TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 18
Number 1
March 2024

DOI: 10.12716/1001.18.01.08

Revisiting Unsinkable Ships: From Titanic to Helge Ingstad, the Long-Standing Issues and Persistent Risks of Ship Disasters

K. Johansen[1] & O.T. Gudmestad[1,2,3]
[1] *UiT The Arctic University of Norway, Tromsø, Norway*
[2] *Western Norway University of Applied Sciences, Haugesund, Norway*
[3] *University of Stavanger, Stavanger, Norway*

ABSTRACT: The objective of this paper is to take a closer look at the theory of damage stability, i.e., origin, construction, organization and human developments, regulations, and in this context pinpoint a possible causal relationship between two specific ship losses: the losses of RMS Titanic and KNM Helge Ingstad. The paper does not discuss direct causes but rather tries to discuss possible causal links to the fact that the water intrusion was not limited or stopped by the ships` watertight subdivisions. References regarding assessments of the well-known loss of RMS Titanic are based on extensive studies carried out while assessment of possible ship construction defects and outcomes regarding poor decision-making related to the KNM Helge Ingstad loss refer to findings published in the National Safety Investigation Agency (NSIA) Part 2. The purpose of the paper is to set focus on the application of lessons learned after the loss of RMS Titanic associated to the main findings in the NSIA part 2 report. In this context, focus on whether the degree of competence we gain through Maritime Education and Training (MET) is sufficient, and then how this competence affects the practice. More specific, competence related to lessons learned regarding ship damage stability aspects such as survivability and recoverability.

1 INTRODUCTION

Seafaring has always depended on marshalling the laws of buoyancy to attain floatability and stability. The law of buoyancy deal with the upward counterforces of a body's downward gravitational force when immersed in fluid [1]. Buoyancy is equal to a body's fluid displacement, which enables the explanation why bodies (ships) can float in water. More specific, if the density of the fluid a body displaces is higher than the density of the body itself, then the body will float in the fluid. The ancient Greek mathematician and physicist Archimedes (287 – 212 BC), is considered as the originator of the concept of the law of buoyancy, floatability and stability of floating bodies [2]. The density of e.g., a ship can be explained as a combination of the weight of the ship hull and the air in the cavity of the part of the hull that is immersed in the water. Therefore, it is possible for a ship made of e.g., steel to float. What is challenging related to this concept is if the air inside the ship hull is displaced with water e.g., when the ship hull is breached allowing flood to enter the hull. Within ship terminology, water intrusion is related to the concept of ship damage stability.

According to The United Nations Conference on Trade and Development (UNCTAD) [3], the world fleet have continued to grow from the late 20th century to resent time. Despite that fleet grow, the total ship loss figures at sea have largely halved during the last decade.

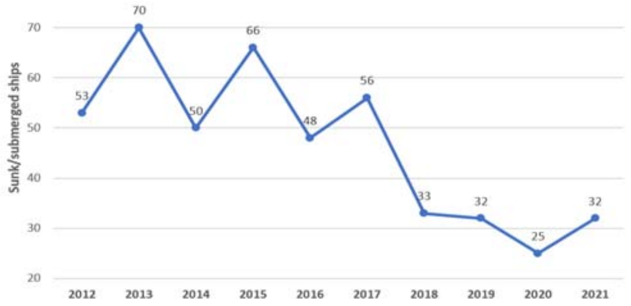


Figure 1. Annual lost (sunk/submerged) ships of 100 GT+, 2012-2021, Source: Lloyd`s List Intelligence Causality Statistics [4].

This rapid halving of ship losses indicates that the industry's efforts to combat such maritime hazards have produced good results.

Continuous regulatory, MET and technological development in ship engineering, construction and communication have contributed to a renewed and modern way of ship operation. The vessels today are equipped with up-to-the-minute weather updates, damage control and emergency response system, as well as a team of well-trained crews to ensure safe and secured operation.

However, despite that ships have been constructed and equipped in practically unsinkable way, total losses still occur with deadly consequences. Tracing back to the sinking of Titanic in 1912 where the ship lost floatability following the hull damage after colliding with iceberg to today’s state of the art warships like e.g., HI, shows that challenges due to ship loss still remain.

