we take ship's size and basic hull type into consideration, is really small. As far as ULCC are concerned, the sample is only one nonDH.

<u>One should be really careful, when trying to draw conclusions after studying such a small sample</u>.

Table 4.47. Group ages of large tankers involved in NASF. Focus on ship's size and hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	non DH	DH	Non DH
0-5	50,0%	0,0%	66,7%	19,0%	62,5%	0,0%	50,0 %	14,3%	-	0,0%
6-10	50,0%	50,0%	0,0%	14,3%	12,5%	16,7%	0,0%	42,9%	-	0,0%
11-15	0,0%	0,0%	16,7%	19,0%	12,5%	50,0%	50,0 %	28,6%	-	100,0%
16-20	0,0%	25,0%	16,7%	19,0%	12,5%	16,7%	0,0%	14,3%	-	0,0%
>20	0,0%	25,0%	0,0%	28,6%	0,0%	16,7%	0,0%	0,0%	-	0,0%
Total cases	6	4	6	21	8	6	2	7	-	1
Average age	4,5	15,8	6,2	14,7	6,9	14,8	8,5	9,4	-	14

DH fleet is younger than non DH fleet. Despite that, it still remains problematic that DH Panamax, Aframax and Suezmax failed at a small average age. As far as non DH tankers are concerned, VLCC failed at the smallest average age.

4.4.1. Event location, ship operation, environment

Table 4.48. Event location. Unknown cases excluded.Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
limited waters	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
open sea	33,3 %	50,0%	33,3 %	35,7%	50,0 %	75,0%	100,0 %	66,7%	0	0
congested	0,0%	0,0%	0,0%	14,3%	50,0 %	0,0%	0,0%	16,7%	0	0
terminal	50,0 %	50,0%	66,7 %	50,0%	0,0%	25,0%	0,0%	16,7%	0	0
shipyards,drydocks	16,7 %	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
	6	2	6	14	8	4	2	6	0	0

Table 4.49. Operating condition. Unknown cases excluded). Focus on ship's size and basic hull type.

	Panamax	Aframax	Suezmax	VLCC	ULCC

	DH	nonDH	DH	nonDH	DH	Non DH	DH	Non DH	DH	nonDH
Berth	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
Sailing / En-route	33,3%	50,0%	20,0%	58,3%	100,0%	100,0%	100,0%	100,0%	0	0
Discharging	0,0%	0,0%	40,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
Port	0,0%	0,0%	0,0%	8,3%	0,0%	0,0%	0,0%	0,0%	0	0
Anch./Moor./Manoeuv.	66,7%	0,0%	0,0%	16,6%	0,0%	0,0%	0,0%	0,0%	0	0
Loading	0,0%	50,0%	20,0%	16,7%	0,0%	0,0%	0,0%	0,0%	0	0
Ballasting	0,0%	0,0%	20,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
Bunkering	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0	0
Total	6	2	5	12	6	3	2	6	0	0

Table 4.50. Loading condition. Unknown cases excluded. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	nonDH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
loaded	100,0%	100,0%	75,0%	85,7%	100,0%	100,0%	100,0%	100,0%	0	0
unloaded	0,0%	0,0%	25,0%	14,3%	0,0%	0,0%	0,0%	0,0%	0	0
total	2	2	4	7	1	2	1	4	0	0

Table 4.51. Weather. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
bad	16,7%	25,0%	16,7%	14,3%	37,5%	33,3%	100,0%	57,1%	0	100,0%
no data	83,3%	75,0%	83,3%	85,7%	62,5%	66,7%	0,0%	42,9%	0	0,0%
total	6	4	6	21	8	6	2	7	0	1

4.4.2. Outcome of event

Table 4.52. Percentage of NASF accidents, that led to LOWI. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
LOWI	DH	nonDH	DH	nonDH	DH	nonDH	DH	nonDH	DH	nonDH
Yes	66,7%	100,0%	0,0%	61,9%	25,0%	83,3%	50,0%	71,4%	0	0,0%
No	33,3%	0,0%	100,0%	38,1%	75,0%	16,7%	50,0%	28,6%	0	100,0%

Total	6	4	6	21	8	6	2	7	0	1
Average age of LOWI	4	15,8	-	15,5	4	11,5	4	9,6	-	14

As already discussed, non DH ships seem to be more vulnerable to LOWI than DH, something possibly attributed to greater age.

The small average age of DH Panamax, Suezmax and VLCC, that suffered LOWI, is an indicator of deficient structures .Furthermore, it is remarkable, that not even a single DH Aframax suffered LOWI.

Some information regarding DH large tankers that suffered LOWI:

- DH Panamax:4 different ships, built 2002-2006, 2 in South Korea, 1 in China, 1 in Croatia
- DH Suezmax:1 ship, that had LOWI 2 times in the same year, built in South Korea
- DH VLCC: built in Japan in 2002

Table 4.53. Percentage of NASF, in which the ship broke in pieces. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
yes	0%	25%	0%	10%	0%	0%	0%	0%	-	0%
no	100%	75%	100%	91%	100%	100%	100%	100%		100%

3 cases, in which a large tanker with known hull type broke in pieces- 1 non DH Panamax and 2 nonDH Aframax

Table 4.54. Various outcomes. Focus on ship' size and basic hull type.

	Panamax		Aframax		Suezmax	
	DH	Non DH	DH	Non DH	DH	Non DH
towed away	16,7%	25,0%	0,0%	4,8%	12,5%	0,0%
sailed by her means	66,7%	75,0%	100,0%	90,5%	87,5%	83,3%
remains afloat	100,0%	75,0%	100,0%	90,5%	100,0%	100,0%
sold for demolition	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
broken up	0,0%	0,0%	0,0%	4,8%	0,0%	0,0%
ship other transfer	0,0%	0,0%	16,7%	0,0%	0,0%	0,0%
ship internal transfer	0,0%	0,0%	0,0%	4,8%	0,0%	0,0%
total cases	6	4	6	21	8	6

	VLCC		ULCC	
	DH	Non DH	DH	Non DH
towed away	0,0%	0,0%	0,0%	0,0%
sailed by her means	100,0%	100,0%	0,0%	100,0%
remains afloat	100,0%	100,0%	0,0%	100,0%
sold for demolition	0,0%	0,0%	0,0%	0,0%
broken up	0,0%	0,0%	0,0%	0,0%
ship other transfer	0,0%	0,0%	0,0%	0,0%
ship internal transfer	0,0%	0,0%	0,0%	0,0%
total cases	2	7	0	1

Table 4.55. Distribution of NASF by degree of severity. Focus on basic hull type and ship's size.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
serious	66,7%	50,0%	83,3%	23,8%	12,5%	16,7%	100,0%	57,1%	-	0,0%
non serious	33,3%	50,0%	16,7%	61,9%	87,5%	66,7%	0,0%	42,9%	-	100,0%
Unknown	0,0%	0,0%	0,0%	14,3%	0,0%	16,7%	0,0%	0,0%	-	0,0%
total	6	4	6	21	8	6	2	7	0	1

Table 4.56. Distribution of serious NASF by severity level. Focus on basic hull type and ship's size.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
serious cases	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	non DH
serious	100,0 %	50,0%	100,0 %	100,0 %	100,0%	100,0 %	100,0 %	100,0%	-	-
total loss	0,0%	50,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	-	-
Total serious cases	4	2	5	5	1	1	2	4	0	0

Table 4.57. Nature of NASF. Ship's part damaged. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	nonDH	DH	Non DH	DH	nonDH	DH	nonDH	DH	nonDH
Deck damage	0%	0%	20%	18%	43%	0%	0%	0%	-	-
Hull damage	100%	75%	0%	59%	0%	100%	100%	100%	-	-
Internal	0%	25%	80%	24%	57%	0%	0%	0%	-	-
total(unknown excluded)	3	4	5	17	7	4	1	5	0	0

DH: Panamax and VLCC present mostly hull damage, whereas Aframax and Suezmax mostly internal and deck damage and not at all hull damage. The sample for Aframax and Suezmax is bigger and thus more trustworthy, if general conclusions should be drawn.

Non DH: All ship types present mostly hull damage.

4.4.3. Fatalities, injuries

There were two fatalities in total, which resulted from NASF. It could be considered as an occupational accident. The accident happened on a 24 year old Panamax tanker. Her hull type is not known.

4.4.4. Oil spill information

As far as DH large tankers are concerned, there is only one case of environmental pollution causes by NASF. In particular, it is a Aframax tanker with (assumed) 1t of spilled oil. Therefore mostly non DH tankers will be examined here.

Table 4.58. NASF, that led to environmental pollution and tones of spilled oil. Focus on basic hull type.

	cases	Oil spilled(t)
DH	1	1
Non DH	16	149371
Unknown hull type	***22***	***24668***
total	39	174039

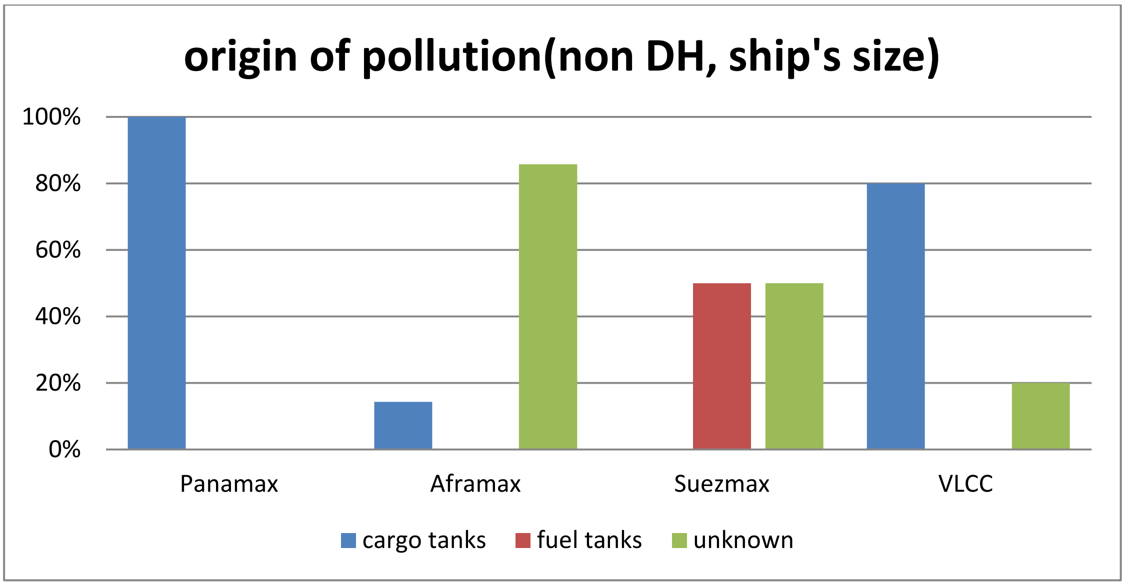


Figure 4.56. Origin of pollution among the ship for non DH tankers. Focus on ship's size.

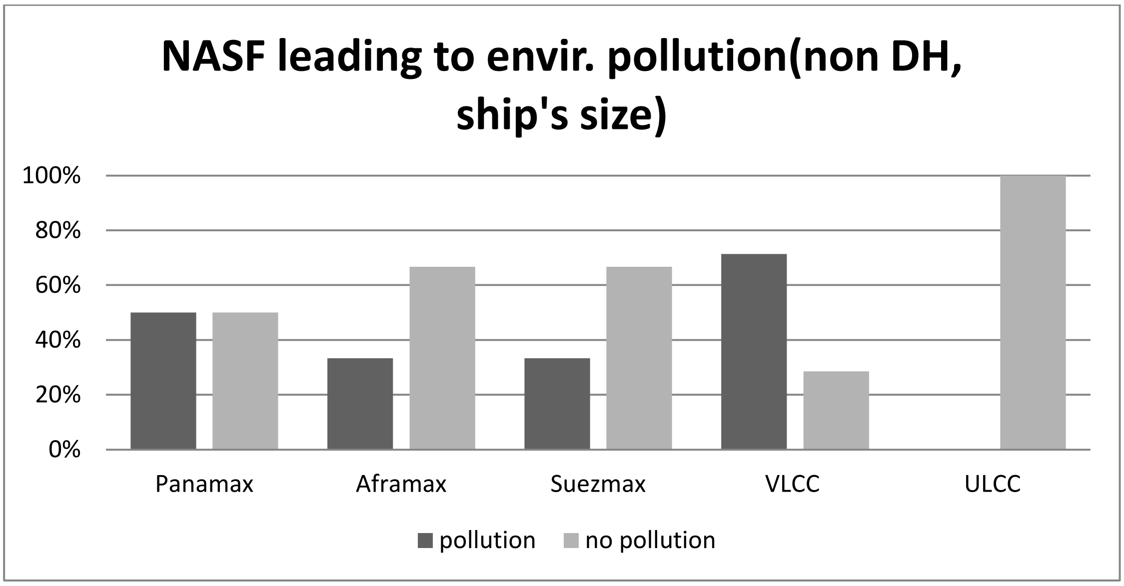


Figure 4.57. Percentage of NASF, that led to environmental pollution. Non DH tankers. Focus on ship’s size.

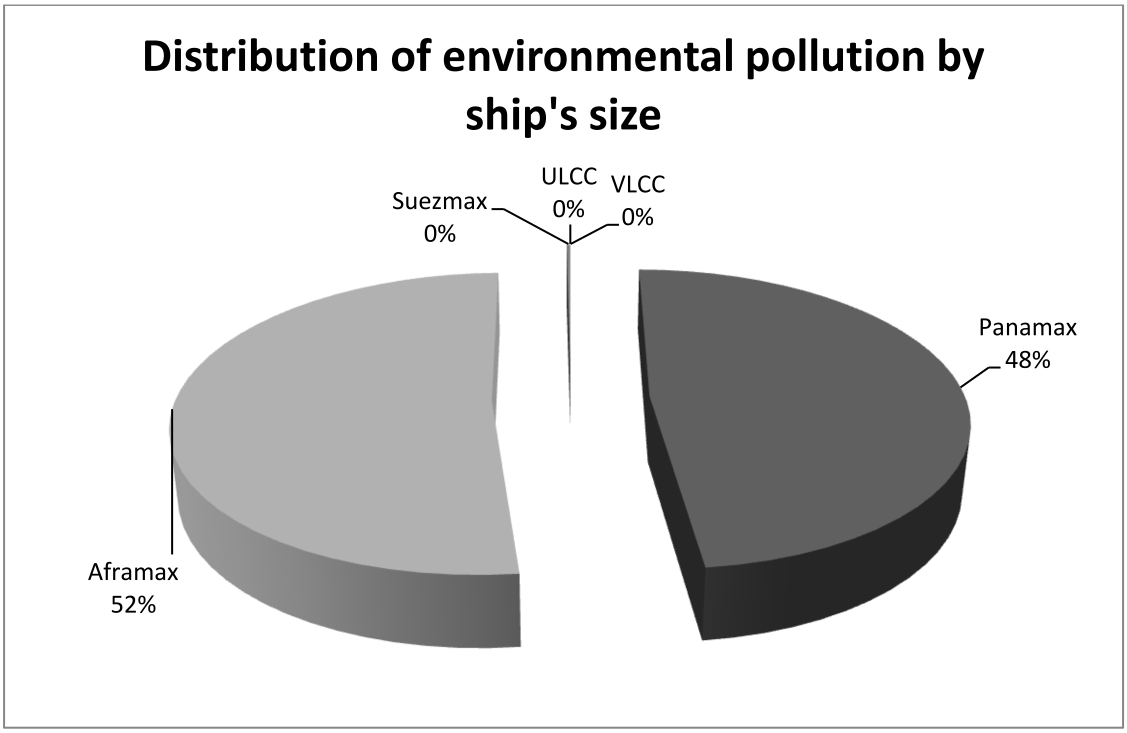


Figure 4.58. Distribution of total environmental pollution (as percentage of tonnes of spilled oil) by ship’s size.

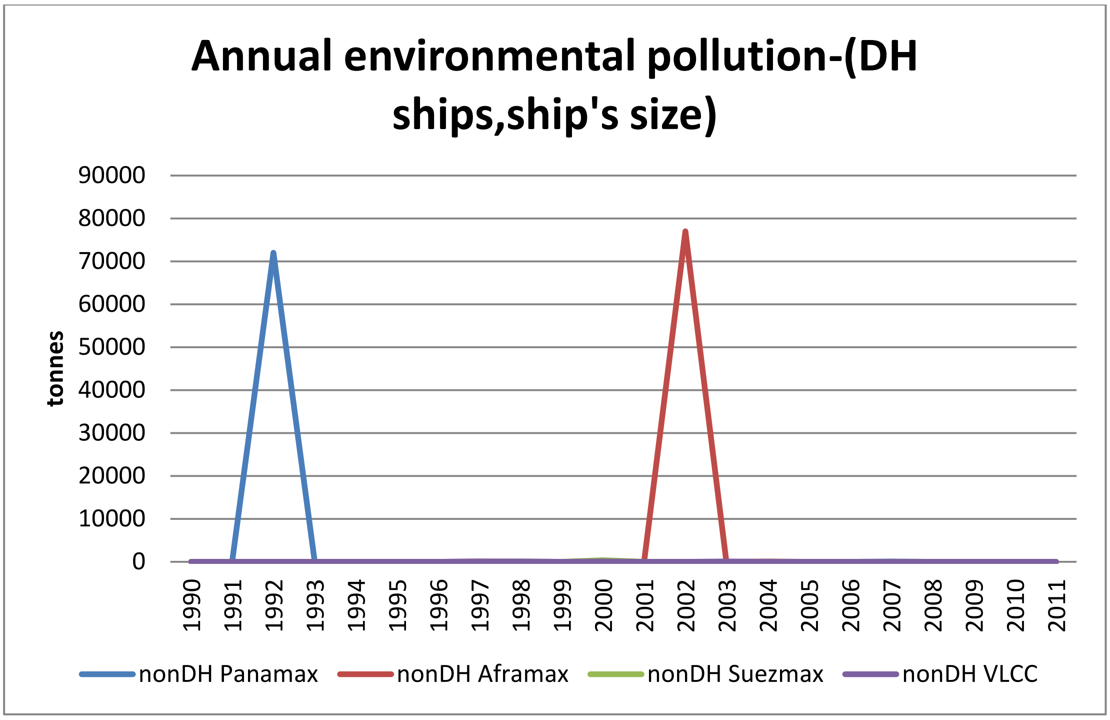


Figure 4.59. Annual environmental pollution caused by non DH tankers. Yearly spill tonne rate. Focus on ship's size.

4.4.5. Shipyards, flags, classes

Table 4.59. Class when accident occurred. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
American Bureau of Shipping	4		1	1	3	1	1	1		
Bureau Veritas							1			
Det Norske Veritas	1		2		1					
Lloyds Register	1					1		1		
Hellenic Register of Shipping		1								

Table 4.60. Class when ship was built. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
American Bureau of Shipping	2				1		1			
Det Norske Veritas	1		1							
Lloyds Register	1							1		

The sample in the tables above is very small and thus no logical conclusions can be drawn.

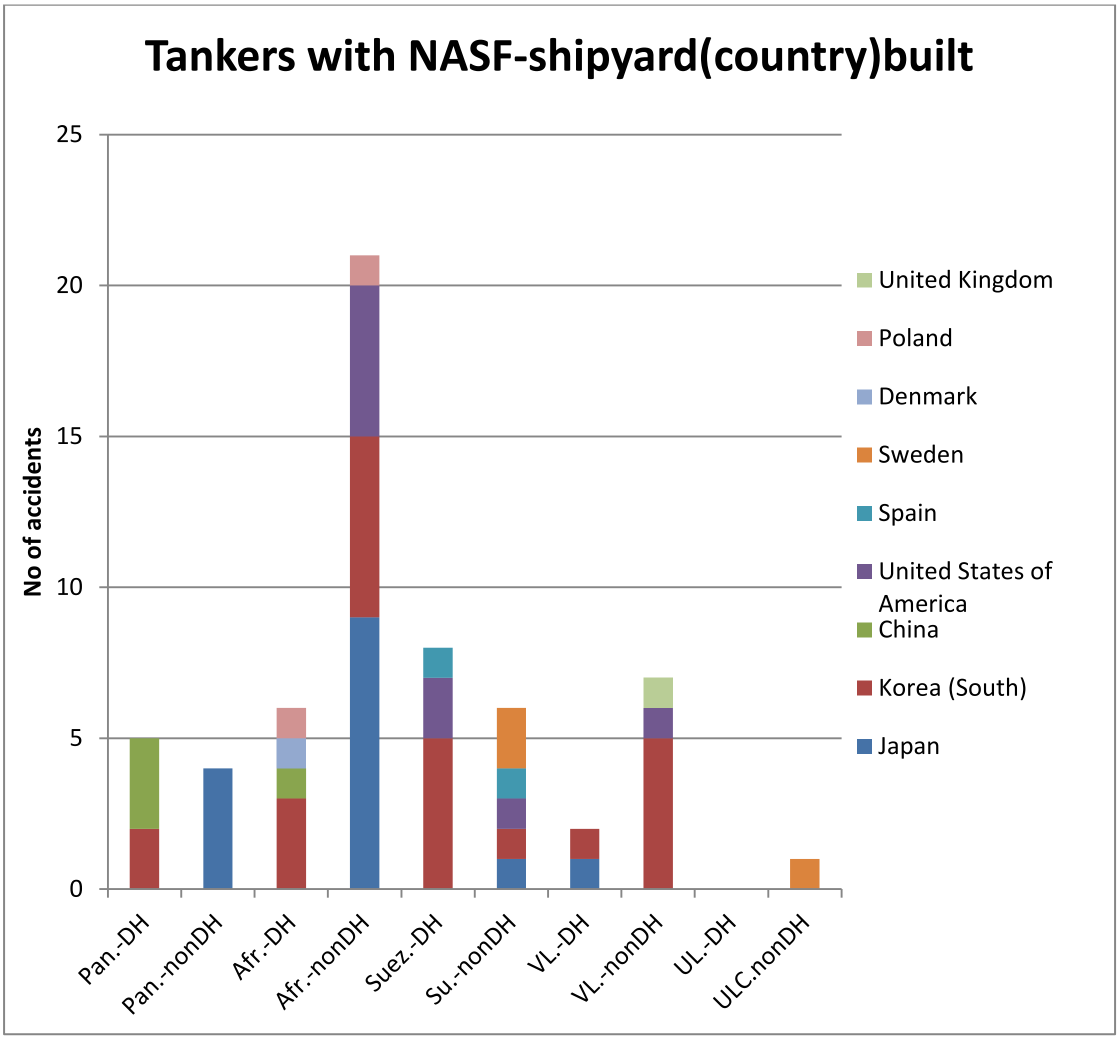


Figure 4.60. Shipyard (country) of built for tankers, that presented NASF. Focus on ship's size and hull type.

Table 4.61. Shipyard (country) of built for tankers, that presented NASF. Focus on ship's size and hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
shipyard built	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
China	3		1							
Croatia	1									
Denmark			1							
Sweden						2				1
Japan		4		9		1	1			
Korea (South)	2		3	6	5	1	1	5		
United States of America				5	2	1		1		

Spain					1	1				
Canada										
Belgium										
Poland			1	1						
Finland										
Netherlands										
France										
Italy										
Norway										
United Kingdom								1		
Total	6	4	6	21	8	6	2	7	0	1

Table 4.62.a. Information about shipyards (countries), where DH PANAMAX, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Korea (South)	2	50%	0%	100%	50%	0%		6
China	3	66,70%	0%	33,30%	33,30%	0%	0%	4
Croatia	1	100%	0%	100%	100%	0%	0%	3
TOTAL	*6*	*66,70%*	*0%*	*66,70%*	*50%*	*0%*	*0%*	*4,5*

Table 4.62.b. Information about shipyards (countries), where Non DH PANAMAX, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	4	50%	25%	100%	75%	0%	25%	15,8
TOTAL	*4*	*50%*	*25%*	*100%*	*75%*	*0%*	*25%*	*15,8*

Table 4.62.c. Information about shipyards (countries), where DH AFRAMAX, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Korea (South)	3	100%	0%	0%	0%	33%	67%	1,7
China	1	0,00%	0%	0,00 %	0,00 %	0%	0%	1
Denmark	1	100%	0%	0%	0%	0%	100%	16
Poland	1	100,00%	0%	0,00 %	0%	0%	100%	15
Total	*6*	*83,30%*	*0%*	*0*	*0%*	*17%*	*67%*	*6,2*

Table 4.62.d. Information about shipyards (countries), where Non DH AFRAMAX, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	9	22%	11%	67%	56%	11%	0%	13,1
Korea(South)	6	33,30%	17%	50,00%	33,30 %	0%	50%	12,8
U.S.A.	5	20%	0%	60%	60%	40%	0%	21,6
Poland	1	0,00%	0%	100,00 %	0%	0%	100%	5
Total	*21*	*23,8%*	*10%*	*61,90%*	*48%*	*14%*	*19%*	*14,7*

Table 4.62.e. Information about shipyards (countries), where DH SUEZMAX, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Korea(South)	5	0%	0%	40%	0%	40%	40%	3,2
U.S.A.	2	0%	0%	0%	0%	0%	100%	16
Spain	1	100%	0%	0%	0%	100%	0%	7
Total	*8*	*13%*	*0%*	*25%*	*0%*	*38%*	*50%*	*6,9*

Table 4.62.f. Information about shipyards (countries), where Non DH SUEZMAX, that presented NASF, were built**.**

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	1	0%	0%	100%	100%	0%	0%	16
Korea(South)	1	0%	0%	100%	100%	0%	0%	14
Spain	1	0%	0%	100%	100%	0%	0%	7
Sweden	2	50%	0%	50%	0%	0%	0%	18,5

U.S.A.	1	0%	0%	100%	100%	0%	0%	15
Total	*6*	*17%*	*0%*	*83%*	*67%*	*0%*	*0%*	*14,8*

Table 4.62.g. Information about shipyards (countries), where DH VLCC, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Japan	1	100%	0%	100%	100%	0%	0%	4
Korea(South)	1	100%	0%	0%	0%	0%	0%	13
Total	2	100%	0%	50%	50%	0%	0%	8,5

Table.4.62.h. Information about shipyards (countries), where Non DH VLCC, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Korea(South)	5	60%	0%	80%	80%	0%	0%	7,4
United Kingdom	1	0%	0%	0%	0%	0%	0%	16
U.S.A.	1	100%	0%	100%	100 %	0%	0%	13
total	7	57%	0%	71%	71%	0%	0%	9,4

Table 4.62.i. Information about shipyards (countries), where DH ULCC, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
TOTAL	0	0%	0%	0%	0%	0	0%	0

Table 4.62.j. Information about shipyards (countries), where Non DH ULCC, that presented NASF, were built.

					ship's part damaged			average age
	cases	serious	broken in pieces	LOWI	hull	deck	internal	(when NASF occurred)
Sweden	1	0%	0%	0%	0%	0%	0%	14
TOTAL	1	0%	0%	0%	0%	0	0%	14

Conclusions:

- Except for Suezmax, in all other cases DH NASF are characterized as serious in greater percentage compared to non DH NASF, something interesting if combined with the fact, that only non DH large tankers broke in pieces. Possible explanation is something already mentioned, in particular that accidents tend to be characterized as serious easier, as years go by.
- The greater average age, at which NASF for non DH tankers occurred, could be partly explained by the fact that non DH fleet is older. Nevertheless, the fact that some DH large tankers presented NASF at really small age, is an indicator of manufacturing mistakes among others. DH Panamax suffer NASF at the smallest average age.
- Non DH large tankers present mostly hull damage. As far as DH tankers are concerned, the picture is not that clear. DH Aframax and DH Suezmax present mostly internal damage, whereas DH Panamax, DH VLCC (only 2 cases though!) present mostly hull damage.
- Non DH designs present more often LOWI than DH designs for all ship's sizes.
- DH Aframax are the only ones, that did not present LOWI.

Table 4.63. Flag when ship was built. Focus on ship's size and hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
Flag	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
Bahamas			2							
Bermuda	1									
Cyprus	1									
Greece	1									1
India					1					
Italy										
Liberia	2		1		4	1	1	2		
Marshall Islands			1							
Norway					1					
Norway(NIS)			1	2						
Panama		1		2		1	1			
Qatar				1						
Singapore	1			1						
Sweden										
U.S.A					2					
USSR										
Venezuela		1								

TOTAL cases	6	2	5	6	8	2	2	2	0	1
top 11 FOC?	67%	50%	80%	33%	50%	100%	100%	100%	-	0%

Table 4.64. Flag when NASF occurred. Focus on ship's size and hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
Flag	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
Panama				7	2	2		2		
Australia				3						
Bahamas			1	1						
Bermuda	1									
Bermuda(British)	1									
Cyprus				2						
France(FIS)							1			
Greece	1			3						1
Liberia		2		1	4	1	1	1		
Malta		1				1				
Marshall Islands	2		1							
Mauritius										
India					1					
Iran										
Iraq										
Kuwait							0	1		
Gibraltar										
Isle Of Man										
Libya						1				
Malaysia				1						
Norway(NIS)			2	1						
Norway					1	1				
Philippines										
Portugal(MAR)										
Qatar				1						
Singapore	1		1					2		
Sweden								1		
TAAF			1							
Tuvalu										
U.S.A.										
Venezuela		1								
TOTAL cases	6	4	6	20	8	6	2	7	0	1
top 11 FOC?*	*50%*	*75%*	*33%*	*55%*	*75%*	*67%*	*100%*	*43%*	*-*	*0%*

*TOP 11 Flags Of Convenience: Panama, Malta, St. Vincent, Liberia, Cyprus, France(FIS), Marshall Islands, Antigua, Cayman Islands, Bahamas, Bermuda.

4.4.6 Frequencies

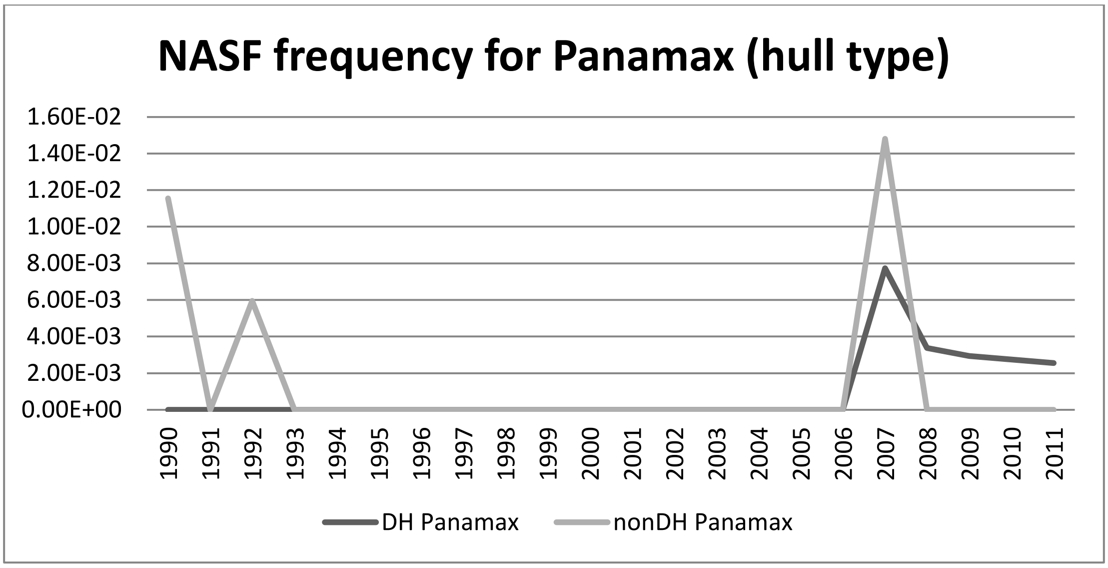


Figure 4.61.a. NASF frequency per shipyear for PANAMAX tankers. Focus on basic hull type.

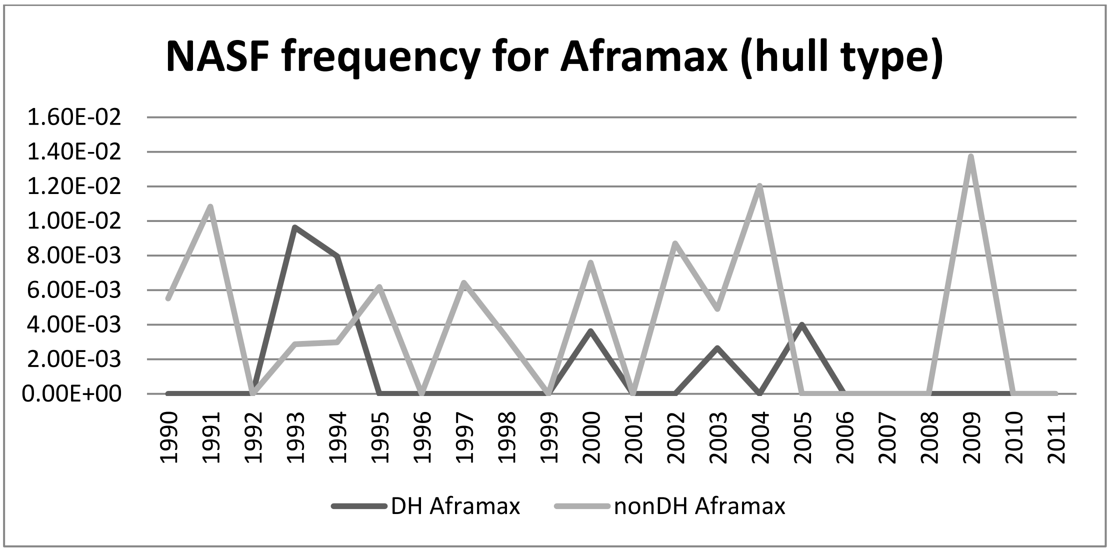


Figure 4.61.b. NASF frequency per shipyear for AFRAMAX tankers. Focus on basic hull type.

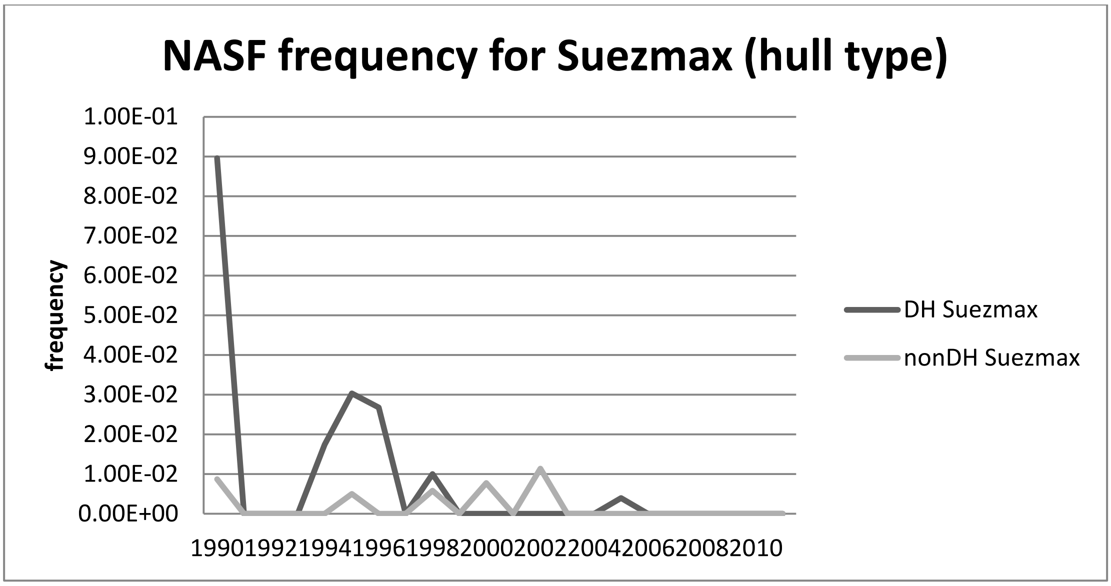


Figure 4.61.c. NASF frequency per shipyear for SUEZMAX tankers. Focus on basic hull type.

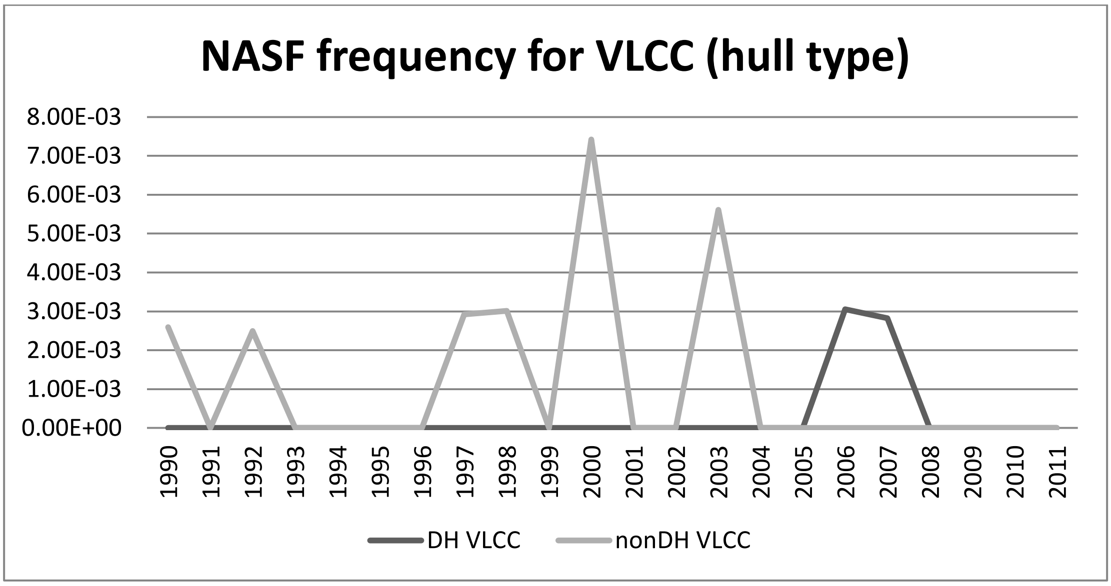


Figure 4.61.d. NASF frequency per shipyear for VLCC tankers. Focus on basic hull type.

In the 4 charts above it one should observe the trends rather than the absolute value, as the sample is small.

Table 4.65. NASF frequency per shipyear. Focus on ship's size and basic hull type.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH	DH	Non DH
freq.	2,05E-03	1,58E-03	7,71E-04	4,14E-03	2,08E-03	2,19E-03	4,66E-04	1,28E-03	0	1,48E-03

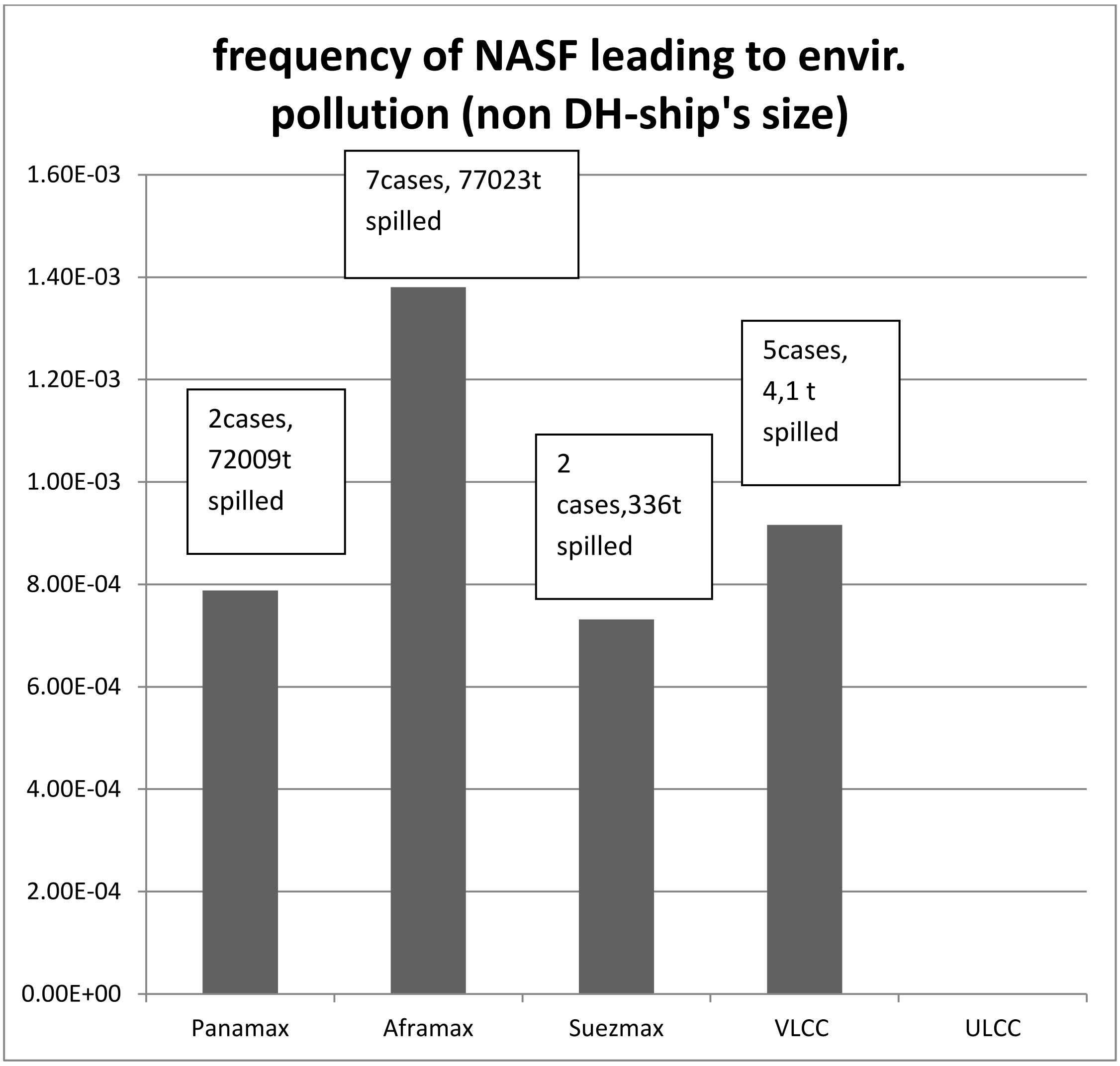


Figure 4.62.a. Frequency per shipyear of NASF, that led to environmental pollution for studied period. Non DH tankers.

Non DH Aframax present the highest frequency of pollution due to NASF.

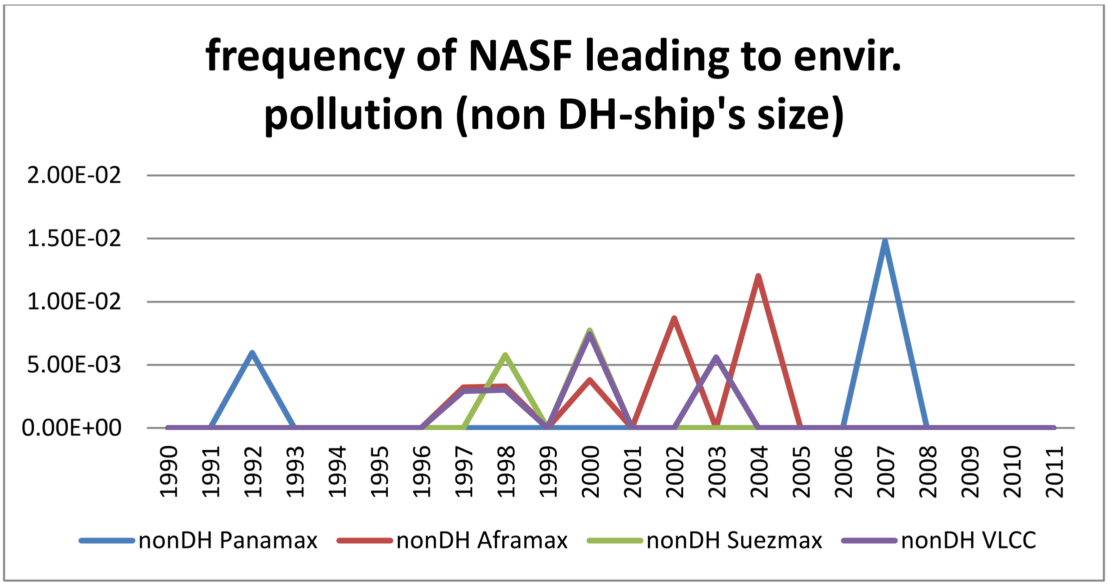


Figure 4.62.b. Frequency per shipyear of NASF, that led to environmental pollution. Non DH tankers. Focus on ship's size

Table 4.66. Annual number and frequency of NASF, that led to environmental pollution. Non DH tankers. Focus on ship's size.

	Panamax		Aframax		Suezmax		VLCC		ULCC	
year	cases	frequency	cases	frequency	cases	frequency	cases	frequency	cases	frequency
1990	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1991	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1992	1	5,95E-03	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1993	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1994	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1995	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1996	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
1997	0	0,00E+00	1	3,21E-03	0	0,00E+00	1	2,92E-03	0	0
1998	0	0,00E+00	1	3,29E-03	1	5,78E-03	1	3,01E-03	0	0
1999	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2000	0	0,00E+00	1	3,79E-03	1	7,73E-03	2	7,42E-03	0	0
2001	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2002	0	0,00E+00	2	8,69E-03	0	0,00E+00	0	0,00E+00	0	0
2003	0	0,00E+00	0	0,00E+00	0	0,00E+00	1	5,62E-03	0	0
2004	0	0,00E+00	2	1,20E-02	0	0,00E+00	0	0,00E+00	0	0
2005	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2006	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2007	1	1,48E-02	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2008	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2009	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
2010	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0

2011	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0,00E+00	0	0
TOTAL	2	7,88E-04	7	1,38E-03	2	7,31E-04	5	9,16E-04	0	0

4.5 Large tankers built after 1981

This chapter is in fact a subchapter, that could be included in the chapters above. As far as fleet at risk by age is concerned, there is data available only for large tankers built after 1981. The thesis in general concerns large tankers regardless of date of built. Therefore and in order to avoid misconceptions, some extra data is provided for large tankers built after 1981 in this separate chapter. Fleet at risk by age, as mentioned in chapter 3 was provided by Germanischer Lloyd.

The examined sample in this case includes 41 cases in total. None of them is an ULCC.

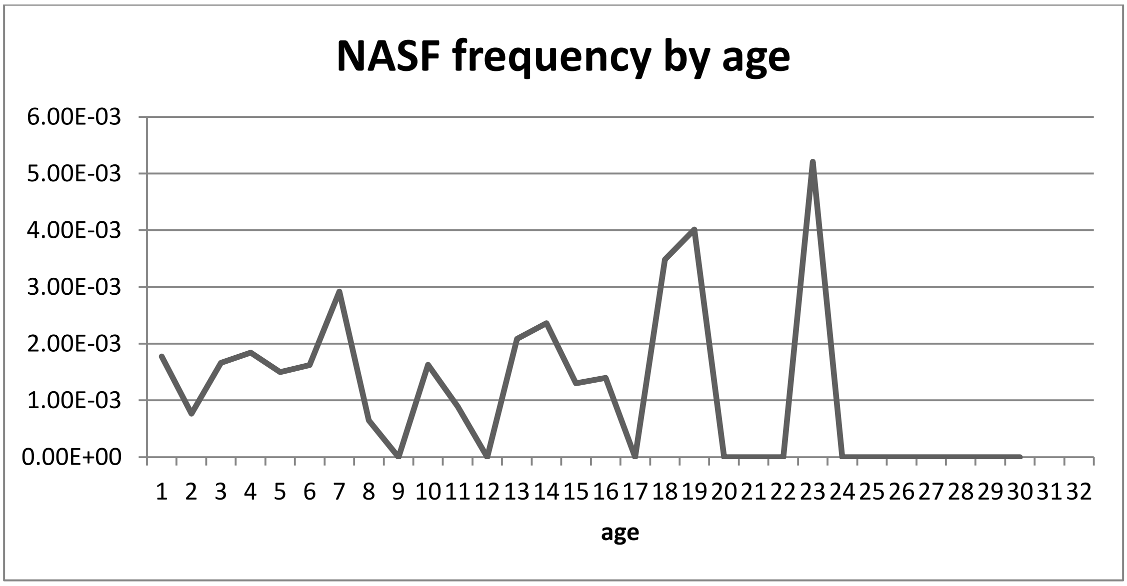


Figure 4.63. NASF frequency per shipyear by age for large tankers, that were built after 1981.