Initially, it may be appropriate to distinguish between ship losses that lead to, and do not lead to a disaster. A disaster is associated to accidents that results in many deaths or major injuries to people, and on the basis of this, the Titanic accident resulting many deaths is a disaster and the HI accident resulting no deaths is a ship loss.

RMS Titanic was a modern passenger ship when she was launched in 1911. In many ways she was a forerunner ship when it comes to damage stability aspects related to survivability, and she was considered by some the “unsinkable ship”. We all know what happened to her and that she, like other ships, was sinkable. Both the Titanic and the HI were designed with watertight subdivisions intended to limit spread of occurred water intrusion followed by hull damage. In general, watertight subdivisions are physical barriers aiming to prevent and limit such spread of occurred water intrusion. For various reasons, these barriers did not work as intended for both of these disasters.

The loss of the Titanic led to various changes related to the exercise of navigational aspects, ship design development, regulations regarding damage stability, and lifeboat requirements. Schröder-Hinrichs et al. [5], marked the first century since the Titanic sank after colliding with an iceberg by discussing possible common human and organizational factors involved in the Titanic and the Costa Concordia disasters. There is a century’s difference between these two disasters, i.e., the Titanic sank in 1912 and the Costa Concordia was left on her side in shallow water after colliding with an underwater reef in 2012. Maritime technology has undergone significant developments from the loss of the Titanic to present time, but the human and organizational factors deal with more or less the same challenges. Schröder-Hinrichs et al. study [5], focused on discussing factors that led to these disasters, more specifically the underlying factors, i.e., blunt end: organizational factors and sharp end: human factors. According to Woods et al. [6], blunt end factors are often linked to indirect causes of accidents, while sharp end factors are linked to direct causes. Hollnagel [7], describes the difference between blunt end and sharp end factors as distal factors (working there and then) and proximal factors (working here and now), respectively, and he also describes how these factors in combination can lead to an accident. Both blunt end and sharp end factors are contextually related to respectively risk management and emergency response measures, which are disciplines that involves in advance management for avoiding disasters and response measures to limit the consequences when a disaster has occurred [8]. The impact of the sharp end factors is design dependent. Devices with deficient design for proper emergency response measures will not respond as desired.

On 8 November 2018, the Norwegian frigate KNM Helge Ingstad (HI) and the oil tanker Sola TS collided in Fensfjorden on the western coast of Norway. The consequence of the collision was materially catastrophic, in that the frigate sank. This accident shows that, despite ship designed according to present standards and well-trained crew, sinking could happen.

For the Titanic, the sharp end emergency response could not have impacted the outcome (ship loss) because of design flaws followed by subsequent flooding [9]. HI had a more adaptable design related to sharp end emergency response measures and could thus have been saved [10].

The study this paper is based on has common features with the study of Schröder-Hinrichs et al. (2012), in that it focuses on what lessons we have learned or not learned from the Titanic loss to present time. What separates these studies is the focus regarding the lessons we have learned or should have learned from e.g., the loss of the Titanic. More specific, what we have learned about the damage stability aspect of survivability, i.e., both ship design developments and possible operational aspects regarding measures to prevent ships from sinking (recoverability).

The methodological approach related to the purpose of the paper dealt with a comprehensive literature study combined with an analysis of the NSIA Part 2 report of the ship loss of HI. The focus of the literature study was based on the keywords: Damage stability, Maritime Education and Training (MET), Seamanship competence, Human Elements, IMO, SOLAS, Naval Ship Code (NSC), Construction and Regulations. The literature dealing with the keywords was obtained via search engines such as e.g., Researchnet, Google Scholar, Sciencedirect, Web of Science.

The NSIA Part 2 report was published by the Norwegian Safety Authority in April 2021 with the aim of elucidating the sequence of events from the accident occurred until the ship was lost. The content is based on the investigation of decisive events taken from interviews with crewmembers and other involved parties, and technical investigations on board. In addition, the content is supported by information obtained from the Ministry of Defence, the Norwegian Defence Materiel Agency (NDMA), the Norwegian Armed Forces Materiel Safety Authority, the Royal Norwegian Navy, Det Norske Veritas (DNV) and Navantia. In the investigation, NSIA had access to and used classified information that is not publishable in accordance with the Norwegian Security Acts and defence sector restrictions (NSIA, 2021). The result of the total search led to 53 citations regarding the search terms and aspects concerning both of the aforementioned ship losses.