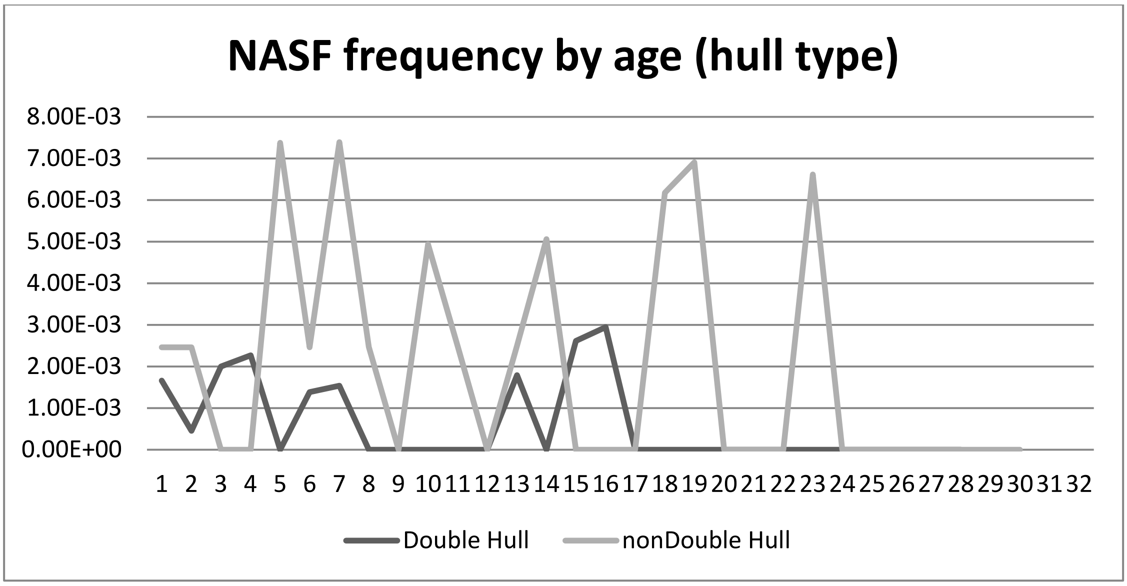


Figure 4.64. NASF frequency per shipyear by age for large tankers, that were built after 1981. Focus on basic hull type.

Table 4.67. Frequency and number of NASF for studied period. Focus on basic hull type.

	cases	frequency
Double Hull	20	$1x10^{-3}$
non Double Hull	21	$2,48x10^{-3}$

According to the diagram above, non double hull large tankers are more likely about to suffer NASF and at a younger age (as far as frequencies are concerned).

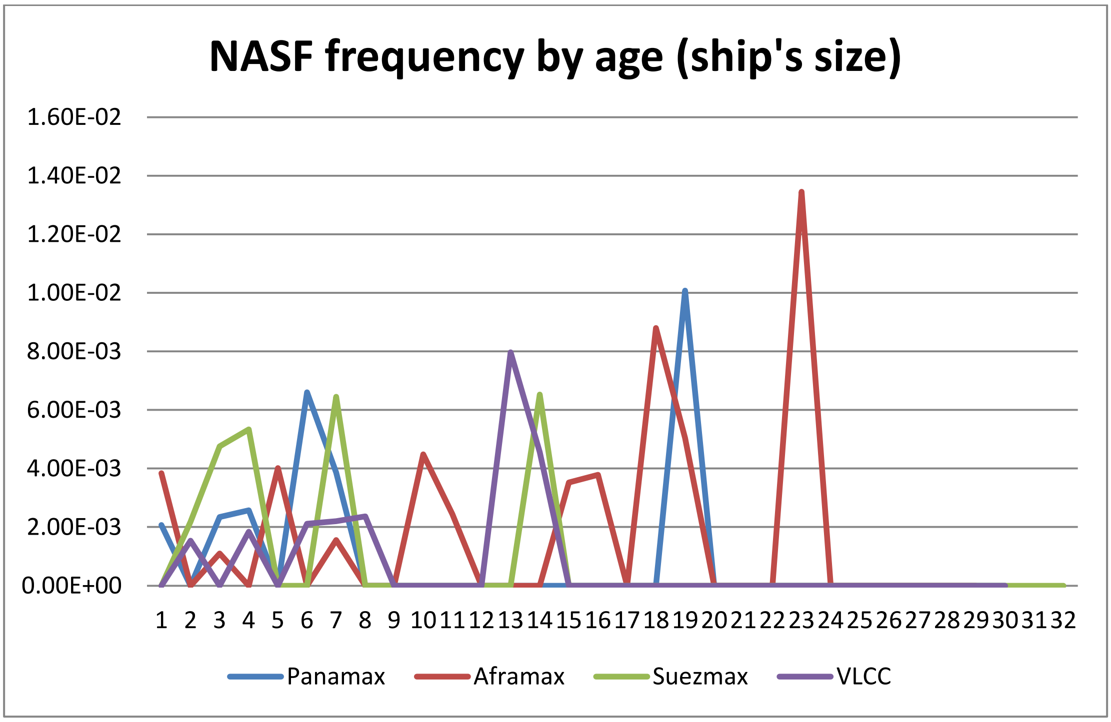


Figure 4.65. NASF frequency per shipyear by age for large tankers, that were built after 1981. Focus on ship' size.

Table 4.68. Frequency and number of NASF for studied period for large tankers, that were built after 1981. Focus on ship's size.

	cases	frequency
Panamax	7	$1{,}48x10^{-3}$
Aframax	18	$1{,}69x10^{-3}$
Suezmax	8	$1{,}62x10^{-3}$
VLCC	8	$1{,}13x10^{-3}$
ULCC	0	0

There is no clear tendency to comment on, when studying the above diagram. Aframax seem to present the most "peaks", but no clear conclusion could be drawn.

The overall frequencies do not present great differences.

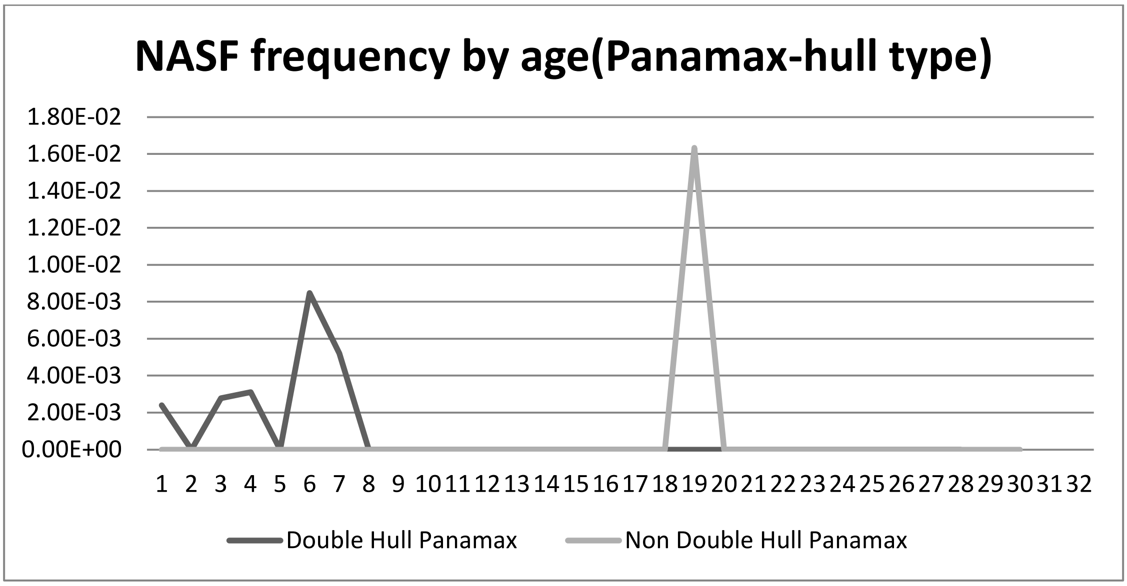


Figure 4.66.a. NASF frequency per shipyear by age for PANAMAX, that were built after 1981. Focus on basic hull type.

Table 4.69.a. Frequency per shipyear and number of NASF for studied period. PANAMAX tankers built after 1981. Focus on basic hull type.

	cases	Frequency
Double Hull Panamax	6	$1{,}91x10^{-3}$
Non Double Hull Panamax	1	$6{,}26x10^{-4}$

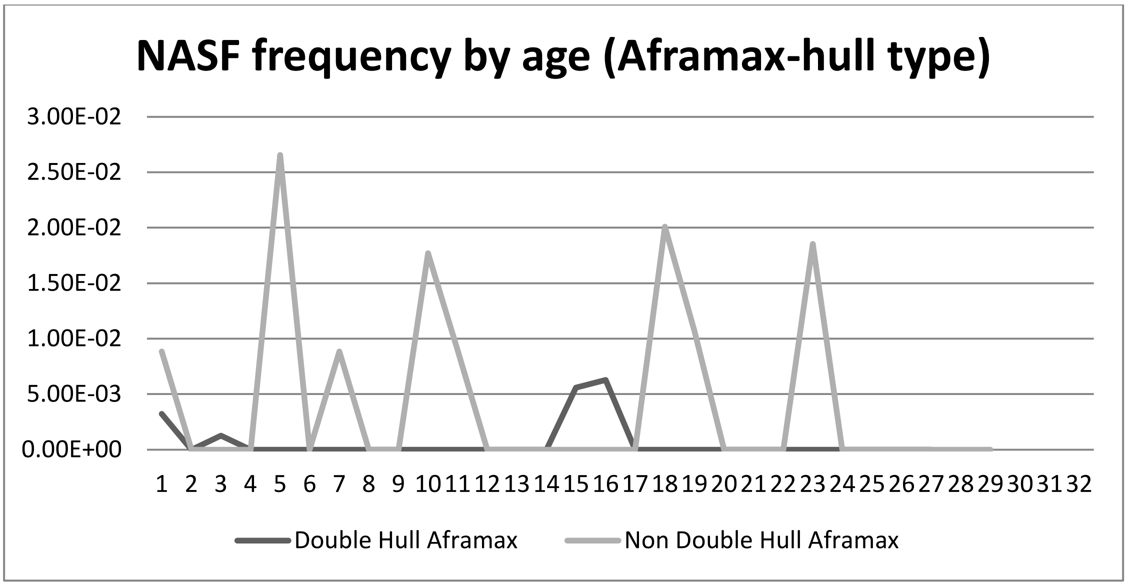


Figure 4.66.b. NASF frequency per shipyear by age for AFRAMAX, that were built after 1981. Focus on basic hull type.

Table 4.69.b. Frequency per shipyear and number of NASF for studied period. AFRAMAX tankers built after 1981. Focus on basic hull type.

	cases	Frequency
Double Hull Aframax	6	$7,3x10^{-4}$
Non Double Hull Aframax	12	$4,92x10^{-3}$

Non Double Hull Aframax tankers are the ones that present the highest NASF frequency compared to the other ship's sizes and hull types. 6 were built in South Korea and 5 in Japan between 1985 and 1992.

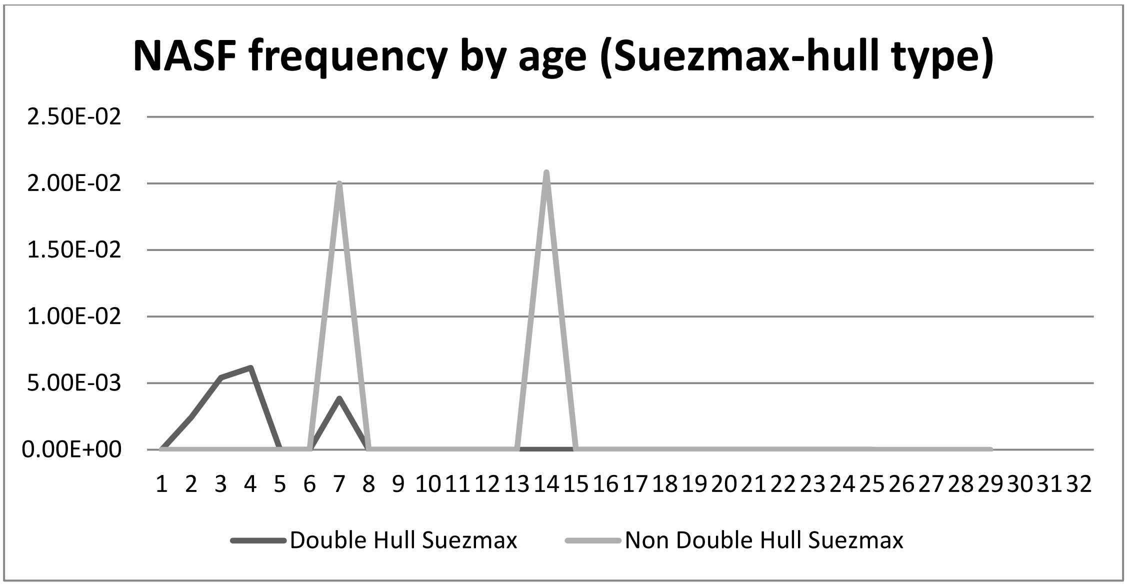


Figure 4.66.c. NASF frequency per shipyear by age for SUEZMAX, that were built after 1981. Focus on basic hull type.

Table 4.69.c. Frequency per shipyear and number of NASF for studied period. SUEZMAX tankers built after 1981. Focus on basic hull type.

	cases	frequency
Double Hull Suezmax	6	$1{,}52 \times 10^{-3}$
Non Double Hull Suezmax	2	$1{,}97 \times 10^{-3}$

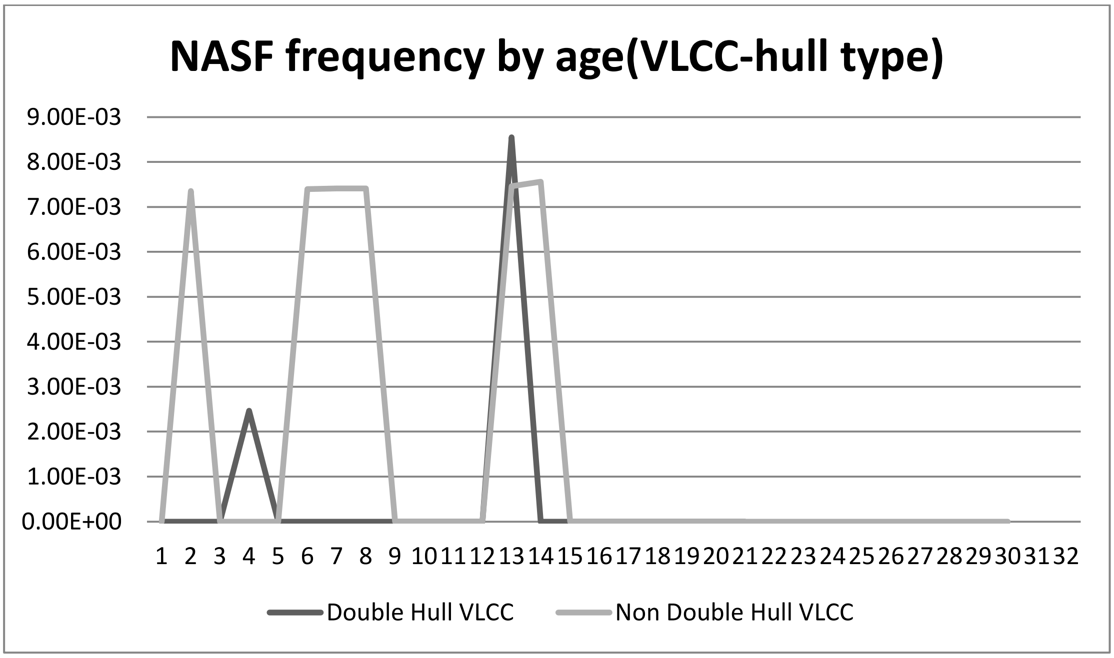


Figure 4.66.d. NASF frequency per shipyear by age for VLCC, that were built after 1981. Focus on basic hull type.

Table 4.69.d. Frequency per shipyear and number of NASF for studied period. VLCC tankers built after 1981. Focus on basic hull type.

	cases	frequency
Double Hull VLCC	2	$4{,}41 \times 10^{-4}$
Non Double Hull VLCC	6	$2{,}38 \times 10^{-3}$

When hull type and ship's size are used as parameters, the sample becomes very small. Therefore one should be really careful, when trying to draw conclusion in such cases.

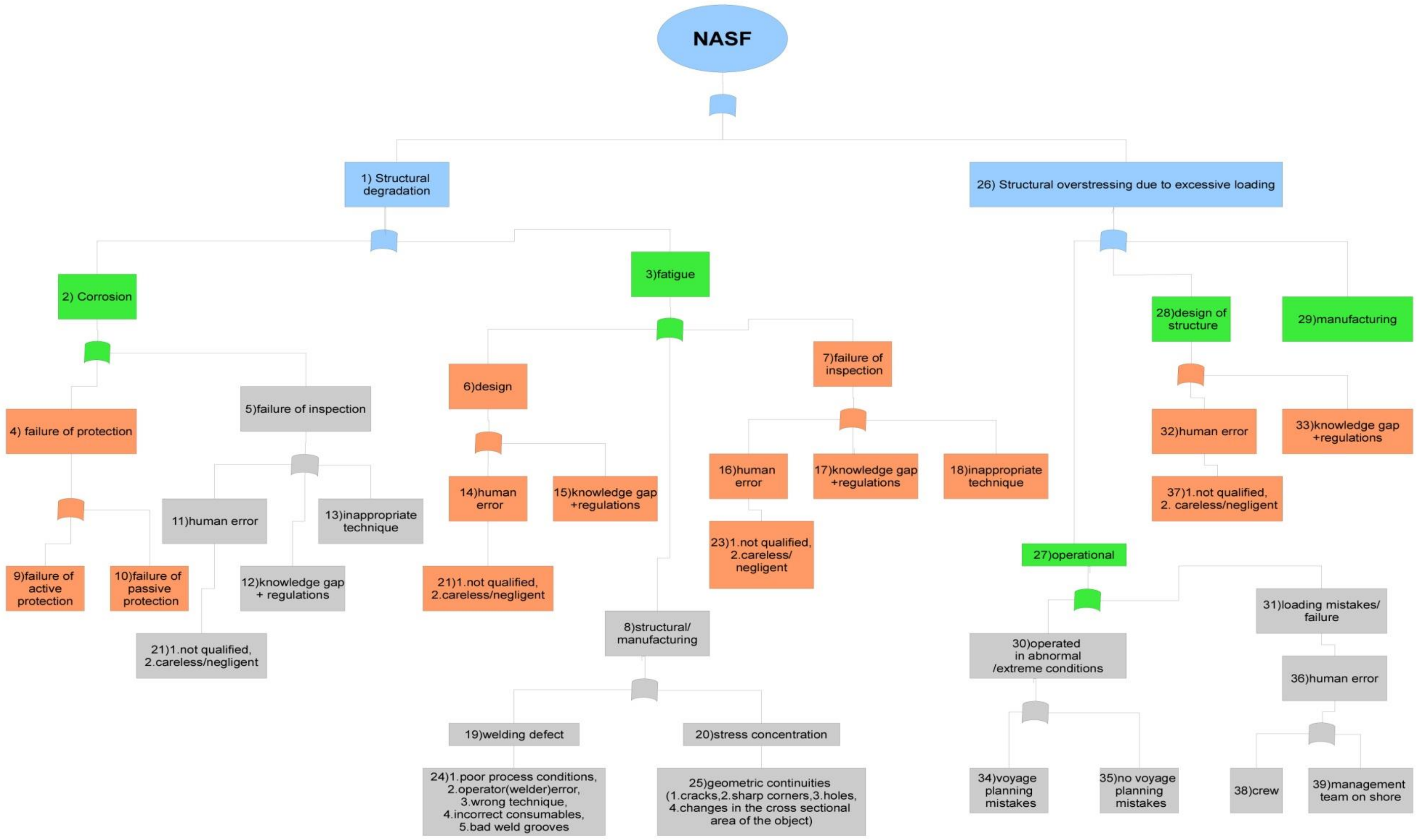
No ULCC built after 1981 presented NASF.

4.6 NASF fault tree

In order to analyze the causes of NASF, NTUA-SDL database uses 3 categories for the origin of NASF: excessive loading, structural degradation, poor design/construction. My goal was to further develop this idea. The target of this NASF fault tree is to emphasize on the aggravating factors that could lead to a Non Accidental Structural Failure. In order to develop it, I studied apart from NTUA-SDL database also:

- DNV-GL documents
- Analytical reports of NASF accidents
- Papers-publications on NASF

Very useful was also the contribution of inspectors of GL and of Dr. Rainer Hamann, who was my tutor during my internship at DNV-GL.



NASF
1) Structural degradation
26) Structural overstressing due to excessive loading
2) Corrosion
3)fatigue
4) failure of protection
5)failure of inspection
6)design
7)failure of inspection
8)structural/ manufacturing
9)failure of active protection
10)failure of passive protection
11)human error
12)knowledge gap + regulations
13)inappropriate technique
14)human error
15)knowledge gap +regulations
16)human error
17)knowledge gap +regulations
18)inappropriate technique
19)welding defect
20)stress concentration
21)1.not qualified, 2.careless/negligent
21)1.not qualified, 2.careless/negligent
23)1.not qualified, 2.careless/ negligent
24)1.poor process conditions, 2.operator(welder)error, 3.wrong technique, 4.incorrect consumables, 5.bad weld grooves
25)geometric continuities (1.cracks,2.sharp corners,3.holes, 4.changes in the cross sectional area of the object)
27)operational
28)design of structure
29)manufacturing
30)operated in abnormal /extreme conditions
31)loading mistakes/ failure
32)human error
33)knowledge gap +regulations
34)voyage planning mistakes
35)no voyage planning mistakes
36)human error
37)1.not qualified, 2. careless/negligent
38)crew
39)management team on shore

Figure 4.67. NASF fault tree

Explanations-under discussion with respect to NASF fault tree

-Knowledge gap/regulations: 1) The scientific effort has not covered in total and effectively a knowledge field/ area.2) The scientific knowledge has covered a knowledge field, but that knowledge was misinterpreted/misused (false regulations). In category "structural failure due to excessive loading –design-knowledge gap" are also cases like this one included: (for example)A ship designed for weather conditions in Mediterranean sea encounters a bigger wave(worse weather) ,than that, it was designed for and suffers a NASF.

-welding defect: as far as shipbuilding industry is concerned, welding is the most commonly used way to join materials.

-no voyage planning mistakes: ship was operated in a right way, but was not possible to deal in a better way with weather and failure occurred.

-It is obvious, that further analysis is possible in order to identify other possible causes. For example, possible causes for voyage planning mistakes are inappropriate equipment and human error. It is open to discussion, how "far" behind it is meaningful to go, as far as causes are concerned.

-NASF→excessive loading→structural/manufacturing and design: although in a way operated, that complies with builders instructions, excessive loading problems occurred.

-"inspection" : is used as term in order to imply not only the inspections that are carried out by inspectors and surveyors, but also to imply inspection (monitoring) as carried out by crew , while the ship is en route for example. (for example: corrosion in engine room bilge wells, having as cause, that waste water was not removed from the bilges, after the exhaust gas boiler had been cleaned using water). Open to discussion, if it should be distinguished between "inspections and surveys" and "monitoring in general (including for instance monitoring while the ship is en route and when there are no inspectors to perform an inspection, but crew should "inspect")

The most important parts of such a model are two: 1) whether it succeeds in providing meaningful information for the studied subject in a few words, 2) its appliance . As far as NTUA SDL database is concerned, the accidents' reports are in most cases not detailed, thus we could not go even till the first subcauses in a lot of cases.

Beneath are typical examples of reports of accidents in the database and indications on the way, that the fault tree could be applied:

Table 4.70. Most typical examples-descriptions

Database text	Causes (faults)
Damage/fracture/crack/hole in tank/plating/bottom/deck/internal structure/bulkhead	1
Damage/fracture/crack/hole in tank/plating/bottom/deck/internal structure/bulkhead <u>during heavy weather</u>	1,26→27→30

Damage/fracture/crack/hole in tank/plating/bottom/deck/internal structure/bulkhead during lightering/loading/unloading	1,26→27→31→36
Oil leakage	None, because of inadequate information

Table 4.71. Other examples-descriptions

Database text	Categories-causes
Crack in weld of a tank	1→3→8→19
Cracked weld in ballast tank while loading	1→3→8→19,26→27→31→36
Hull holed because of corrosion	1→2
Structural damage because of overpressurisation of a tank	

Unfortunately there are a lot of causes-faults not mentioned at all. That happens for two reasons:

1. Because of lack of details.
2. Because it would be anyway difficult to attribute a NASF to some causes. For instance manufacturing, design and inspection causes could not get easily discovered. Who could find out and report also, whether the inspection was not carried out properly?

Other comments:

- Structural degradation is assumed in almost all cases. It does not seem logical, that a ship presents a structural failure unless it was somehow corroded and got influenced by fatigue. There are underlying factors, such as manufacturing errors, something that seems to be the case in young tankers, that suffered a NASF, but one could only assume it, if such piece of information is not included in the accident's report.
- Other causes could be assumed in a lot of cases, but the aim was to concentrate on the not questionable information.
- According to inspectors, I discussed the matter of NASF with, it is not sure, whether the inspectors will write down detailed or completely honestly the reasons, why an accident occurred. That has to do mainly with insurance and compensation matters…

Furthermore, it would be interesting to see how the fault tree could be used, when studying an accident, for which we possess also analytical reports. That is the case for the well-known accident of tanker "PRESTIGE" (see chapter 4.7.2 for more details on the subject). For this accident the causes are:

1. 1→3→6→15. Some constructional details of PRESTIGE did not meet the requirements of ABS for fatigue strength of new ships (note: it was not obligatory to meet the requirements for younger ships). It is worth noting that the methodology for fatigue strength of new ships (S-N curves developed by United Kingdom Department of Energy) had not yet been incorporated in the regulations of classification societies, when PRESTIGE was built .
2. 1→2 This is a common problem for tankers, specially for older ones. 18 months had passed since the last special survey, during which some parts of steel of a starboard wing tank were found corroded beyond acceptable levels and were replaced. The degree of corrosion, that occurred meanwhile, does not seem enough to cause tank's structural failure, also taking into consideration the existing circumstances
3. 1→2,1→3→8→20.The welding of new and old (and corroded) steel could create points of stress concentration at the interface between them and accelerate the corrosion rate of the old and uncoated steel. As far as the examined tank is concerned, great parts of steel were replaced during the special surveys of 1996 and 2001.
4. possibly 1→2→5 and 1→3→7. IACS surveyors investigated the accident and expressed doubts about certain inspection procedures and practices followed then by ABS .

4.7 Characteristic NASF events

4.7.1 Accident of "KATINA P"

Non DH tankership Katina P (DWT of about 70000t, built 1966 in Japan) sank on 26/4/1992 causing an environmental pollution of about 70000t heavy fuel oil.

Narrative

Before 16/4/1992- The ship departs from Rio de Janeiro and heads through the Atlantic Ocean to Bangladesh in order to be scrapped. While en route, the ship was called back in order to pick up fuel oil (#6 heavy fuel oil)[4] from Venezuela and deliver it to Fujirah in U.A.E.(United Arab Emirates).

[4] #6 heavy fuel oil is a residual oil with great viscosity and demands preheating at 104-127 grad Celsius.

16/4/1992- Tanker «KATINA P» is transferring almost 70000 tDWT (#6 heavy fuel oil) from Venezuela to the Persian gulf. She encounters heavy sea, while en route. As a result she sustains a crack in the starboard side amidships. In particular, the crack is developed in the shell plating of two cargo tanks and almost 4000t of fuel oil flow out.

17/4/1992-19/4/1992- The crew grounds intentionally the vessel on a sandbar six miles offshore of Maputo Bay. The goal is to prevent the ship from sinking. The ship is being anchored and abandoned by the crew members. While the ship is aground, fuel oil keeps on flowing out from its tanks. Meanwhile a Protection and Indemnity club representative embarks on the ship and inspects it. His estimation is that the ship is about to break up.

21/4/1992- Following a request for assistance from the Mozambique Ministry of Foreign Affairs, a US Coast Guard response team arrives on site in the evening and inspects the ship, while being on a helicopter. Katina P presents a heel of 7 degrees at her starboard side , the deck edge is located 1m under the sea level. Meanwhile fuel oil flows from its port fore part and oil spills surround the ship.

22/4/1992- In an attempt to prevent further environmental damage by the stranded tanker Katina P in the Maputo Bay, the crew embarks again on board. The ship is towed by the tow boat «John Ross» and heads to Mozambique Channel. The goal is to perform a ship to ship transfer of the cargo.

26/4/1992- While the towing procedure is going on for the fourth consecutive day, the ship buckles amidships, breaks in two pieces and sinks having the rest of the cargo in her tanks. The existence of an oil spill is reported, which covers a surface of 3 square sea miles.

<u>Initiating event</u>

The ship was caught in gigantic waves. That resulted in failure of the shell plating in the ship's starboard side. Almost 350 sq. m. of plating were cut off from No2 ballast tank and No3 Cargo tank. In addition to this, a part of weather deck collapsed.

<u>Information about the sinking of the ship</u>

-The ship broke at a point of the hull, which is precisely stern of the manifold and where the midship segregated ballast tanks are located.

- Ship's location was 173km (93sm) off Mozambique's coast , 440 km (237sm)northeastern of Maputo. The depth in the region was almost 2000m.

-Weather conditions were good.

Causes-aggravating factors

There are no detailed reports available, in order to accurately determine the causes. Initially a great part of the shell plating of two tanks failed, most likely during ship's sagging and at a point located near midship. Possible causes and aggravating factors for this Non Accidental Structural (NASF) are:

-Corrosion: The ship was 26 years old by the time the accident occurred. That means that corrosion could have influenced the structure largely. This factor could be examined further, if the reports of the latest surveys and inspections of the tanks, that took place, were available.

-Fatigue: the methodology for fatigue strength for new ships (S-N curves, developed by United Kingdom Department of Energy) was not integrated in the classification societies' regulations, when Katina P was built.

-Adverse weather conditions: the accident's report makes it clear, that the first failure (initiating event) took place, while the vessel was travelling in very bad weather conditions.

-Bad condition of the structure: that is a general, but meaningful observation, if we take into consideration that the ship was initially en route to Bangladesh in order to be scrapped.

-Failure to locate all possible weaknesses-deficiencies during surveys and inspections.

- For a ship that old it could be easily guessed that from time to time deficient parts of plating have been replaced with new ones. However, that could lead to the creation of stress concentration zones in the interface between the old and the new metal, something that accelerates corrosion.

Table 4.72. Main particulars-further information

Built by	Hitachi Shipbuilding Mukaishima- Onomichi, Japan
Year built	1966
Final flag	Malta
Class	Hellenic Register (Greek)
Length overall	238 m
Breadth	36,45 m
Depth	16,36 m
Hull type	(pre MARPOL) single hull
Cargo	heavy fuel oil
Gross tonnage	30890 tons

Consequences-compensation-coping with the spill

Pollution caused by the accident of KATINA P had major socioeconomic consequences for Mozambique. The territory that was polluted was of great significance, as far as flora and fauna are concerned. Furthermore, fish are a major part of Mozambicans' diet and a lot of them are fishermen. Therefore, there was obviously an impact on their life, at least for fishermen's families and for the period of time, during which fishing was prohibited, as they were deprived of their means of livelihood.

The sum of money, that Mozambique received as compensation for the environmental pollution, was pretty small (4,5 mil.$). The lack of expertise and contingency plans and the fact that Mozambique had not signed the International Maritime Organization (IMO) conventions, enabling compensation in the event of a spill, justified this low level of compensation (see table beneath for an estimation of the maximum sum of money Mozambique could receive as compensation for the oil spill).

There were delays and problems concerning the oil spill response. This is attributed to the civil war at that time in Mozambique and to the lack of resources and expertise.

Taking into consideration the type of the fuel oil(#6 heavy fuel oil) that was transferred, the most likely scenario is: fuel oil solidified at water temperature (3 grad Celsius at the sea bottom at the territory, where the ship sank) and remained there for several months. Subsequently and taking the strong currents of that area into consideration, fuel oil-at least a part of it- was swept away southern of Mozambique.

Suspicious activities

-The decision, that a ship to ship transfer of the cargo should take place far away from the grounding place, although a Protection and Indemnity club representative inspected the ship and clarified that the ship was about to break in two parts.

-It is not obvious, why somebody should prefer to import fuel oil from Venezuela to the Persian Gulf.

-There are questions concerning: a) the location, where the ship was stranded and why it was preferred, b) the route that KATINA P followed, while it was towed away. There are suspicions that the ship's owner was attempting to cover up traces of unlawful activity.

Lessons to be learnt

-The combination of flag of Malta and Greek classification society does not seem to be trustworthy.

-It is clear , that if there were available databases concerning the sea currents in the area and trained personnel, it would be possible to do simulation studies to predict the pathways of the oil spill, and to design ways and means of containing and eliminating it with international assistance.

-The ship was en route to be scrapped and obviously not in the best condition. Despite that, it was fully loaded and travelled in the open sea, a combination that led to structural overstressing.

Table 4.73. Maximum amounts of compensation available under the IMO conventions (expressed in US$ millions- rates as at September 2013)

TANKER'S GROSS TONNAGE	**1969 CLC**	**1992 CLC(post-Nov 2003)**	**1992 FUND (post Nov-2003)**	**Supplementary FUND**	
5000	1	6,6	299,7	1107	
25000	4,9	25,3	299,7	1107	
50000	9,82	48,6	299,7	1107	
100000	19,64	95,2	299,7	1107	
140000	20,7	132,4	299,7	1107	

CLC: International Convention on Civil Liability for Oil Pollution Damage

FUND convention: International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage

<u>Additional witness</u>

Below is the testimony of Wayne Stephen, second engineer of « John Ross», the tow boat that was towing KATINA P, when the latter sank.

"I was guided to your site by your book The Tankship Tromedy. I particularly viewed your data on the Katina P, as I was the Second Engineer on board the John Ross, the salvage tug that took Katina P in tow. I also lay claim to having taken the photographs you have published on your site.

My recollection of events is slightly different to those described in your database.

The vessel was carrying a cargo of HFO from Brazil to Fujairah, coals to Newcastle and was then destined to be broken up. The initial breaking up of the vessel was noted by the ship's crew as she rounded the Cape. Vessel was cracked on the starboard side through the side shell plating. However, the crack was aft of the cargo manifold, also a location of SBT. The Chief Officer of John Ross reported that most of the deck longitudinals had been detached from the deck.

The vessel was not grounded off Maputo. She was anchored and abandoned by the ship's crew. The Master, Chief and 2nd Engineer returned to the vessel when the salvage operation was commenced. This was not expected to be successful as own vessel was on a daily hire rate rather than a Lloyd's Open Form contract. On our arrival at Katina P's location, it was observed that the hull forward of the break was upright whilst the accommodation section had a pronounced starboard list. Katina P was taken in tow with the intention of meeting with a lightening ship to try and recover as much oil as possible. Katina P sank before the arrival of the lightening ship.

Some 40 personnel, involved in restoring power to the boilers in order to have the cargo pumps operational were transferred from Katina P to our vessel, and two others also in attendance without incident. One person delayed leaving the vessel as he attempted to rescue the ship's cat, but he was unable to catch it and had to leave.

Of interest is that the lightening ship, the name of which I do not recall, was an OBO which proceeded to Richard's Bay to load a full cargo of coal. During loading the main sea water line ruptured at night and the engine room flooded resulting in the ship's sinking. It is understood but not confirmed that the vessel and Katina P were owned by the same company, although naturally in one ship companies."

Interesting points of the testimony:

-The ship was not grounded, but anchored and abandoned.

-The Master, Chief and 2nd Engineer returned to the vessel when the salvage operation was commenced. This was not expected to be successful as own vessel was on a daily hire rate rather than a Lloyd's Open Form contract

-When the tow boat arrived at the place where KATINA P was located, it was observed that the hull forward of the break was upright whilst the accommodation section had a pronounced starboard list.

-The OBO tanker, which was about to perform the lightening, sank. Maybe the second engineer means OBO "ENDEAVOR II"(96000t DWT).

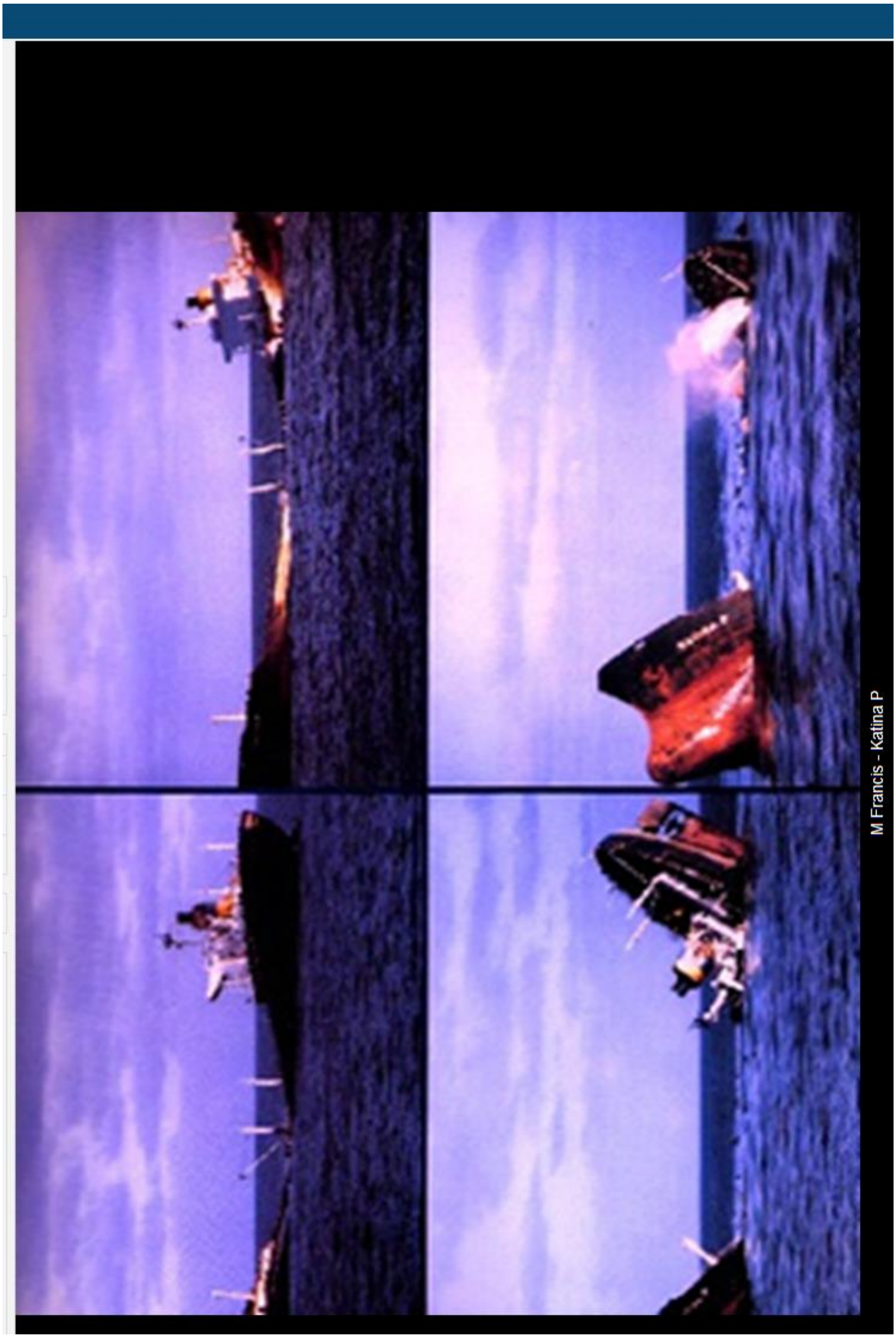


Figure 4.68. Photo taken, when KATINA P broke in two pieces.

4.7.2. Accident of "PRESTIGE"

Non DH tanker Prestige (DWT=81564t, built 1976 in Japan) sank on November 19, 2002 off the northwest coast of Spain, while having in its tanks nearly 77000t fuel oil.

Narrative

22/6/2002-30/10/2002-The ship stays in St. Petersburg, where she is used as a means of storage and transport.

30/10/2002-5/11/2002-She arrives at Latvia with tanks partly filled with FOM 100 fuel oil, except for port and starboard after wing tank 2 and port and starboard wing tank 3. The ship loads extra cargo (fuel oil) and departs for Gibraltar.

13/11/2002- After a trip, during which no problems were reported, Prestige arrives at Traffic Separation Scheme off of Cape Finistere in Spain. During the afternoon of 13th of November the ship encounters a large wave, which results in powerful slamming of the hull. Subsequently the tanker presents a heel of 20 degrees on starboard side. Furthermore the Butterworth covers of some starboard wing tanks were displaced and fuel oil flew out, while sea spray was seen coming out of starboard wing tank 3, which was empty before the accident. Captain's reaction is to fill 2 tanks (port after wing tank 2 , port wing tank 3) and so the heel is reduced to less than 5 degrees. On the same day, the whole crew except for master, chief officer and chief engineer, was transferred by helicopter off the ship.

14/11/2002- After a series of failed attempts connection was established with a tug boat by personnel, who came for this purpose on board. The captain asks permission to sail in place of refuge, a request denied by Spanish authorities, which order, that the ship should sail off the northwest coast. A Spanish surveyor, who has embarked on the ship, starts the main engine after some repairs, despite initial objections of the captain, who thought that the vibrations caused by the operation of the main engine, would result in overstressing of the hull.

15/11/2002- The captain stops the main engine. A salvation team embarks on the ship and repairs some damages (closure of some Butterworth openings) out of several observed (deck plating over starboard wing tank 3 was buckled and the most of the shell plating above the water level in way of starboard wing tank 3 was missing. Starboard after wing tank 2 and starboard wing tank 3 were open to the sea and oil flew out). The Spanish authorities reject again the request - issued this time by the head of the salvation team- to head the tanker towards the Spanish coast in order to perform a ship to ship transfer in a safe place. Instead, they suggest a ship to ship transfer near the Canary Islands. The ship is towed to a northwest direction in an effort to find more favorable weather. At noon on November 15 a sharp deterioration of weather was observed (winds of about 8-9 Beaufort). The ship is evacuated for the evening. In La Coruna the captain is interrogated, while indictments are issued against him by the Harbour Master.

[5]16-11-2002-The Salvation team returns onboard. The wind remains strong (8-9 Beaufort). Furthermore, the deck plating in the area over starboard wing tank 3 is cut off and difficulties exist as far as the connection of Prestige to the towing boats is concerned.

17-11-2002- For reasons unclear, the Spanish authorities ordered that the towing of Prestige should temporarily stop. A series of problems is observed: the winch on the starboard side presents an incline of about 20 degrees, the longitudinal bulkhead between starboard wing tank 3 and centre tank 3 is damaged and a large amount of oil has spilled into the sea.

18-11-2002-In the morning connection to an extra tug boat is achieved. The ship is now connected to 2 tugs. In the night Portuguese authorities prohibit Prestige from entering Portuguese EEZ (Exclusive Economic Zone).

19-1-2002- The ship bends and breaks in two pieces, which sink within a few hours.

Initiating event

The ship was hit by a large wave, something that caused a crack in the shell plating of starboard wing tank 3. The combination of a large wave and an empty tank revealed all the potential structural weaknesses. The increase of pressure within starboard wing tank 3, combined with the deformation, caused by the side and deck structural collapse (of the same tank), led to cracking of the bulkhead. The crack appeared between starboard wing tank 3 and starboard after wing tank 2 and led to the flooding of the second one. The ship quickly began to present heel on its starboard side. According to simulations the ship reached a heel of 10 degrees within two minutes (really fast!) [1].Finally the heel was 15-20 degrees, before the captain took action in order to reduce it.

Weather conditions

During the initial event, that led to the sinking of PRESTIGE, the significant wave height[2] was about 6 m in the area. It is possible that PRESTIGE encountered a 10m wave from tough to crest with a very steep face and a high toppling crest. Before sinking the tanker encountered also for a short period of time waves with a significant height of almost 7m.

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[1] The calculations for ship's heel are based on the scenario of the simultaneous flooding of starboard wing tank 3 and starboard after wing tank 2, which were the only completely empty storage spaces, whose flooding could lead to such a heel.

[2] Significant wave height in an area is the average height (from top to bottom) of one third of the highest waves.

Aggravating factors for structural weakness

It is not possible to determine a specific cause for the failure of the structure, which led to the flooding of two tanks. Factors, that possibly led to the initial failure of starboard wing tank3 -independently or combined-, are:

A) Damage due to contact with another vessel during ship to ship transfer of cargo: the ship served as a storage ship for over 3 months in St. Petersburg. Subsequently she was constantly very close to ships, which were coming in order to load or unload. It is possible, that damages occur to the shell plating, if relatively large ships approach and connect to the storage ship with great speed and/or at an improper angle. It is worth noting, that there was no damage reported as far as this type of accidents are concerned, during the ship's stay in St. Petersburg.

B) Fatigue: It was found that some constructional details of PRESTIGE did not meet the requirements of ABS (American Bureau of Shipping) for fatigue strength of new ships (note: it was not obligatory to meet the requirements for younger ships). It is worth noting that the methodology for fatigue strength of new ships (S-N curves[6] , developed by United Kingdom Department of Energy) had not yet been incorporated in the regulations of classification societies, when PRESTIGE was built .

C) Corrosion: This is a common problem for tankers. 18 months had passed since the last special survey, during which some parts of steel of starboard wing tank 3 were found corroded beyond acceptable levels and were replaced. The degree of corrosion, that occurred meanwhile, does not seem enough to cause tank's structural failure, also taking into consideration the existing circumstances (1. Ship's location was mainly protected areas and not open sea and thus the ship was not subjected to high loads, 2.for a long period of time the tank was empty, thus corrosion was occurring slowly)

D) Replacement of old steel with new one: The welding of new and old (and corroded) steel could create points of stress concentration at the interface between them and accelerate the corrosion rate of the old and uncoated steel. As far as the examined tank is concerned, great parts of steel were replaced during the special surveys of 1996 and 2001 (mostly reinforced frames, side longitudinals, bulkhead's plating between starboard wing tank 3 and starboard after wing tank 2)

E) Failure of the transverse bulkhead between starboard wing tank 3 and starboard after wing tank 2: There was no ballast or cargo in any of the two sides of the bulkhead. 2/3 of tank's steel was replaced in 2001, while the measurements for the remaining 1/3 were within acceptable limits. We could therefore assume, that it appears unlikely, that the bulkhead would have been largely corroded within those 18 months between the last special survey and the accident. Based on the photographic evidence transverse bulkhead's

[6] S-N curves: curves used to calculate the number of repetitions required for fatigue failure, when specific stress is applied.

failure resulted from failure of tank's shell plating, but the possibility, that a weakness of the bulkhead played a role in the cracking of the tank, could not be excluded.