1.1 *Background*

The need for watertight subdivisions is self-evident. The concept dates back to ancient times by the Code of Hammurabi, which was legal texts sanctioned 38 centuries ago in Babylon [2]. Excavations from China show concrete examples were watertight compartment and bulkhead were integrated in ship hulls, reportedly inspired by the structure of the bamboo's hollow sections by watertight membranes. It is not known exactly when these examples were introduced, but two boats with watertight bulkheads have been found by archaeologists, dated to the period of the Tang Dynasty (618–907). The concept was not imitated in Europe until the late 18th and early 19th centuries. Chief engineer in the British Navy, Sir Samuel Bentham (1757–1831) was the first European to design using this technology [11].

Due to the great loss of life and costs caused by shipwrecks during the 19th century, the implementation of regulations to increase safety for seafarers and ships was required. One of the first significant contributors to safety related to regulatory requirements for reserve buoyancy regarding survivability was Samuel Plimsoll. With his influence, a requirement was introduced for all ships to be marked with their own allowance draft or load line mark (Plimsoll mark), to ensure ships had sufficient reserve buoyancy [12]. Reserve buoyancies represent extra buoyancy in addition to the buoyancy that enables a ship to float. It may be defined as the volume of enclosed spaces above the waterline, expressed as the volume or percentage of the total volume of the ship [13]. In the ship load line mark, the reserve buoyancy is visualized as freeboard (the height from the water line to the main or freeboard deck), i.e., the uppermost continuous watertight deck, figure 2. Plimsoll's efforts formed the basis for the establishment of the International Maritime Organization (IMO)'s Load Line Convention, adopted in 1930 [14].

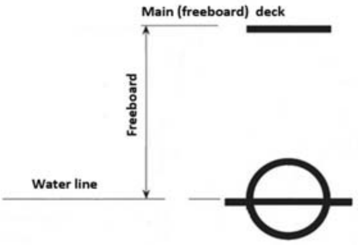


Figure 2. Illustration of the freeboard – load line mark relationship [15].

The first known legal requirement addressing safety at sea regarding watertight bulkheads was issued in the first Merchant Shipping Act of 1854. Furthermore, the first damage stability requirements were introduced in the Safety Of Life At Sea (SOLAS) Convention of 1948, followed by the first specific criterion for residual stability standards in the SOLAS Convention of 1960 [16].

The need for international regulations for dividing ship hulls into watertight subdivisions became relevant after the loss of the Titanic. However, developments regarding technological (ship design), organizational and operational experiences from this disaster have not prevented similar disasters from occurring since. Well-known disasters, e.g., Herald of Free Enterprise, near Zeebrugge, in March 1987, and Estonia, in the Baltic, in September 1994, are highlighted in several research papers like those of Biran and Lopez-Pulido [17] and Goulielmos and Goulielmos [18]. In addition, according to Eliopoulou et al. [19], there were a total of 7391 serious maritime accidents from 2000 to 2012. Most maritime accidents related to collisions, groundings, etc. connected to their study were followed by hull damage, causing flooding. As the title suggests, this paper deals with similarities between the HI disaster and, perhaps the most "famous" ship disaster of all times, the loss of the Titanic.

2 SHIP STABILITY

In naval architecture, the term "stability" is used in several contexts, such as "directional stability". This "stability" refers to how well a ship holds the direction (heading) and is not linked to this study. Stability associated with this study deals with keeping a ship afloat and upright and is defined as ship stability, i.e., "the ship's ability to return to normal upright condition, when disturbed by external forces without danger to the ship or the cargo and human life it carries" [20]. In more detail, ship stability deals with both transverse and longitudinal perspectives and is divided into the following two categories: intact and damage stability. Intact stability refers to ship stability associated with an intact ship hull, i.e., no impact of water intrusion, while damage stability applies to ship stability associated with ship hull damage, i.e., the impact of water intrusion. This study focuses on aspects of the ship's seaworthiness, more specifically aspects of survivability and recoverability associated to damage stability.

2.1 *Basic concepts of damage stability*

Damage stability applies to conditions a ship gains when it is flooded caused by hull damage. Regarding these conditions, the most fundamental goal is that the ship remains afloat and upright, i.e., survives after an accident involving water intrusion has occurred [16]. The afloat and upright conditions refer in this context to deviations from the original longitudinal and transverse planes, more specifically, sinkage, heeling and change of trim, respectively. Sinkage refers to increasingly draft, starboard, port, forward and aft draft. Heel and trim refer respectively to differences in port and starboard drafts and forward and aft drafts.

Vital terms regarding damage stability on naval ships are the relationship between the following: vulnerability, survivability and recoverability. Vulnerability concerns the inability to withstand damage from one or more hits and the probability of serious damage or loss due to hits. Survivability concerns the ship's ability to survive hull damages (stay stable and afloat). Recoverability represents the ability of the ship and its crew to carry out appropriate measures affecting the secondary effects degradation [21], i.e., transform a possible ship loss towards survivability, visualized in figure 3.a. The figure 3.b. visualizes no possible recoverability, i.e., ship loss. According to Boulougouris & Papanikolaou [22], these vital terms apply to risk-based design concepts related to naval ship design, but in principle they could apply to all types of ships.

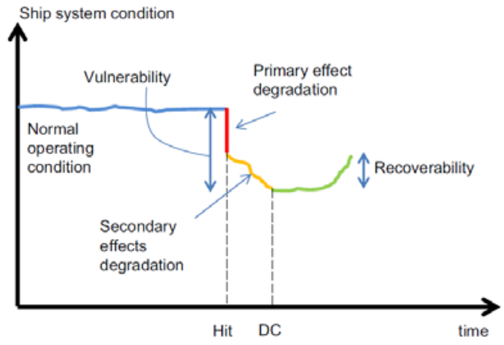


Figure 3.a. Visualization of vulnerability versus recoverability. Source: Ocean Engineering 2013 [22]

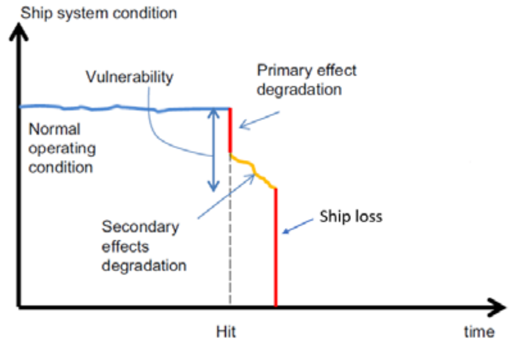


Figure 3.b. Suggested modified visualization of vulnerability versus ship loss, based on fig. 3a.

According to Grech et al. [23], recoverability involves post damage measures i.e., identifying and controlling damage to a ship regarding restoring and maintaining degraded functionality. With reference to naval architecture, recoverability is equivalent to emergency response. The ship's survivability depends on the degree to which a ship is designed with respect to possible survival, i.e., the ability to survive ship damage followed by water intrusion. More specifically, design by adding the hull with, and dividing it into, watertight compartments (subdivision) by using watertight bulkheads and damage control decks (bulkhead decks). The terms "watertight compartments" or "watertight subdivisions" represent dedicated internal watertight spaces for supporting the ship's survivability, i.e., buoyancy. "Bulkhead" is the term for barriers to water intrusion – either vertically, referred to as watertight transverse bulkheads, or horizontally, referred to as damage control decks or bulkhead decks. According to established damage stability requirements, subdivisions are calculated and designed to ensure that a ship can float and be stable based on different scenarios of flooded subdivisions [17].

2.2 *General damage stability regulations*

A serious challenge for a ship's seaworthiness is hull damage that leads to water intrusion in responsive compartments or subdivisions, followed by reduced ship stability caused by changes in draught, trim and heel. The changes referred to are, respectively, draught – the vertical distance between the waterline and the bottom of the hull (keel), trim – ship endwise inclination, heel – ship sideways inclination. If water intrusion exceeds certain limits, these changes can individually or in combination lead to ship loss. The ship's ability to resist loss as a result of hull damage largely depends on the compartmentation and waterproof integrity, followed by survivability.

The first regulations regarding seaworthiness are found in the Code of Hammurabi, 1792–1750 BC [24]. The text of Hammurabi code 235 reads as follows.

If a boatman builds a boat for a man and he does not make its construction seaworthy and that boat ends up in an accident the same year as it was put into operation, the boatman shall reconstruct the boat and reinforce it at his own expense and he shall give the boat, when it is reinforced, to the owner of the boat. [25].