Surveys and inspections

Surveys and inspections were performed in a strictly correct manner apart from some small exceptions. Typical examples are:

- IACS surveyors investigated the accident and expressed doubts about certain procedures and practices followed then by ABS (specifically: official report/documentation on board as far as ESP (Enhanced Survey Procedures) are concerned, management of ballast tanks, management of cargo, cargo tanks' hydrostatic test and official report of IOPP Certification) .

-3 wing tanks were uncoated and were corroded to some degree. If they were categorized under ballast tanks, they should have been inspected during the annual surveys.

Ship's management

Ship's management complied fully with international rules and regulations.

Table 4.74. Main particulars- further information

Shipyard built	Hitachi shipyard, Osaka, Japan
Year of build	1976
Original flag	Panama
Final flag	Bahamas
Class	ABS
Length overall	243,49 m
Length bp	232,02m
Breadth moulded	34,41m
Depth	18,7 m
Summer load draft	14,027m
Service speed(as built)	15 knots
Hull type	Single hull
Service speed(final charter)	12 knots
Propulsion	8 cylinder diesel, 14711 kW
Deadweight	81564 tonnes

Conclusions- Suggestions

-There was no loss of (human) life or serious injury, but French and Spanish coasts were seriously polluted.

-It is not possible to determine with absolute accuracy the cause of the initial failure.

-It is not sure, that structural weakness could be identified during surveys and inspections by the equipment then in use. However it is obvious, that there were sources of danger, that were not identified on time.

-It must be fully clarified, who is the decision maker, when emergencies arise, as it seems that Spanish authorities were confused during the procedures for rescuing PRESTIGE, something that caused greater problems and delays.

-A ship should not be prohibited from entering a place of refuge, if before that all the alternatives and consequences are not examined carefully. It is highly possible that the consequences, that result from a decision to prohibit a damaged ship from entering a place of refuge, are catastrophic and the example of PRESTIGE is really instructive.

-The captain was treated unfairly (imprisonment for 80 days, etc.), something not at all justified by his actions and decisions.


Narrative Prestige Report

November 13 2002 – Initial list

November 19 2002 – The final breaking up

Figure 2

The Bahamas Maritime Authority 15

Figure 4.69. Photo taken, when PRESTIGE broke in two pieces.

4.8 NASF conclusions

Below one may find the conclusions with respect to the occurrence and the consequences of NASF accidents, focusing on a variety of aspects/criteria. The structure of the below given comments follows this principle: section a) gives general comments, sections b), c) provide additional information. Section d) (focus on ship's size and hull type) is not listed here. By subdividing the data in 5 ship sizes and 2 hull type categories, the analysis sample becomes very small for reliable conclusions. Additionally, 58% of the NASF concern tankers with unknown hull types. Therefore, it becomes problematic to draw reliable conclusions, but it is possible to identify significant trends of developments.

a) Full sample

-No straightforward relationship between ship's age and NASF. 44% of NASF concerns ships older than 15 years. This indicates an expected connection between ship's age and structural problems.12% of NASF concerns young ships (till 5 years old); even more these are ships built in more recent years; this reveals possible manufacturing problems in more recent shipbuildings.

-57% of NASF took place in open sea. Despite being built to handle a wide range of weather conditions, open sea is the most dangerous event location for NASF, because of greater developed stresses compared to more protected waters. Surprisingly, a great percentage took place in terminal waters, something that could be attributed to loading mistakes, like ship being overloaded or incorrectly loaded.

- A loaded tanker is more likely to suffer a NASF in comparison to an unloaded tanker according to studied data.

-33% of NASF are weather related. It should be noted, that there was no reporting of good weather. In the rest 67% there was no weather description, maybe because it was not considered as an aggravating factor. Furthermore, bad weather conditions can reveal problems of a structure, that already presents small or big weaknesses. But weather can not affect a seaworthy, correctly designed, manufactured, operated ship, that follows all the right inspection and monitoring procedures.

-60% of NASF leads to Loss Of Watertight Integrity (LOWI), that consists an aggravating factor for ship's seaworthiness.

-35% of the accidents are characterized as serious. Out of the serious ones, 8% are considered as total losses. A growing tension can also be noted: An accident gets more easily characterized as serious over time or-to rephrase it- more rarely is an accident characterized as non serious nowadays.

-NASF frequency for the large tankers of the studied period is $4{,}124 \times 10^{-3}$ failures per shipyear. Over the last 23 years a clear tendency can be noted: The frequency decreases.

Possible factors are regulatory measures, changes in ship design and technology and overall improvement of the safety culture of maritime industry.

-At 68% of the cases the damaged ship's part was hull, 23% internal and 9% deck. One needs to use hull type and ship's size as parameters in order to draw logical conclusions.

-NASF occurred at an average age of 14,4 years. It should be noted that there are great deviations. Ship's built in the 1990's and thereafter present a very small average age of NASF occurrence (5,4 years).

-NASF do not present a great danger for life of crew. In general there were two fatalities, that happened during the same accident.($5{,}56x10^{-5}$ fatalities per shipyear). Contrariwise NASF pose a significant threat for the environment. Frequency is $1{,}1x10^{-3}$ NASF leading to (even the slightest) environmental pollution per shipyear for the large tankers of the studied period. 174039 tonnes of oil were spilled in total. Subsequently, 3 out of 39 pollution related accidents are responsible for 96% of the total environmental pollution (in tones) caused by NASF during the studied period. There are reports available for the two of them in chapter 4.7.

-shipyard(country), the tanker was built in: Some interesting data will be repeated here having the manufacturing country as parameter. a) South Korea: 26 NASF cases, 31% presented hull damage, 27% internal damage, failed at an average age of 8,5 years, built between 1974-2004. b) China: 4 cases, 3 built 2004-2006, failed at an average age of 3,25 years, all DH designs, c) Japan: 48 were built in Japan, average age of 15,8 years Unfortunately, there was no available data as far as fleet at risk by manufacturing country is concerned, and thus frequencies could not be calculated. Therefore, as the above countries are the main tanker shipbuilding countries, the outcome is not surprising.

-There seems to be no obvious relationship between flag, under which the ship was operated, and NASF. The flag states are not the ones responsible for controlling ship's seaworthiness. Their role is limited mostly to crewing issues. A relationship between NASF and ships flying a flag of convenience appears possible, but could not be proved within the frame of this thesis, as we lacked sufficient data for the fleet at risk by flag of operation. Avoiding strict regulations and hiring insufficiently skilled crew in some cases (characteristics of a flag of convenience) are negative factors for the operation of a ship, but their impact on NASF is not straightforward and obvious.

-The relationship between classification societies and ship's seaworthiness is clear, but lack of data makes it impossible to draw precise conclusions.

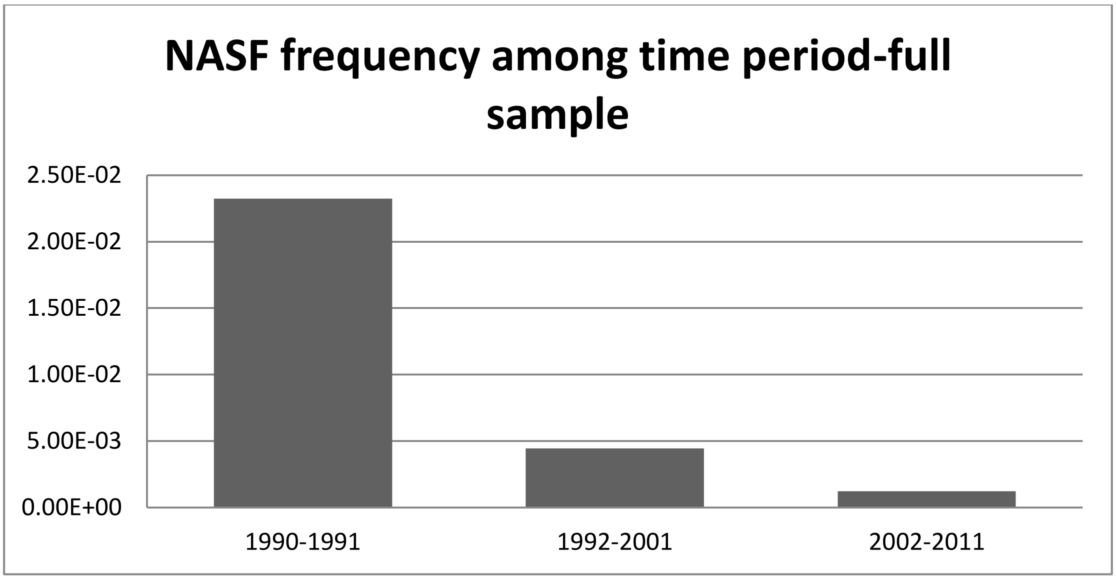

Figure 4.70. NASF frequency per shipyear, when the studied period is divided in 3 time intervals.

b) Focusing on hull type

-The average age of DH tankers, that suffered a NASF is only 6,2, small compared to 13,8 average age of NASF for non DH designs. That piece of information can be misleading. In fact the above can be partly justified, because of the fact that DH fleet is younger than non DH fleet, yet it remains problematic that so young DH tankers suffered a NASF (56%of DH accidents concerns ships till 5 years old). By studying the frequencies, the conclusion can be drawn that a non DH large tanker is more likely to suffer a NASF compared to a DH one ($2{,}37x10^{-3}$ NASF per shipyear for non DH and $1{,}16x10^{-3}$ for DH)

- Although the sample is not big, non DH ships seem to be more vulnerable to LOWI (Loss Of Watertight Integrity) than DH, a prove of superiority of DH concepts, as far as facing of LOWI is concerned. The fact, that non DH fleet is older than DH fleet is of great importance though. Average age of LOWI occurrence for DH tankers is only 4 years and for non DH ones 14,3. For DH that means mostly poor manufacturing and for non DH inadequate maintenance.

-There are no cases, in which a DH tanker broke in pieces and sank compared to 3 such cases for non DH tankers.(2 out of 3 concern PRESTIGE and KATINA P).

-There is a growing trend of characterizing more easily an accident as serious over time or-to rephrase it- more rarely is an accident characterized as non serious, if it is reported. In the period 2001-2011 only two NASF have been considered as non serious.(out of 24 in total during the same period)

- DH tankers present mostly internal structural problems, while non DH tankers present mostly hull problems. Arguments, that justify this can be found at the end of chapter 4.2.2. (key words: global stresses, maintenance, age, simplicity of design)

-There was less than 1 ton of oil spillage resulting from a DH NASF (1 case). In contrast, 16 cases of oil spillage, resulting from a non DH NASF, caused great environmental pollution. It does not go unnoticed, that tankers seem to become gradually environmentally friendlier with the introduction of DH design, although the problem is only partly solved (for example DH designs reduce environmental risk for low energy collision and groundings, but not for high energy ones. That extends beyond the limits of this thesis and will not be discussed further)

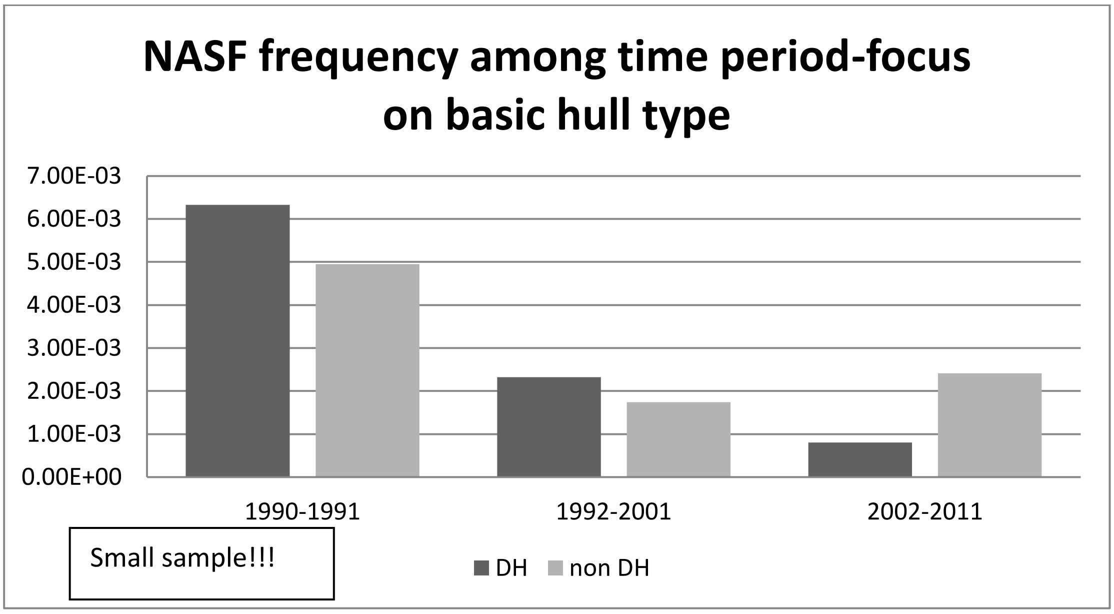

Figure 4.71. NASF frequency per shipyear, when the studied period is divided in 3 time intervals. Focus on basic hull type.

c) Focusing on ship's size

For the younger group ages the noticeable difference is to be found in the interval 5-10 years.28 % of Panamax NASF are to be found within these age limits, by far the highest compared to the other large tanker's sizes. Nevertheless, the overall results do not let us draw precise conclusions, when studied more detailed. The average ages are comparable between the 5 sizes.

-ULCC present the highest NASF frequency per shipyear, something explained partly by the very large developed stresses, when these titans travel in open sea.

-Open sea is more frequently the event location of a NASF, as the ship's size gets bigger. 74% of VLCC and 86% of ULCC NASF took place in open sea compared to 40% for Panamax and Aframax. Furthermore, the larger the ship, the more dimensional limitations it faces. Therefore, it seems logical that no ULCC NASF took place in congested waters. Lastly, as far as Panamax and Aframax are concerned, the percentages for open sea and terminal waters as event location are similar(Panamax 40% and 33%,Aframax 41% and 47% respectively).

- Panamax present LOWI at 83,3%, a percentage significantly greater, than those of the other large tanker's sizes, which vary between 50% and 58%. The causes are not clear. The small sample possibly plays a role.

-Environmental pollution in tones of spilled oil was caused at 99% by Panamax and Aframax.(Note that 3 accidents are responsible for 96% of the total environmental pollution in tones caused by NASF). Panamax (ironically) and Suezmax tankers present the lowest environmental pollution frequencies per shipyear.

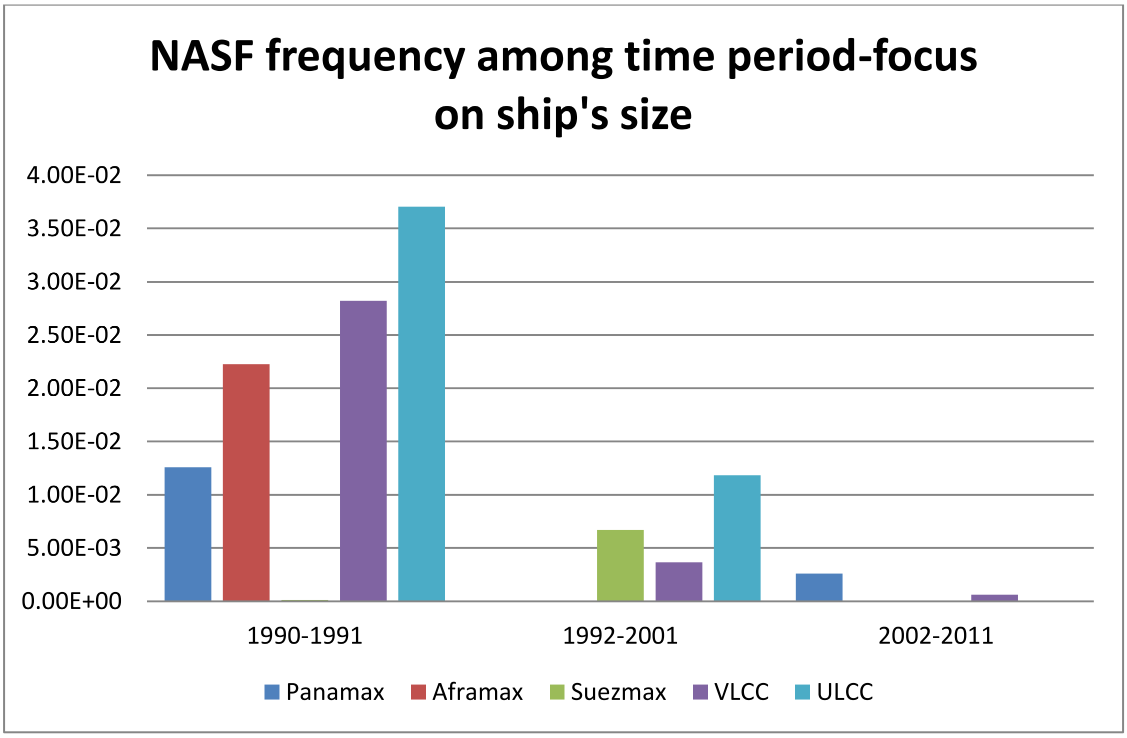

Figure 4.72. NASF frequency per shipyear, when the studied period is divided in 3 time intervals. Focus on ship's size.

After studying chapter 4.5 (Large tankers built after 1981) the following interesting finding should be mentioned:

-Non double hull large tankers are more likely about to suffer NASF and at a younger age (as far as frequencies are concerned). The first part complies with the findings for large tankers regardless of date of built. But the second part provides something new and extra proof, that maritime industry makes steps forward towards becoming safer and environmentally friendlier, as DH designs fail at an older age. Emphasis is put on the second part, because according to the previous data concerning large tankers independently of year of built, DH designs failed at a younger (average) age. That is true, when talking about average age of ships that failed, but not when taking fleet at risk by age into consideration and calculating frequencies. There are two reasons for this "contrast": a)Fleet at risk by age is not available for ships built before 1982. b) Ships built before 1982 are not included in this chapter. As already mentioned non DH fleet is older than DH fleet. So without knowing fleet at risk by age it is difficult to compare age of failure for these two different fleets. The following diagram helps explaining the above arguments in a better way.

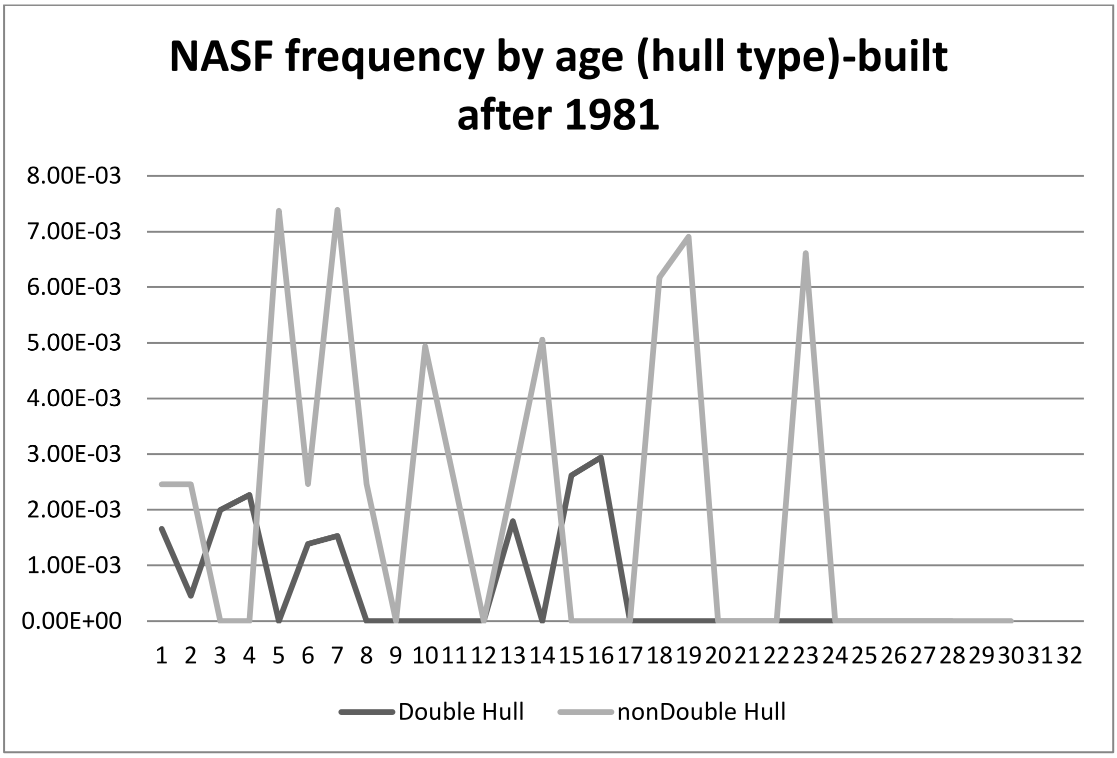

Figure 4.64. NASF frequency per shipyear by age. Tankers built after 1981. Focus on basic hull type.

<u>NOTE</u>: Figure 4.64 is presented for the second time. It can be found in chapter 4.5.

5. Analysis of Machinery Failures

Machinery failure events consist of scenarios where a technical failure of machinery or a related system affects the vessel's seaworthiness (note that, when machinery failure leads to grounding (drift grounding), it is accounted for under grounding events).

The full sample consists of 417 cases.

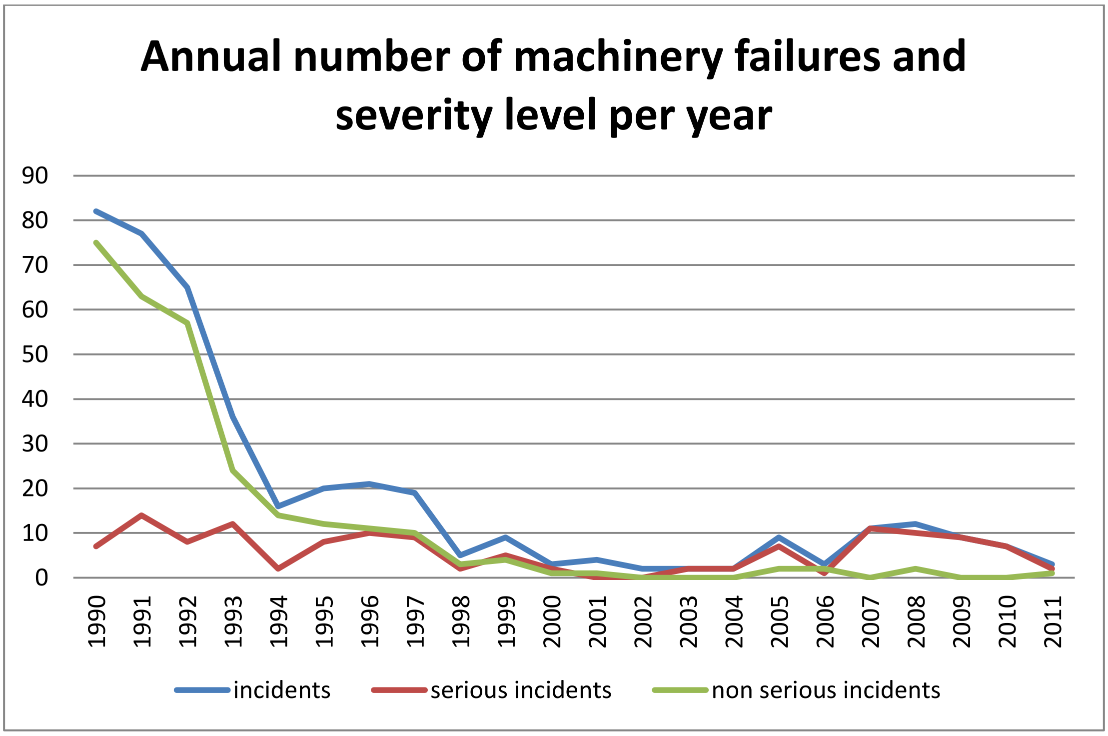

Figure 5.1. Annual number of machinery failures and severity level per year.