Seaworthiness deals with and covers characteristics that affect the ship's ability to remain safe at sea in all conditions and perform as intended [26]. Remaining safe at sea in all conditions includes both intact and damage stability aspects, and regulations regarding these aspects will, therefore, deal with the ship being seaworthy.

The first Merchant Shipping Act of 1854 represents the first known requirement regarding safety at sea concerning watertight bulkheads. This requirement was enacted as a result of the rapid loss of the Birkenhead in 1852. The reason for the rapid loss was that cavalry officers on board had holes cut in the transverse bulkheads to train their horses, i.e., they broke the barriers to water spread [27].

In order to achieve higher survivability standards, regulations for the division of ship hulls into watertight compartments or subdivisions were ratified. These regulations became clearer after the loss of the Titanic. As a result of this loss, the IMO Convention SOLAS was adopted in January 1914. Several changes have been introduced since this adoption, some of them affected by the aforementioned ship disasters involving the Herald of Free Enterprise and Estonia. The IMO Convention for the Prevention of Pollution from Ships (MARPOL) Annex I, regulation 28 deals with guidelines for ship construction and education and training concerning pollution prevention and, more specifically, guidelines dealing with the prevention of pollution from oil, gas and chemical tankers [28]. The MARPOL guidelines will not be addressed in this paper.

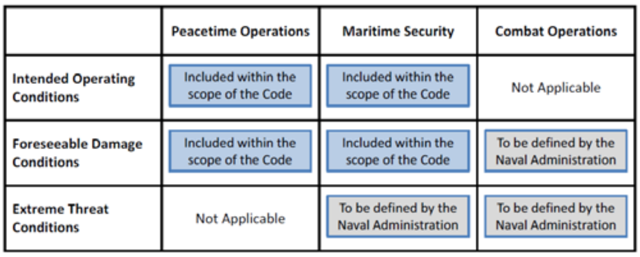
Damage stability regulations related to this paper are addressed for both merchant and particularly for naval warships. Regulations regarding damage stability for warships are in general given in the same regulations that deal with their intact stability, but, in recent years, a number of navies have cooperated with classification societies to approach the same regulations as for merchant ships [26].

Previous assessment approach with regard to ship damage design was based on a deterministic framework. In this deterministic approach, specific lengths of the ship (subdivisions) that could be flooded until ship loss was assessed. In this framework, ship loss was considered when the waterline touched the margin line as a result of water intrusion, i.e., no more reserve buoyancy [29]. The margin line was referred to a line drawn at least 76 mm below the upper bulkhead deck at the side [17]. The deterministic assessment framework with margin line as reference was replaced by a probabilistic assessment framework in SOLAS 2009 and further developed in the SOLAS 2020 requirements [30]. This assessment framework is based on an evaluation of a ship's probability of survive, i.e., remain afloat without sinking or capsizing as a result of an arbitrary collision in a given longitudinal position of the ship hull. The main requirement in this damage stability assessment framework is that the probability of survival of a ship (Attained Subdivision Index A) must be higher than a certain minimum value (Required Index Subdivision R), $A \geqslant R$ [26].

2.3 *Warship damage stability regulations*

Surface warships differ from merchant and passenger ships in that they are constructed for operation in hostile environments, i.e., they must be able to withstand the effects of anti-ship weapons. While merchant and passenger ships operate in accordance with IMO's international regulations, warships compromise their operations between IMO safety regulation aspects and military capabilities. Regarding damage stability regulations, warships are considered part of a much broader vulnerability assessment than merchant and passenger ships because, in addition to possible "normal" accident exposure like the HI accident, they can be exposed to war-related damage. The vital design objective for warships is therefore survivability due to an ability to "fight hurt", i.e., to minimize the vulnerability from the early design stages, in order to maximize survivability [31].

According to Biran & Lopez-Pulido [17], warships are not directly subject to SOLAS damage stability regulations and recommendations. This does not mean that these regulations and recommendations regarding damage stability are not attractive to naval vessels adapted to direct warfare. Naval skips may in principle be subject to these regulations and recommendations, even if their role requires design and operational solutions that are at least in accordance with this Convention. The Allied Naval Engineering Publication (ANEP) – 77 Part 1 covers the content of the North Atlantic Treaty Organization (NATO) Naval Ship Code (NSC), which represents the approved goals, functional objectives, and performance requirements for naval operations of nations in the NATO naval armaments group [32]. The NSC was established in 2004 in a collaboration between NATO navies and classification societies like Lloyd`s Register, DNV, and Bureau Veritas, etc. The purpose of this establishment was to develop a framework for standards and regulations for safety with the same scope and level as IMO`s SOLAS Convention [33]. The code provides a goal-based structure demonstrating that the ship is safe to operate according to navy safety objectives. It includes goals associated with damage conditions in peacetime, not damage inflicted from extreme threat and involvement in combat operations, figure 4.



	Peacetime Operations	**Maritime Security**	**Combat Operations**
Intended Operating Conditions	Included within the scope of the Code	Included within the scope of the Code	Not Applicable
Foreseeable Damage Conditions	Included within the scope of the Code	Included within the scope of the Code	To be defined by the Naval Administration
Extreme Threat Conditions	Not Applicable	To be defined by the Naval Administration	To be defined by the Naval Administration

Figure 4. Applicability of NSC [32].

The following aspects of the NSC in ANEP-77 are essential and can possibly be put in context with the conclusion of the NSIA 2019 report on the HI accident, i.e., what affected the consequences (ship loss).

The Code assumes that the majority of persons normally embarked on a naval ship are able-bodied, with a fair knowledge of the layout of the ship and have received training in safety procedures and the handling of the ship's safety equipment.

Compliance with this Code does not replace the responsibility to comply with IMO conventions and other international and national treaties, conventions and regulations including United Nations Convention on the Law of the Sea (UNCLOS) applied through national and international laws.

Nevertheless, according to Boulougouris & Papanikolaou [22], it seems that the main developments of naval ship design concentrate on improvements related to performance in peacetime, rather than addressing ships' risk to combat-related flooding conditions. According to SOLAS, damage stability aspects deal with "peacetime" hull breaches followed by collision, grounding, brakes along the hull length etc., and not combat related damages.

3 REVIEWS OF THE LOSS OF RMS TITANIC AND KNM HELGE INGSTAD

3.1 *RMS Titanic*

RMS Titanic was a British cruise steamliner designed and constructed by the Harland & Wolff shipyard in Belfast, Northern Ireland, and launched on May 31, 1911. The ship was operated by the White Star Line and sank after striking an iceberg on her maiden voyage in the North Atlantic Ocean on 15 April 2012 [34]. The exact number of people on board is somewhat uncertain, but, according to Vassalos et al. [35], it is estimated that 2224 people were on board, of whom 1513 died as a result of the sinking.

Technical data and specifications: overall length: 852 feet 9 inches (269 m), beam: 92 feet 6 inches (28 m), draught: 34 feet 7 inches (10.5 m) [36]. According to Stettler & Thomas [37], the pre-collision draft is assumed to be 30’9” forward and 33’9” aft, and she had a displacement of 48,300 tons.

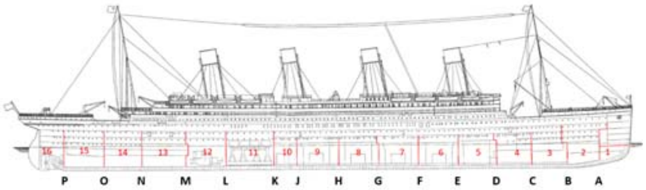


Figure 5. Titanic bulkhead arrangement illustration.

As figure 5 shows, the number of transverse watertight bulkheads was 15 (A-P), i.e., dividing the vessel into 16 transverse watertight compartments from bow to stern. From the figure it also appears that the ship had no bulkhead (damage control) deck. The illustrations in figures 5 and 6 represent modifications originating from Hahn Titanic-Plans [38].

The Titanic sank in less than three hours, despite the shipbuilder's statement that the ship would stay afloat for two to three days, even if affected by the worst possible accident at sea [39]. The water intruded into the ship through the hull breach followed by the collision with the iceberg and spread further through the vertical bulkheads. According to [39], the hull damage caused by the collision allowed water to intrude into the six foremost compartments. The most likely way the sinking developed was first through the filling of compartments two to five and the forepeak, as a direct result of the impact of the iceberg. Through this filling, the ship was trimming forward, causing water to spread to connected compartments, as illustrated in figure 6.