Studying the frequencies will let us draw more precise conclusions. At first glance, the peaks are to be noticed within the first time interval of the studied period.

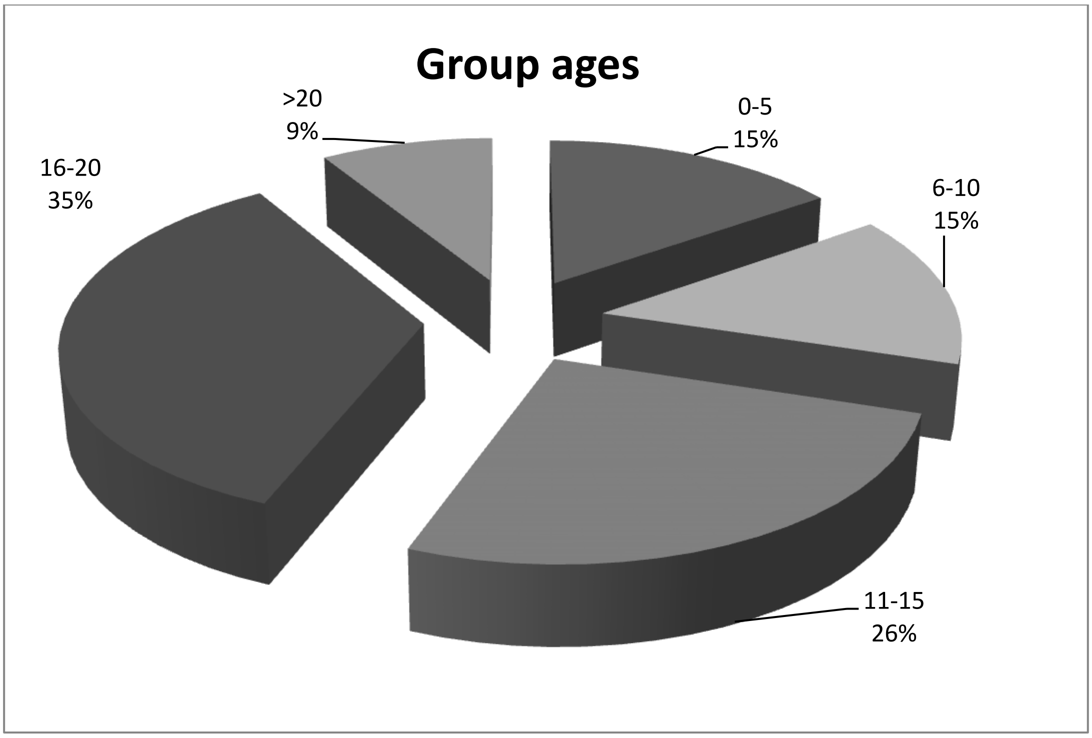

Figure 5.2. Group ages of large tankers, which suffered machinery failure.

One should focus on the fact, that 15% concern ships 5 years old or younger. That should mainly be attributed to manufacturing problems, rather than inspection issues, which become of greater importance, as the machines become older.

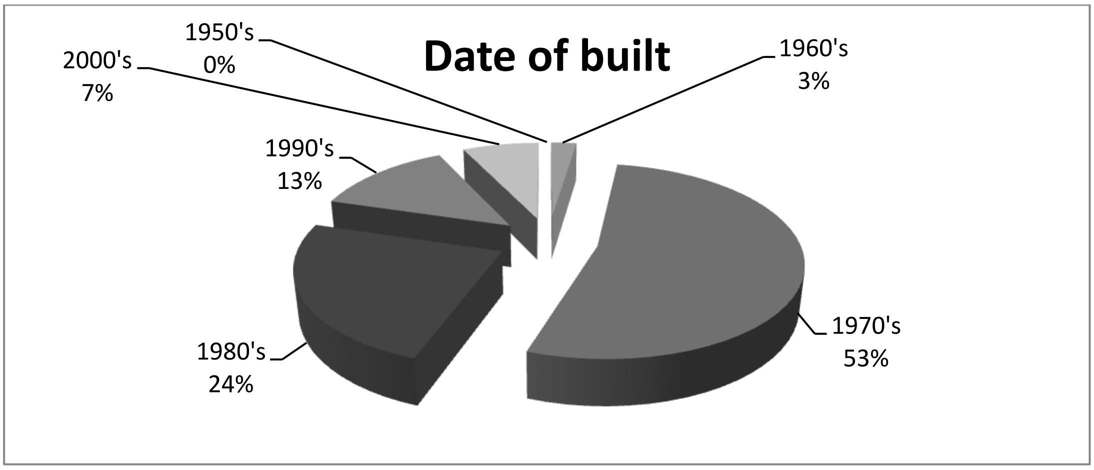

Figure 5.3. Date of built of large tankers, which suffered machinery failure.

The fact that most large tankers, that presented a machinery failure, were of relative old age(>10 years) could be possibly attributed to inadequate maintenance.

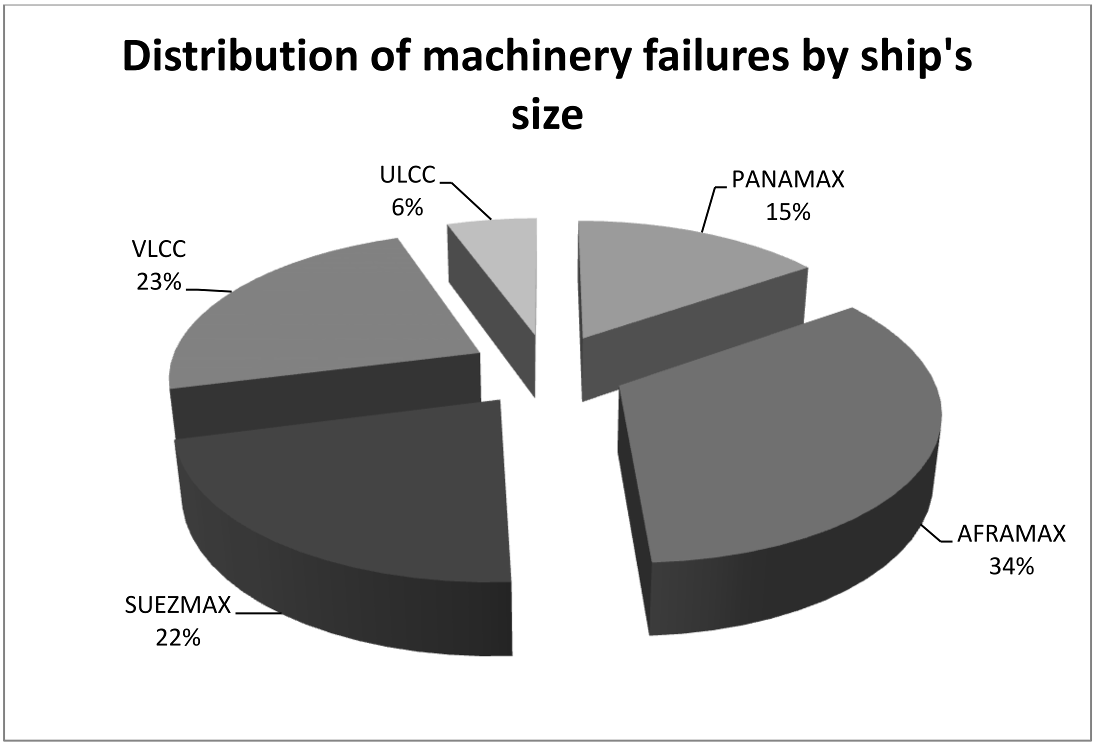

Figure 5.4. Distribution of machinery failures by ship’s size.

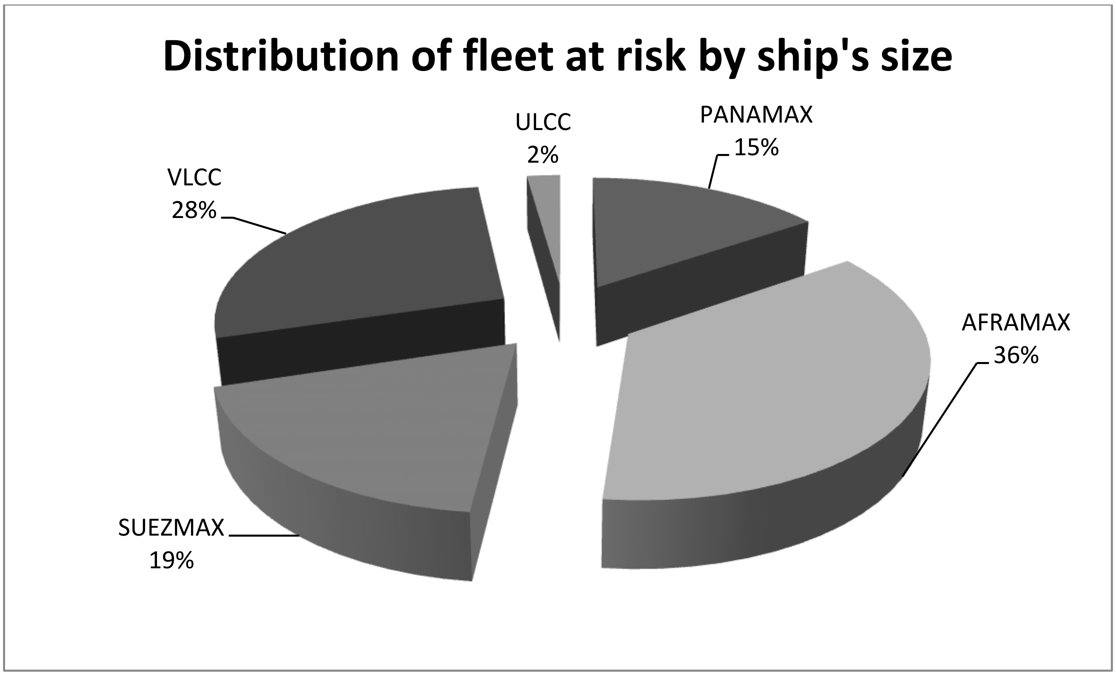

Figure 5.5. Distribution of fleet at risk by ship’s size.

Ship’s size does not seem to be an important parameter, when it comes to machinery failure.

5.1 Event location, ship operation, environment

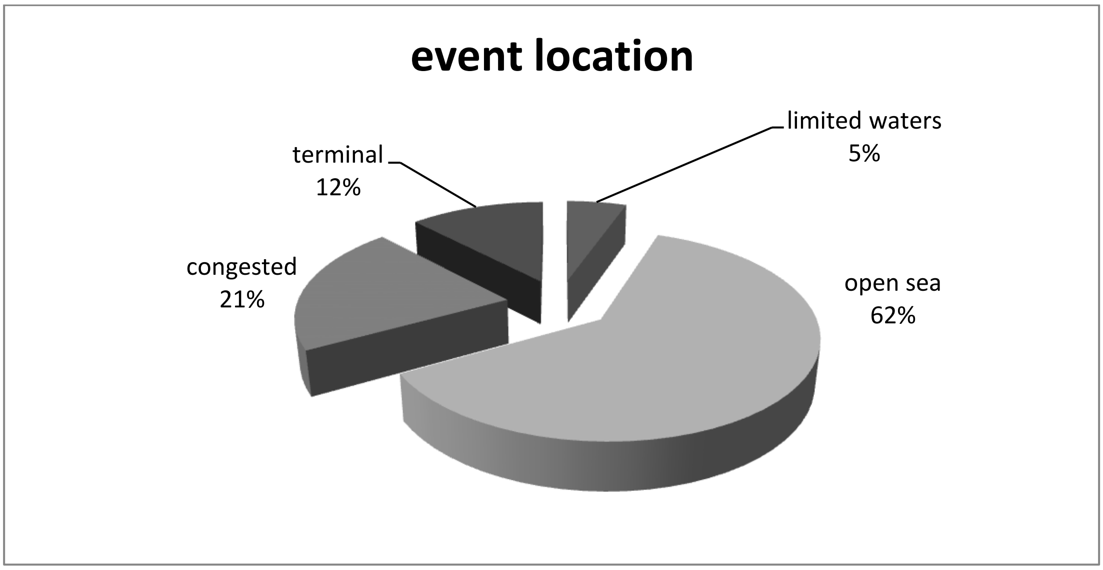

Figure 5.6. Event location. Unknown cases excluded.

Open sea it the event location mostly represented here. That is maybe because, machinery systems could be tested closely to their maximum potential in the constantly changing conditions of the open sea.

Unknown cases: 121/417 (29%)

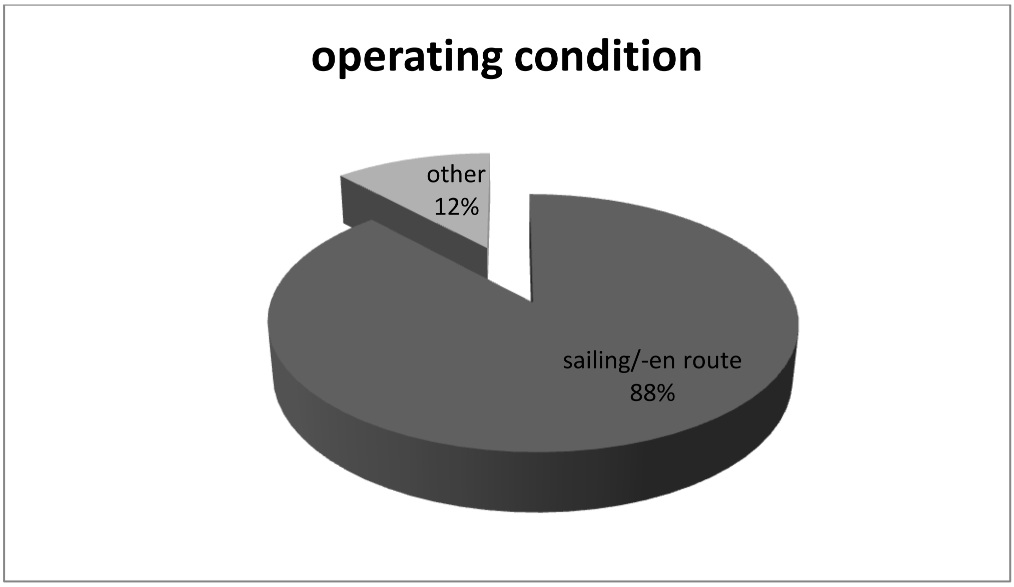

Figure 5.7. Operating condition. Unknown cases excluded.

Unknown cases: 129/417 (31%)

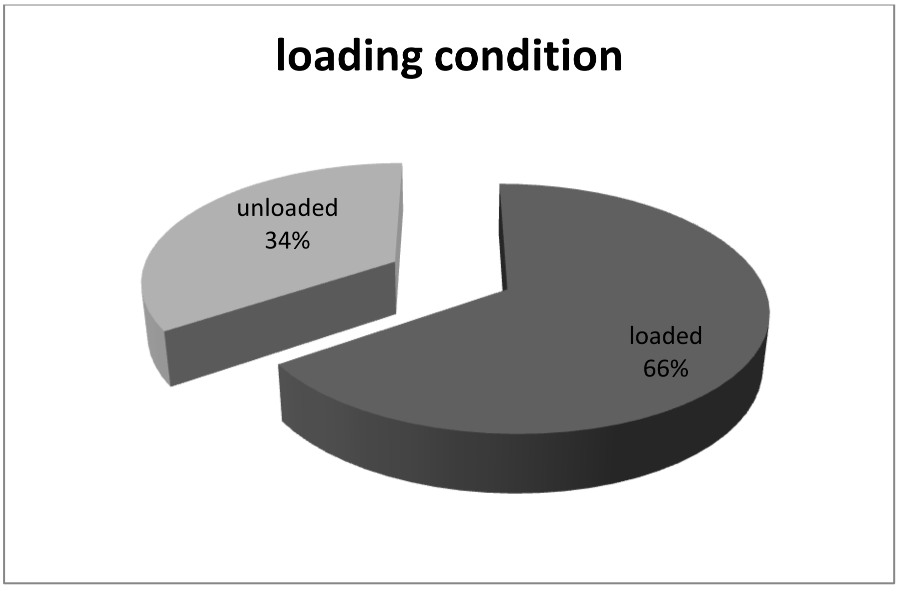

Figure 5.8. Loading condition. Unknown cases excluded.

Unknown cases: 388/417 (93%) !!! The sample in this case is relatively small and thus no safe conclusions could be drawn.

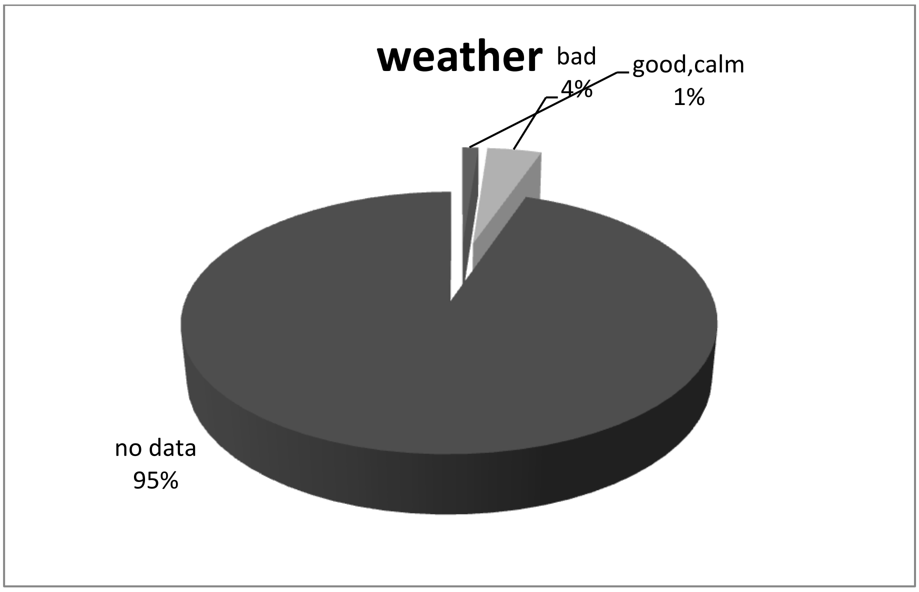

Figure 5.9. Weather.

Weather is theoretically an important parameter, because during heavy weather a machine could be tested to its “maximum potential”. Unfortunately lack of details does not allow us to draw more precise conclusions.

5.2 Outcome of event

There was no tanker, that presented machinery failure, that suffered LOWI (Loss Of Watertight Integrity) or broke in pieces. Also in all cases the tanker remained afloat.

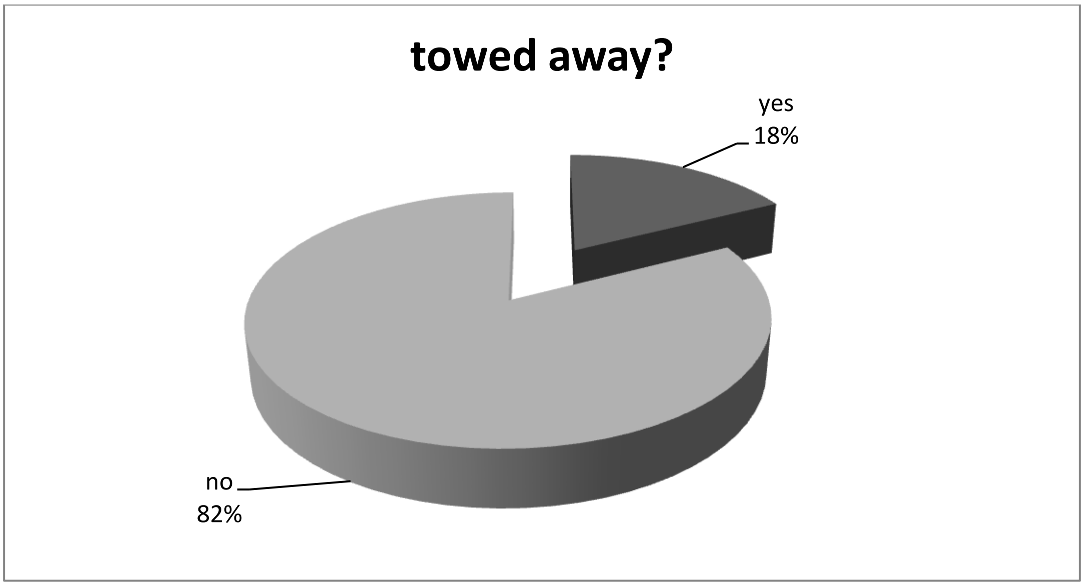

Figure 5.10. Percentage of machinery failure cases, in which the ship was towed away after the accident.

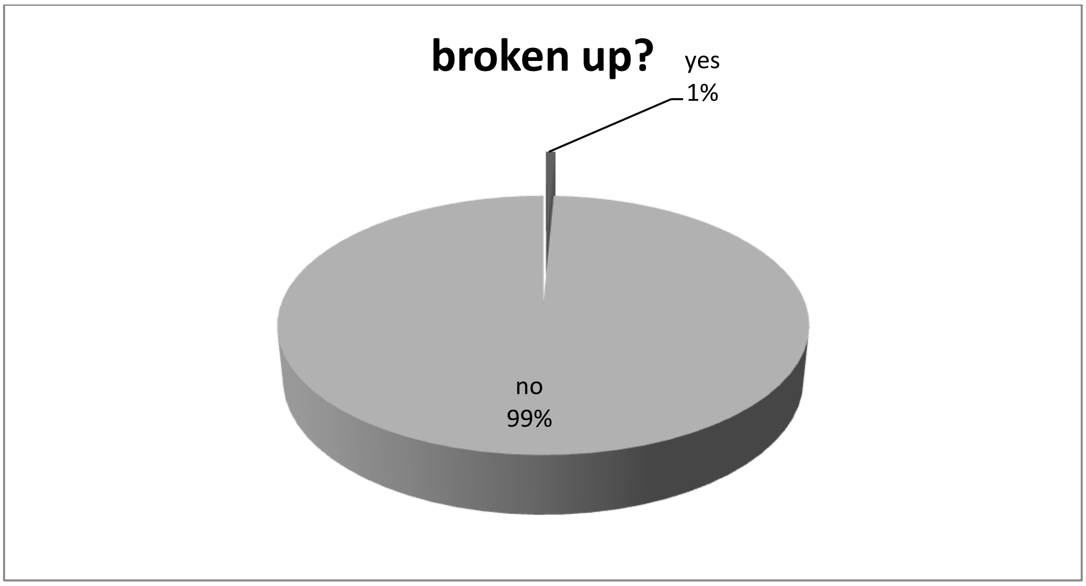

Figure 5.11. Percentage of machinery failure cases, in which the ship was broken up after the accident.

3 cases of machinery failures led to the ship being broken up afterwards, as the ships were old (>23 years old) and it was considered of no financial benefit to repair them. It is not clear in the database, but it is also possible, that the ships were any way about to get broken up.