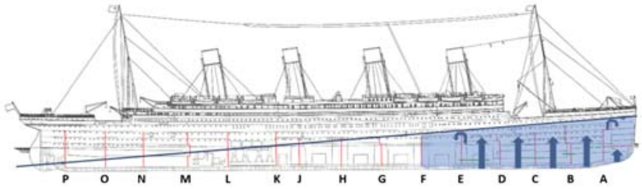


Figure 6. Titanic. Illustration of water intrusion spreading over the transverse bulkheads.

3.2 *KNM Helge Ingstad*

In accordance with the information presented in the official report of HI by NSIA [10], KNM Helge Ingstad was a Norwegian-registered frigate (warship) in the Fridtjof Nansen-class, designed and built at the Spanish state-owned shipyard, Navantia. The HI was owned by the Norwegian state, represented by the Ministry of Defence and operated by the Royal Norwegian Navy by the following pennant number, 313. The HI was launched on 23 November 2007. In 2018, the frigate and the tanker Sola TS collided outside the Sture terminal in Hjeltefjorden, Bergen, causing the HI to sink. The frigate had a crew of 137 people, of whom seven were slightly injured; no one died.

Technical data and specifications: overall length: 134 m, beam: 16.8 m, draft max: 7.6 m, displacement: 5290 tons.

Figure 7. KNM Helge Ingstad bulkhead arrangement illustration.

As figure 7 shows, the number of transverse watertight bulkheads was 12 (blue lines), i.e., dividing the ship into 13 transverse watertight compartments from bow to stern. The blue and green longitudinal lines mark, respectively, the bulkhead deck and the damage control deck. The red longitudinal line marks the double bottom. The basis for the figure 7 and figure 8 illustrations is taken from the general arrangement of the Fridtjof Nansen-class [10].

The HI ran aground approximately 10 minutes after the collision and sank at a later date, caused by flooding of the seven rearmost compartments (7–13). In this context, there will be no focus on the grounding after the collision, as the NSIA report concludes that it did not directly cause the loss of the HI, as “the lack of closure would in any case lead to a sinking”. The water intrusion probably spread into the HI by the following route (dark blue directional arrows), according to NSIA, cf. figure 8:

- Directly into compartments 10 and 11 (yellow) through the damaged area (red).
- Through the hollow propeller axle from compartment 10 into compartment 8.
- From compartment 8 into the connecting compartments 7 and 9 through stuffing boxes in the bulkheads.
- From compartment 11 into compartments 12 and 13 below the damage control deck.
- Into the quarterdeck (dark red) through open hatches, pressure valves, and airlocks.

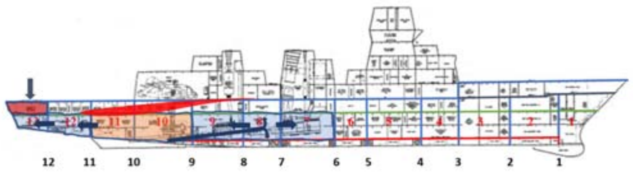


Figure 8. Illustration of water intrusion causing the sinking.

The damaged area (red) illustrated in figure 8 represents an estimate of the damage, based on images of the hull damage to the ship, and could thus to some extent deviate from the actual damage.

It should particularly be noted that, in the case of the HI, the water did flow from compartment 8 into the connecting compartments through openings in the bulkheads, and that the lack of closure in any case would have led to the sinking. The objective of bulkheads is to provide full closure i.e., prevent water flowing into nearby compartments. In the case of the Titanic, the limited heights of the vertical bulkheads and lack of bulkhead deck did not provide proper closure. The HI design allowed water to spread into the ship from compartment 10 to compartment 8, furthermore, during the construction of the ship, openings were cut in the bulkheads for cables and pipes i.e., the bulkheads had reduced function. Anyway, the NSIA part 2 report showed that this design flaw was not decisive for the sinking. The HI sinking was, according to the report, caused by a combination of the aforementioned design flaws and the inability of the operators to secure the ship in advance of the sinking and to implement propriate recoverability measures. More specifically, the report showed that the ship was operated with openings between bulkheads and had additionally open hatches [10]. It is therefore a learning point for ship operators to ensure that bulkheads and hatches are closed.