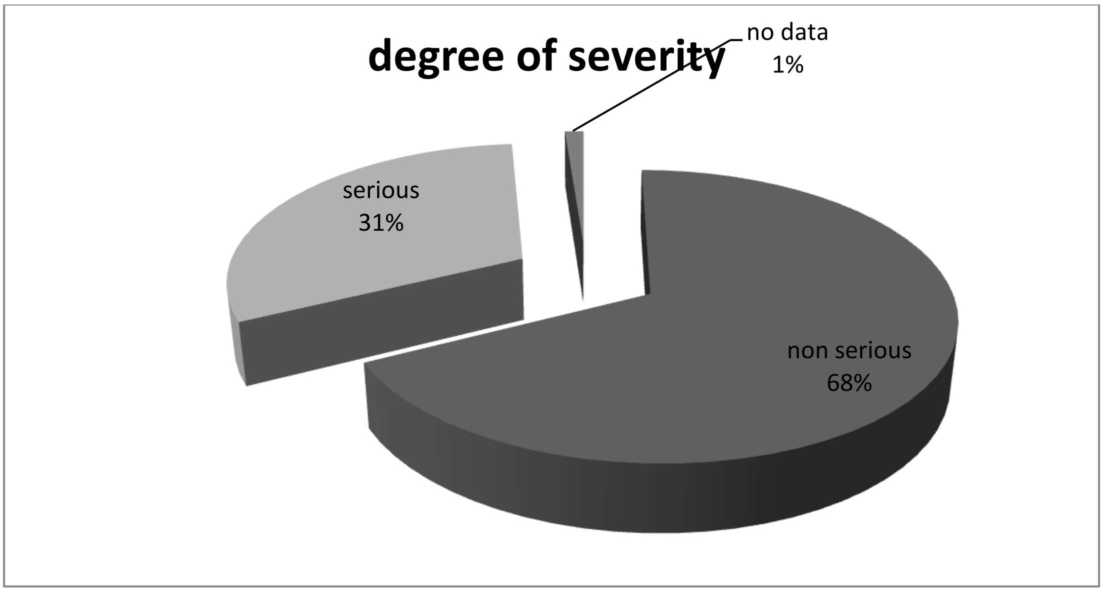

Figure 5.12. Distribution of machinery failures by degree of severity.

260 out of 417 machinery failures took place between 1990 and 1993. Studying also frequencies leads us to the conclusion, that as we go back in the studied period, accidents are mostly characterized as non serious. On the other hand, studying more recent accidents, we understand that nowadays machinery failures are mostly characterized as serious. To sum up, the above arguments mean that an accident that happened in early 90's and a similar one, that took place in the late 00's could be characterized as non serious and serious respectively, although they had similar consequences.

Table 5.1. Annual number of machinery failures and degree of severity.

year	accidents	serious	non serious
1990	82	7	75
1991	77	14	63
1992	65	8	57
1993	36	12	24
1994	16	2	14
1995	20	8	12
1996	21	10	11
1997	19	9	10
1998	5	2	3
1999	9	5	4
2000	3	2	1
2001	4	0	1
2002	2	0	0
2003	2	2	0
2004	2	2	0

2005	9	7	2
2006	3	1	2
2007	11	11	0
2008	12	10	2
2009	9	9	0
2010	7	7	0
2011	3	2	1
	417	130	282

NOTE:5 accidents are not characterized as serious or non serious.

5.3 Fatalities, injuries

There are two cases, in which human life was seriously affected:

1. A crew member was washed overboard during heavy weather (after a machinery failure) and was injured.
2. A steam pipe in the engine room burst and one crew member was killed.

The frequency per shipyear is 2 cases/35406,6 shipyears= 5,65x10^{-5} fatalities per shipyear. The frequency it to be neglected compared to frequencies of other categories of tanker's failures.

5.4 Oil spill information

Total oil spilled because of machinery failures are 1,7 t. Out of these1 ton is assumed. With a pollution frequency 8,47x10^{-5} environmental pollution cases per shipyear machinery failures do not possess a real threat against environment. In one case the origin of the pollution was a cargo tank, in the second one a fuel tank and in the last one unclear.

5.5 Shipyards, flags, classes

Table 5.2. Class, when accident occurred.

class	cases
American Bureau of Shipping	26
Bureau Veritas	11
Det Norske Veritas	25
Indian Register	3
Lloyds Register	23
Nippon Kaiji	1
South Korean Register	1
TOTAL	90

NOTE: Data available only for 90 cases

Table 5.3. Shipyard (country) of built for large tankers, that presented machinery failure.

Shipyard (country)	cases
Japan	19
Korea (South)	47
China	8
Yugoslavia	6
India	2
Sweden	1
Spain	2
Norway	0
Ukraine	3
Brazil	1
Poland	1
Russia	1
United States of America	7
TOTAL	98

NOTE: Data available only for 98 cases.

Shipyard, where the tanker was built in, seems of low importance compared to the company that manufactured a machinery system.

Table 5.4. Flag, when machinery failure occurred.

Flag			
Liberia	119	Australia	11
Greece	37	Bermuda	9
Venezuela	3	Sri Lanka	2
Singapore	12	Libya	5
Panama	45	Tuvalu	3
UAE	1	Gibraltar	1
Cyprus	17	Kuwait	11
Iran	5	Sa.	1
Belize	5	Hong Kong	2
Philippines	1	Malaysia	10
France	1	Spain	3
Italy	2	Marshall Islands	9
United States of America	2	KOREA (NORTH)	1
India	5	Saint Vincent	3
Barbados	1	Korea (South)	1
Malta	16	Japan	3
Bermuda (British)	1	Norway	2
Isle of Man (British)	2	Denmark International Register (DIS)	2
Isle of Man	1	Romania	1
Comoros	1	TAAF	1
St Kitts & Nevis	1	PORTUGAL (MAR)	1
Norwegian International Register(NIS)	24	Luxembourg	1
Bahamas	28	TOTAL	414
Yugoslavia	1		

NOTE: No data available for 3 cases.

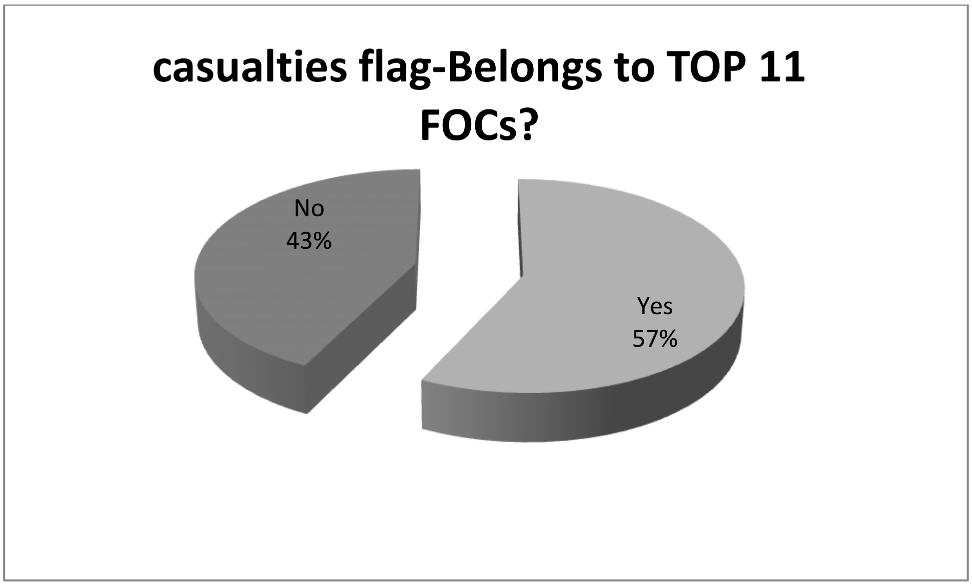

Figure 5.13. Flag, when machinery failure occurred. Does it belong to TOP 11 FOC?

TOP 11 Flags Of Convenience –according to world fleet in 2009 (merchant ships in general-not only large tankers) in DWT-are: Panama, Malta, St. Vincent, Liberia, Cyprus, France FIS, Marshall Islands, Antigua, Cayman Islands, Bahamas, Bermuda. They account for almost 55% of the entire world fleet as of 2009 (independently of ship type, DWT over 1000t) .It is worth noting that ships registered under flags of Panama, Malta, St. Vincent, Antigua, Cayman Islands, Bahamas are in US target list, as far as Port State targeting is concerned (as of 2009).

TOP 11 FOC (Flags Of Convenience) account for almost 55% of the entire world fleet. Considering the above figures, the conclusion can be drawn, that flag does not seem to play a significant role in machinery failures.

5.6 Frequencies

Table 5.5. Frequency per shipyear, number and average age of machinery failures by ship's size.

ships' size	cases	frequency	Average age of machinery failure
PANAMAX	64	1,17E-02	13,1
AFRAMAX	141	1,10E-02	12,4
SUEZMAX	91	1,38E-02	13,4
VLCC	98	1,00E-02	13,8
ULCC	23	2,97E-02	16,1
TOTAL	417	1,18E-02	13,3

We draw the conclusion, that ship's size does not affect in an obvious way machinery failures. Exception applies for ULCC and could possibly be attributed to small sample and to the fact that ULCC are older compared to the other large tanker's categories. ULCC tankers, that suffered a machinery failure were built between 1974 and 1977 (one exception, built in 1980's). Maintenance and inspection are of greater importance, as a ship gets older.

Table 5.6. Frequency of serious, non serious and in total machinery failures per shipyear.

category	Frequency per shipyear
machinery failures in total	1,17Ex10^{-2}
non serious machinery failures	7,96Ex10^{-3}
serious mach. failures	3,67Ex10^{-3}

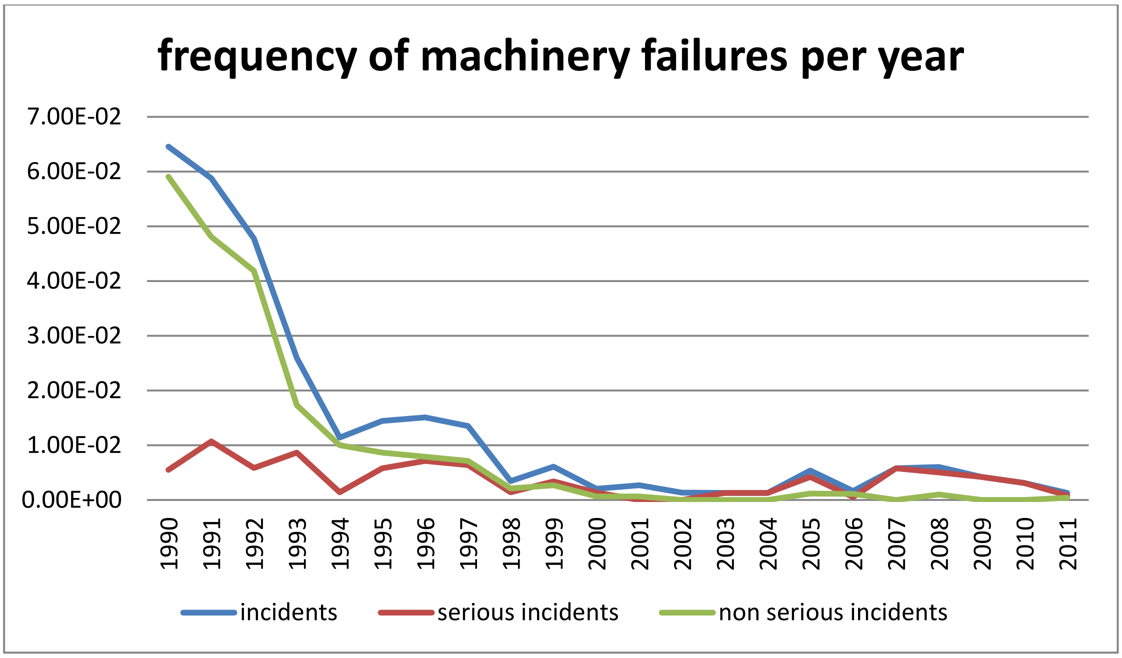

Figure 5.14. Frequency of machinery failures per shipyear and severity level.

The peaks and thus the worst situation for machinery failures is to be found within the first years of the 1990's. From then on, machinery failures are less and less frequent, as the years go by. There is a tendency for deterioration from 2007 on, but it can be considered as negligable. The picture is clear and more positive, as time goes by.

The fact, that failures tend to be characterized mostly as serious, as time goes by, could be confirmed again. At first it was noticed, while studying Non Accidental Structural Failures (NASF).

The very high frequencies, that can be observed between 1990 and 1992 could not be fully explained. It is amazing though, that 224 out of 417 machinery failures in total for the studied period took place within this relatively small interval! Here is some data regarding these 224 cases:

- In general the average age of failure is 14 years. 12.9 % are characterized as serious.
- When taking ship's size into account: a) Panamax: 34/224, average age of 13.2 years and 9% serious.. b) Aframax: 74/225, average age of 12.8 years and 12% serious. c) Suezmax: 43/224, average age of 14.9 years and 14% serious. d)VLCC: 56/224, average age of 14.8 years and 12.5% serious. e) ULCC: 17/224, average age of 15.4 years and 24% serious.

5.7 Large tankers built after 1981

This chapter is in fact a subchapter that could be included in the chapters above. As far as fleet at risk by age is concerned, there is data available only for large tankers built after 1981. The thesis in general concerns large tankers regardless of date of built. Therefore and in order to avoid misconceptions, some extra data is provided for large tankers built after 1981 in this separate chapter. Fleet at risk by age, as mentioned in chapter 3 was provided by Germanischer Llloyd.

In total there are 141 cases that large tankers built after 1981 presented a machinery failure.

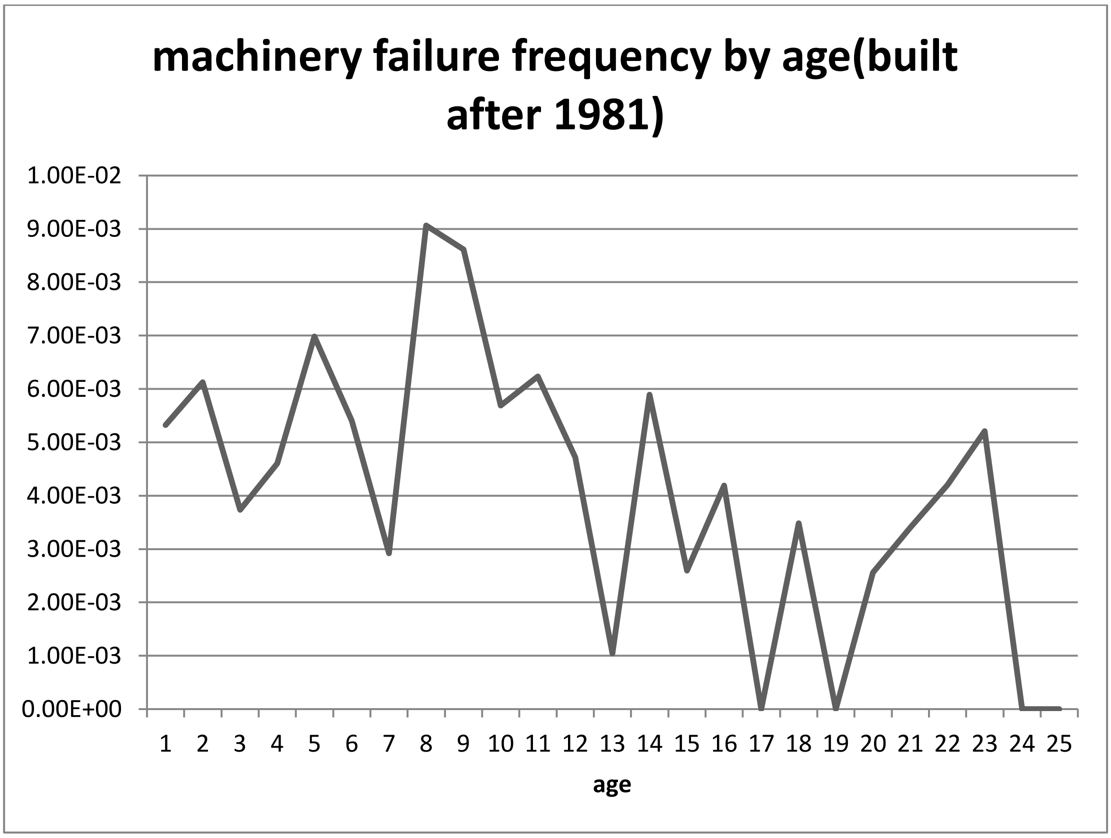

Figure 5.15. Frequency of machinery failures per shipyear by age. Large tankers built after 1981.

Surprisingly, the greatest frequencies are to be seen at a young rather than at old age. That should be attributes mainly to bad manufacturing of the machinery systems and also operating of the ship. Maintenance is also an important parameter, but could not be considered as a main cause, because maintenance becomes more important as ships become older and older ships present lower frequencies of machinery failures.

Table 5.7. Number of machinery failures by age. Ships built after 1981.

ship's age	Machinery failure cases
1	15
2	16
3	9
4	10
5	14
6	10
7	5
8	14
9	12
10	7
11	7
12	5
13	1
14	5
15	2
16	3
17	0
18	2
19	0
20	1
21	1
22	1
23	1
24	0
25	0
TOTAL	141

5.8 Machinery failures categorization

After studying NTUA-SDL database the target was to categorize somehow the different machinery failures of the database. At first, the idea was to focus on the causes of the machinery failures. Unfortunately, that was not possible for two reasons:1) The database rather describes what failed than analyzing the reasons. That is only rarely here the case.2) Ship’s machinery does not consist of independent pieces of equipment, but at a great percentage of codependent systems and machines.

As a result the final decision was to make a categorization that answers to the question “What did break down?” or “Where did the failure occur?”. There were 3 categorizations available:

1. One developed after reading the database, without including the machinery systems and equipment that were not mentioned in the studied database. There are 6 basic categories namely “main engine”, ”shaft and propeller”, “steering gear”, “inert gas system”, “auxiliary and emergency systems and machines” and “insufficiently reported”.
2. One I found during my stay at Germanischer Lloyd headquarters in Hamburg and is the one used by surveyors of GL.(“Tables Equipment System Surveys-SIS”).
3. SFI by SpecTec. SFI group system is a functional oriented classification system for subdivision of ship technical and economic information. SFI uses a 3 digit code, that breaks the ship into functions, systems and subsystems.

Finally, I worked with the SFI-categorization, which is really clear and functional. The basic categories remained the same and after some alterations the result is this:

Table 5.8. Main and subcategories of machinery failure categorization.

Main categories	**1) Machinery main components**	**2) Systems for machinery main components**	**3) Ship common systems**
Sub categories	1. Diesel engines for propulsion	1. Fuel systems	1. Ballast and bilge systems, gutter pipes outside accommodation
	2. Steam machinery for propulsion	2. Lube oil systems	2. Fire& lifeboat alarm, fire fighting &wash down systems
	3. Other types of propulsion machinery	3. Cooling systems	3. Air &sounding systems from tanks to deck
	4. Propellers, transmissions, foils	4. Compressed air systems	4. Special common hydraulic oil systems
	5. Boilers, steam and gas generators	5. Exhaust systems and air Intakes	5. Central heat transfer systems w/chemical fluids/oil
	6. Motor aggregates for main electric power production	6. Steam condensate and feed water systems	6. Common electric and electronic systems
	7. Other aggregates and generators for main and emergency electric power production	7. Distilled and make-up water systems	7. Electric power supply
	8. Nuclear reactor plants	8. Automation systems for machinery	8. Common electric distribution systems

			9. Electric cable installation
			10. Electric consumer systems

4) Ship equipment	**5) Equipment for cargo**	**6) Insufficiently reported**
1. Maneuvering machinery and equipment	1. Loading/discharging systems for liquid cargo	
2. Navigation & searching equipment	2 .Freezing, refrigerating and heating systems for cargo	
3. Communication equipment	3. Gas ventilation systems for cargo holds/tanks	
4. Repairing/ maintenance/cleaning/ equipment workshop/store outfit, name plates	4. Auxiliary systems &equipment for cargo	

Below are the components of each subcategory, so that it becomes clear which machinery systems are included in each category and subcategory:

1) Machinery main components

1. Diesel engines for propulsion →a) diesel engines.

2. Steam machinery for propulsion→ a) steam turbines/condensers, b) high pressure turbines, c) medium and low pressure turbines, d) main condensers, e) steam engines with condensers.

3. Other types of propulsion machinery → a) gas turbines/air preheaters, b) electric generator / electric motor plants, c) fan plants, waterjet pump plants with nozzles, d) special propulsion aggregates.

4.Propellers, transmissions, foils → a) fixed propeller plants including nozzles, b) main shaft brake, c) controllable pitch propeller, plants including nozzles, d) special propellers plants including nozzles (excluding side thrusters), e)spare propellers, f) main reduction gears with thrust bearings and couplings, g) central gears (joint auxiliary gear, not for propulsion), h) foils, sails with mast and rigging.

5.Boilers,steam and gas generators→a) main boilers, b) auxiliary boilers, c) exhaust gas boilers, d) steam converters, e) control heating and thermal oil boilers, f) gas generators.

6. Motor aggregates for main electric power production→a) motor aggregates

7.Other aggregates and generators for main and emergency electric power production→a) steam turbo aggregates, b) gas turbo aggregates, c) harbour and emergency aggregates with equipment, d) shaft generators, e) generators with hydraulic drive.

8.Nuclear reactor plants.

2) Systems for machinery main components

1. Fuel systems→ a) fuel oil transfer and drain systems, b) fuel oil purification plants, c) fuel oil supply systems, d) heating coils in fuel oil tanks, e) gas fuel systems, f)solid fuel systems (e.g. coal).

2. Lube oil systems→a) lube oil transfer and drain systems, b) lube oil purification plants, c) lube oil systems for propulsion, machinery and transmissions, d) lube oil systems for motor/turbo aggregates, e) lube oil systems for gas generators, common lub oil systems for other machinery.

3. Cooling systems→a) sea water cooling systems, b) fresh water and other cooling systems.

4.Compressed air systems→ a) starting air systems (high pressure),b)general purpose air systems for E/R (low pressure),c) general purpose air systems for deck (low pressure),d) instrument air supply systems.

5. Exhaust systems and air intakes→a) fresh air intakes(not ventilation),b) exhaust gas systems for propulsion machinery, c) exhaust gas systems for motor aggregates, d) exhaust gas system for boilers, e) ash/slag handling systems.

6. Steam condensate and feed water systems→ a) primary full pressure steam systems, b) primary reduced pressure steam systems in E/R, c) primary reduced pressure systems outside E/R, d) primary drain blowoff, exhaling steam and dearation system in E/R, e) primary condensate systems, f) primary feed water systems, g) secondary steam systems in E/R, h) secondary steam systems outside E/R, i) secondary condensate and feed water systems.

7. Distilled and make-up water systems→a) freshwater production system, b) technical freshwater system.

8. Automation systems for machinery →a) maneuvering consoles, main consoles, b) common automation equipment, E/R alarm systems, c) automation equipment for propellers machinery and transmission, eng. telegraph, d) automation equipment for boilers, e) automation equipment for motor/ turbo aggregates, f) automation equipment for nuclear reactor plants, g) automation equipment for other machinery components, h) cables/ loads and piping for automation systems for machinery.

3) Ship common systems

1. Ballast and bilge systems, gutter pipes outside accommodation →a) ballast systems, solid ballast, b) heating coils in ballast tanks, c) bilge systems, d) gutter pipes outside accommodation, e) drainage from indoor cargo holds, f) condensate drain system, g) drainage from technical spaces.

2. Fire& lifeboat alarm, fire fighting & washing down systems→a) fire detection, fire &lifeboat alarm systems, b) emergency shutdown system, c) fire/wash down system, emergency fire pumps, sprinkler system, d) fire fighting systems for external fires, e) fire fighting systems with gas (CO2,halon, etc), f) fire fighting systems with foam, g) fire fighting systems with steam and water spraying, h) fire fighting systems with powder, i) no pressurized deluge system or fire fighting with other means.

3. Air & sounding systems from tanks to deck→a) bleed and overflow pipe systems, b) manual sounding system, c) automatic/remote sounding system.

4. Special common hydraulic oil systems→a)special common hydraulic oil systems.

5. Central heat transfer systems with chemical fluids/oil→a) heating oil treatment systems, b) heating oil distribution systems for E/R, c) heating oil distribution outside E/R.

6. Common electric and electronic systems→a) common computer systems.

7. Electric power supply→a) (generators/alternators), b) transformers, c) batteries and chargers, d) rectifiers& converters, e) electric shore supply systems.

8. Common electric distribution systems →a) main switchboards, b) emergency switchboards, c) group starters, d) local starters, e) distribution panels &boards.

9. Electric cable installation→a)cable trays & installation in engine & boiler rooms, b)cable trays with installation in accommodation, c)cable trays &installation on deck & in cargo holds, d)special cables.

10. Electric consumer systems→a)electric lighting systems for engine & boiler room, b)electric lighting systems for accommodation, c)electric lightning systems for deck and cargo holds, d)electric fans, e)elektriske motorer.

4) Ship equipment

1.Manoeuvering machinery &equipment→ a) rudder with welded parts, b) rudder carriers, rudder stocks, rudder bearings, c) steering gear/ columns, telemotor systems, rudder indicators, emergency st, d) side thrusters, e) stabilizers, f) brakes, g) bubble plants, h) dynamic positioning systems.

2. Navigation& searching equipment→a) radar plants, b) GPS, DECCA, LORAN, OMEGA, radio direction finder- equipment, c) gyro plants, autopilots, compasses, d) underwater searching

equipment, e) navigation TV, f) nautical utility equip, clockworks, weather facsimile g) radar, signal, observation and antenna masts, h) integrated navigation systems.

3. Communication equipment→a)radio plant, GMDSS, b)lifeboat radio transmitters, EPIRBS, c)data transmission plants, communication, d) VHF/UHF telephones, e)calling/command/crew call telephone plants, walkie-talkies, f)speaking tubes, tube post plants, g)light & signal equipment, lanterns, typhoons.

4.Repairing/ maintenance/ cleaning equipment workshop/store outfit ,name plates →a) machine tools, cutting & welding equipment, b) tools/ equipment for engineers, electr., boatswains, carpenters, c) painting equipment, scaffolding, paint rafts/boats (gigs), d) cleaning equipment, garbage chutes, e) garbage disposal plants, incinerators, f) outfitting in store rooms and workshops, g) clamps/foundations for spare parts, h) name plates/marking on machinery, equipment, pipes, cables.

5) Equipment for cargo

1. Loading/discharging systems for liquid cargo→a) loading/discharging pumps, b) loading/discharging systems on deck, c) loading/discharging systems in pump rooms, d) loading/discharging systems in cargo tanks, e) loading/discharging systems for lpg/ lng in gaseous phase ,f) separate stripping systems, g) mud systems with pumps, piping, h) submerged turret loading system, STL, i) bow loading system(BLS).

2. Freezing refrigerating & heating systems for cargo→a) insulation & sheathing of cargo holds/tanks, b) freezing &refrigerating systems for dry cargo, c) direct cooling systems for liquid cargo, d) cascade cooling systems for liquid cargo, e) indirect cooling/heating systems, cargo oil heating.

3. Gas/ventilation systems for cargo holds/tanks→a)ventilation systems for refrigerated cargo holds, b)closed ventilation/return vapour systems for cargo holds, c)open ventilation systems for cargo holds, d)ventilation/gas freeing systems for tanks, wind sails with equipment, e) blow-off system from safety valves(pressure/vacuum valves), f)inert gas systems with conditioning plant.

4. Auxiliary systems & equipment for cargo →a) sounding, surveillance & operating equipment for cargo systems, b) tank cleaning systems & equipment, c) separate cooling water systems for cargo equipment, d) insulation drying system for cargo holds/tanks, e) equipment for addition of preservatives, inhibitors, spirits, f) special structures for loading/discharging over stern/stem.

6) Insufficiently reported

Cases that are not easily categorized, because of lack/ insufficiency of data.

417 cases where studied. Some cases were categorized in more than one categories, because in these cases more than one pieces of equipment/systems presented a failure.

Below stand the cases for each category and subcategory as absolute numbers and as percentages:

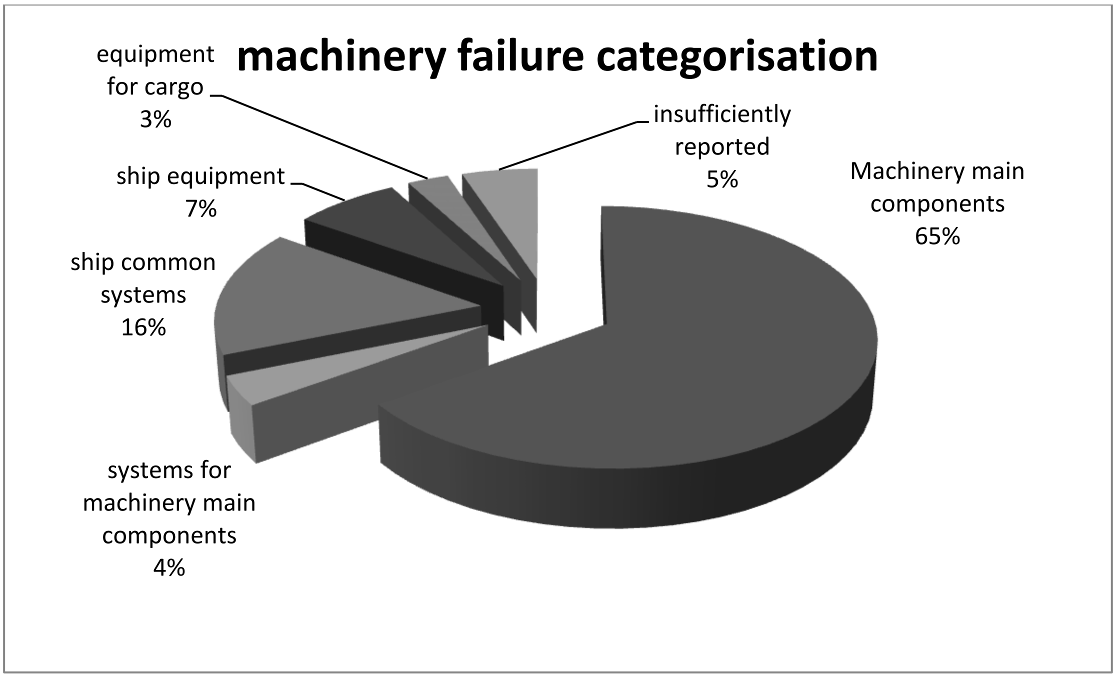

Figure 5.16. Main machinery failure categories. Distribution by machinery system, that failed.

Table 5.9. Main machinery failure categories. Distribution by machinery system, that failed.

	category	cases	percentage
1	Machinery main components	278	65%
2	Systems for machinery main components	16	4%
3	Ship common systems	68	16%
4	Ship equipment	31	7%
5	Equipment for cargo	12	3%
6	Insufficiently reported	22	5%
	TOTAL	427	100%

Table 5.10.a. Machinery main components (1st category)

1	**Machinery main components**	cases	percentage
1.1	Diesel engines for propulsion	156	56%
1.2	Steam machinery for propulsion	10	4%
1.3	Other types of propulsion machinery	1	0%
1.4	Propellers, transmissions, foils	38	14%
1.5	Boilers, steam and gas generators	53	19%
1.6	Motor aggregates for main electric power production	-	-
1.7	Other aggregates and generators for main and emergency electric power production	14	5%
1.8	Nuclear reactor plants	-	-
1.9	Without subcategory(no further categorization possible)	6	2%
	TOTAL	278	100%

Table 5.10.b. Systems for machinery main components (2nd category)

2	**systems for machinery main components**	cases	percentage
2.1	Fuel systems	5	31%
2.2	Lube oil systems	1	6,3%
2.3	Cooling systems	4	25%
2.4	Compressed air systems	1	6,3%
2.5	Exhaust systems and air Intakes	-	-
2.6	Steam condensate and feed water systems	4	25%
2.7	Distilled and make-up water systems	-	-
2.8	Automation systems for machinery	-	-
2.9	Without subcategory (no further categorization possible)	1	6,3%
	TOTAL	16	100%

Table 5.10.c. Ship common systems (3rd category)

3	ship common systems	cases	percentage
3.1	Ballast and bilge systems, gutter pipes outside accommodation	1	1,5%
3.2	Fire& lifeboat alarm, fire fighting &wash down systems	1	1,5%
3.3	Air &sounding systems from tanks to deck	-	-
3.4	Special common hydraulic oil systems	-	-
3.5	Central heat transfer systems with chemical fluids/oil	-	-
3.6	Common electric and electronic systems	-	-
3.7	Electric power supply	65	95,5%
3.8	Common electric distribution systems	1	1,5%
3.9	Electric cable installation	-	-
3.10	Electric consumer systems	-	-
3.11	Without subcategory (no further categorization possible)	-	-
	TOTAL	68	100%

Table 5.10.d. Ship equipment (4th category)

4	ship equipment	cases	percentage
4.1	Maneuvering machinery and equipment	31	100%
4.2	Navigation & searching equipment	-	
4.3	Communication equipment	-	
4.4	Repairing/maintennce/cleaning/ Equipment workshop/store outfit, name plates	-	
4.5	Without subcategory(no further categorization possible)	-	
	TOTAL	31	100%

Table 5.10.e. Equipment for cargo(5th category)

5	**equipment for cargo**	cases	percentage
5.1	Loading/discharging systems for liquid cargo	7	58%
5.2	Freezing, refrigerating and heating systems for cargo	-	-
5.3	Gas ventilation systems for cargo holds/tanks	5	42%
5.4	Auxiliary systems &equipment for cargo	-	-
5.5	Without subcategory (no further categorization possible)	-	-
	TOTAL	12	100%

Comments

-Typical descriptions in the NTUA/SDL database of cases characterized as “insufficiently reported” are:”minor repairs”, ”cylinder pipe out of order”, ”adrift”, ”machinery trouble”, ”machinery trouble and adrift”, ”mechanical problems”, “broke down on numerous occasions”, “repairs to machinery to heat the fuel”, “hydraulic pump”.

-The greatest of percentage concerns main engine problems. One should keep in mind that maybe a lot of these 156 cases concern a machinery main component and not necessarily the main engine itself. The vast percentage of the database descriptions are really short and lack details.

-The ship’s machinery systems that present the most of the failures are: main and auxiliary engines, propellers and transmission mechanisms-gears, boilers, generators, alternators, rudders and steering gear.

5.9 Conclusions-machinery failures

-The most possible scenario of a large tanker's machinery failure is this one: A ship is en route in open sea and its main engine presents a failure. The age of this hypothetical ship is 15-20 years old, when "Group ages of large tankers, which suffered machinery failure" (figure 5.2-independently of year of built) is studied and rather young (<10 years), when "Frequency of machinery failures per shipyear by age" (figure 5.15-built after 1981) is taken into consideration.

-Machinery failures, that did not lead to another accident category (collision, contact, grounding) are the category of tanker's failures with the least social interest, because they do not seem to possess a real threat against human life and environment. Machinery failures affect mostly financial interests, because their usual consequence is the delay of the transportation of the cargo. For example a main engine fails and 3-4 days are required in order to be fixed.

-Ship's size does not seem to play a role. Exception applies for ULCC and could possibly be attributed to small sample and to the fact that ULCC are older compared to the other large tanker's categories. Maintenance and inspection are of greater importance, as a ship gets older.

-Of little importance seem to be shipyard, where the ship was built and flag. Class maybe plays a role, because they are the ones in charge of inspecting the different machinery systems. To sum up, manufacturers, operators and inspectors of a machine are the ones responsible for the quality and maintenance of a machine. Manufacturers are the company, where the machine was built, operators are the crew and inspectors are the classification society and the ones who were sent by the ship's ownership to attend and inspect during the building procedures. Lastly, even if ship's size does play a role, it is difficult to assume that for instance a boiler failure could be attributed to the ship's size. Manufacturing and inspection seem of greater importance.

-There is no real evidence that weather is important. Nevertheless, most of the machinery failures occurred, while the ship was en route in open sea, thus operating condition and location as parameters should not be neglected.

-To find out the causes of machinery failures seems difficult, because ship's machinery consists of codependent rather than individual systems.

-After studying the sample for large tankers built after 1981, the surprising conclusion can be drawn, the greatest machinery failure frequencies are to be seen at a young rather than at old age (see figure 5.15). That should be attributes mainly to bad manufacturing of the machinery systems and also operating of the ship. Maintenance is also an important parameter, but could not be considered as a main cause, because maintenance becomes more important as ships become older and older ships present lower frequencies of machinery failure.

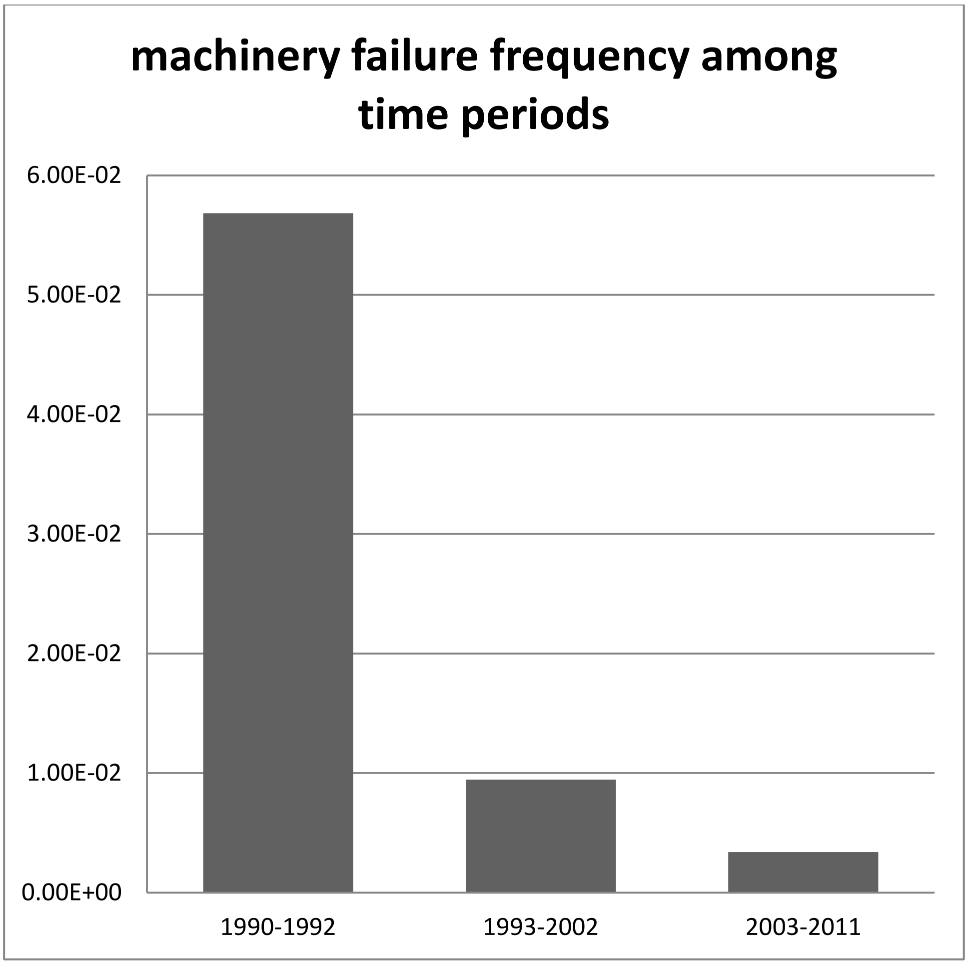

Figure 5.17. Machinery failure frequency per shipyear, when the studied period is divided in 3 time intervals. Independently of year of built.

Frequencies of machinery failures for large tanker ships independently of year of built are shown in Fig. 5.17. A significant drop of failure frequencies after 1992 is observed. This may be attributed to

- improvements of technology, training and maintenance procedures
- gradual phase out of older tankers.

6 Conclusions-The way ahead

No straightforward relationship between ship's age and ***NASF*** was observed. 44% of NASF concerns ships older than 15 years. This indicates an expected connection between ship's age and structural problems.12% of NASF concerns young ships (till 5 years old).Even more these are ships built in more recent years; this reveals possible manufacturing problems in more recent shipbuildings. NASF occurred at an average age of 14,4 years. It should be noted that there are great deviations. Ship's built in the 1990's and thereafter present a very small average age of NASF occurrence (5,4 years). The average age of DH tankers, that suffered a NASF is only 6,2, small compared to 13,8 average age of NASF for non DH designs. That piece of information can be misleading, because DH fleet is younger than non DH fleet, yet it remains problematic that so young DH tankers suffered a NASF (56% of DH accidents concerns ships till 5 years old). By studying the frequencies, the conclusion can be drawn that a non DH large tanker is more likely to suffer a NASF compared to a DH one ($2,37x10^{-3}$ NASF per shipyear for non DH and $1,16x10^{-3}$ for DH). When focusing on ship's size the noticeable difference is to be found in the interval 5-10 years.28 % of Panamax NASF are to be found within these age limits, by far the highest compared to the other large tanker's sizes. The average ages of NASF occurrence are comparable between the 5 tanker sizes.

NASF frequency for the large tankers of the studied period is $4,124x10^{-3}$ failures per shipyear. Over the last 23 years the frequency decreases. Possible factors are regulatory measures, changes in ship design and technology and overall improvement of the safety culture of maritime industry. ULCC present the highest NASF frequency per shipyear, something explained partly by the very large developed stresses, when these titans travel in open sea.

After studying the available data for large tankers built after 1981 the conclusion has been drawn that non double hull large tankers are more likely about to suffer NASF and at a younger age (as far as frequencies are concerned). The first part complies with the findings for large tankers regardless of date of built. But the second part provides something new and extra proof, that maritime industry makes steps forward towards becoming safer and environmentally friendlier, as DH designs fail at an older age.

An accident gets more easily characterized as serious over time or-to rephrase it- more rarely is a reported accident characterized as non serious nowadays.

57% of NASF took place in open sea. Surprisingly, a great percentage took place in terminal waters, something that could be attributed to loading mistakes, like ship being overloaded or incorrectly loaded. Open sea is more frequently the event location of a NASF, as the ship's size gets bigger.

A loaded tanker is more likely to suffer a NASF in comparison to an unloaded tanker.

33% of NASF are weather related, although weather can not affect a seaworthy, correctly designed, manufactured, operated ship, that follows all the right inspection and monitoring procedures.

60% of NASF leads to Loss Of Watertight Integrity (LOWI). Panamax present LOWI at 83,3%, a percentage significantly greater, than those of the other large tanker's sizes, which vary between 50% and 58%. Non DH ships seem to be more vulnerable to LOWI than DH. The fact, that non DH fleet is older than DH fleet is of great importance though. Average age of LOWI occurrence for DH tankers is only 4 years and for non DH ones 14,3. For DH that means mostly poor manufacturing and for non DH inadequate maintenance.

At 68% of the cases the damaged ship's part was hull, 23% internal and 9% deck. DH tankers present mostly internal structural problems, while non DH tankers present mostly hull problems. (key words: global stresses, maintenance, age, simplicity of design)

NASF do not present a great danger for life of crew ($5,56x10^{-5}$ fatalities per shipyear). Contrariwise NASF pose a significant threat for the environment. Frequency is $1,1x10^{-3}$ NASF per shipyear leading to (even the slightest) environmental pollution for the large tankers of the studied period. 174039 tonnes of oil were spilled in total. 3 out of 39 pollution related accidents are responsible for 96% of the total environmental pollution (in tones) caused by NASF. Environmental pollution was caused at the greatest percentage by non DH Panamax and Aframax tankers.

Shipyard(country), the tanker was built in: Unfortunately, there was no available data as far as fleet at risk by manufacturing country is concerned, and thus frequencies could not be calculated.

There seems to be no obvious and straightforward relationship between flag, under which the ship was operated, and NASF. A relationship between NASF and ships flying a flag of convenience appears possible, but could not be proved within the frame of this thesis, as we lacked sufficient data for the fleet at risk by flag of operation.

The relationship between classification societies and ship's seaworthiness is clear, but lack of data makes it impossible to draw precise conclusions.

The most possible scenario of a large tanker's ***machinery failure*** is this one: A ship is en route in open sea and its main engine presents a failure. The age of this hypothetical ship is not clear.

Machinery failures, that did not lead to another accident category (collision, contact, grounding) are the category of tanker's failures with the least social interest, because they do not seem to possess a real threat against human life and environment. Machinery failures affect mostly financial interests, because their usual consequence is the delay of the transportation of the cargo.

Ship's size does not seem to play a role. It is difficult to assume that for instance a boiler failure could be attributed to the ship's size. Manufacturing and inspection seem of greater importance. Of low importance seem also shipyard, where the ship was built and flag. Class maybe plays a role, because they are the ones in charge of inspecting the different machinery systems. Lastly, even if ship's size does play a role, it is difficult to assume that for instance a boiler failure could be attributed to the ship's size. Manufacturing and inspection seem of greater importance.

There is no real evidence that weather is important. Nevertheless, most of the machinery failures occurred, while the ship was en route in open sea, thus operating condition and location as parameters should not be neglected.

To find out the causes of machinery failures seems difficult, because ship's machinery consists of codependent rather than individual systems.

Machinery failure frequency gets less, as time goes by, proving that manufacturing, operating and inspecting of machinery systems become better and more effective.

This thesis focused on the statistical analysis and study of two of the less studied tanker accident categories, namely Non Accidental Structural Failures (NASF) and machinery failures of large tankers.

As seen above lack of data determines the potential of the current thesis. Among others it would be of great importance, if the following data was available: 1) fleet at risk by flag, class and manufacturing country, 2) the class and hull type of the examined accidents with unknown class and hull type, 3) more precise technical text in the database. Unfortunately, access to that kind of data is difficult. I assume, that even if the same thesis could be "repeated" with enriched data, then the results would be far more striking and clear. For example, there were some indications of problematic manufacturing in the recent years, for instance in China based shipyards, but no safe conclusions could be extracted based on the currently available data. Furthermore, it would be interesting to see how practical the developed NASF fault tree is, that means to check at what extent it could cover the different causes of a NASF. This could be proven after studying enough analytical reports of accidents (when available). On the spotlight should be the measures, that should be applied in order to decrease even more the frequency and severity of the accidents. Last but not least, similar researches on NASF and machinery failures for other ship sizes and ships with fundamentally different designs (for instance containerships, passenger ships) will make the in depth understanding of these two accident categories possible.

7 References-Sources

1) Schelin, J., “State Aids and the operation of ships: International ship registers”, p. 54, EC shipping Policy, The 17th Nordic Maritime Conference, 2-4 September 1996
2) West T., European Parliament, Directorate General for Research, “Outflagging and Second Ship Registers: Their Impact on Manning and Employment”, Working Paper, European Parliament, Directorate General for Research, 2000
3) The Maritime Transport Committee of the OECD, "Study of the Expansion of the Flags of Convenience and of Various Aspects Thereof”, Lloyds’ of London Press, 1992
4) Wikipedia.org
5) Australian Maritime Safety Authority, “Comparison of single and double hull tankers”, discussion paper”, Discussion paper
6) SpecTec, “SFI codification system”
7) Maritime-connector.com
8) Foutzopoulos R., “Analysis of serious incidents on IACS-cellular containerships, built after 1981 for the period 1990-2011”, Diploma thesis , NTUA, 2012.
9) A. Papanikolaou, E. Eliopoulou, “Impact of ship age on tanker accidents”, Proceedings of the 2nd Int. Symposium on “Ship Operations, Management and Economics”, The Greek Section of the Society of Naval Architects and Marine Engineers (SNAME), Athens, Sep. 17-18, 2008
10) M. Rausand, “System Reliability Theory (2nd ed.)”, Wiley, 2004

Accident of “KATINA P”

1) www.cedre.fr
2) www.wikipedia.org
3) www.poptel.org.uk
4) www.the-conference.com
5) www.c4tx.org
6) www.web.archive.org
7) www.itopf.com
8) NTUA-SDL database

Accident of “PRESTIGE”

1) Bahamas Maritime Authority, “REPORT OF THE INVESTIGATION into the loss of the Bahamian registered tanker “Prestige” off the northwest coast of Spain on 19 November 2002”