4 TITANIC VS HI, SIMILARITIES AND DIFFERENCES DUE TO DAMAGE STABILITY ASPECTS LEADING TO SHIP LOSS

In order to understand the causes of the losses of the Titanic and the HI and to be in a position to analyse the progress (or lack of progress) in design and the improved (or lack of improved) understanding of ship damage stability, there is a need to compare similarities and differences related to damage stability. See table 1.

Table 1. Damage stability similarities/differences between the Titanic and the HI.

Similarities	Differences
Collision	Time period
Hull damage followed by water intrusion	Survivability
Killability	Recoverability
Transverse bulkhead arrangement	Ship type
Loss of bulkhead integrity	Design regulation available
Loss of watertight compartment buoyancy effect	Damage control deck and double bottom
Ship loss	Maritime education and training
Blunt end influence	Sharp end influence

4.1 *Similarities due to damage stability aspects*

- Collision – Both ships collided, with an iceberg and a ship, respectively, which led to hull damage, followed by subsequent water intrusion.
- Killability – Both ships were exposed to total ship kill, which, according to Ball & Calvano (1994), is damage leading to ship loss through insufficient buoyancy.
- Transverse bulkhead arrangement – The Titanic and the HI had, respectively, 16 and 13 transverse watertight compartments, ref. figures 4 and 6.
- Loss of bulkhead integrity – The Titanic lost bulkhead integrity by water spread due to the lack of a bulkhead (damage control) deck, ref. figure 5. The HI lost bulkhead integrity due to water spread through the propeller shaft and through open hatches, ref. figure 7.
- Loss of watertight compartment buoyancy effect – Due to the loss of bulkhead integrity, more watertight compartments than survivability demanded were flooded, i.e., lost their buoyancy.
- Ship loss – Both the Titanic and the HI sank.
- Blunt end influence – For the Titanic, the blunt end influence refers to ship design flaws in the construction of the watertight integrity, material failure, and number of lifeboats in relation to number of passengers (Gannon, 1995). Accordingly, for this disaster, there were no blunt end factors that could influence the possibilities for the ship's recoverability, due to major hull damage. For the HI, blunt end influence also refers to ship design through the construction of watertight integrity. In addition, this influence also refers to organizational and systematic aspects that may have affected the recoverability, for example, the crew's lack of sufficient expertise provided by the Navy, lack of coordination between the Navy and the Norwegian Defence Materiel Agency's crisis plans, and the Norwegian Navy's lack of an overview of the total risks that had a direct impact on the course of events (NSIA, 2021).

4.2 *Differences due to damage stability aspects*

- Time period – The time period between the Titanic and HI accidents is from 2018–1912 = 106 years.
- Survivability – The Titanic lost its survivability due to severe hull damage, which exceeded its recoverability. According to NSIA (2021), the investigation shows that appropriate efforts and measures could have prevented the HI from sinking, i.e., the HI had recoverability.
- Ship type – The Titanic was a cruise ship (steamer), while the HI was a frigate (warship).
- Design regulations available – The Titanic was designed according to the latest innovations of safety technology with respect to survivability. Regulations and recommendations regarding ship design were at this time based on The Merchant Shipping Act, 1854. Rule 300 of this Act describes the following demands regarding the building and equipping of steamships:
  - Every steamship built of iron, of One hundred Tons or upwards the building of which commenced after the Twentyeighth Day of August One thousand eight hundred and forty-six, and every Steam Ship built of Iron of less

  Burden than One hundred Tons the building of which commenced after the Seventh Day of August One thousand eight hundred and forty-one (except Ships solely used as Steam Tugs), shall be divided by substantial transverse Water-tight Partitions, so that the Fore Part of the Ship shall be separated from the Engine Room by One of such Partitions, and so that the After Part of such Ship shall be separated from the Engine Room by other of such Partitions.
  - Every steamship built of iron the building of which commences after the passing of this Act, shall be divided by such Partitions as aforesaid into not less than Three equal Parts, or as nearly so as Circumstances permit. (Merchant Shipping Act, 1854)
- The HI crew had undergone MET according to the International IMO Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). This convention set minimum standards of competence by MET for ship officers in charge of a navigational watch. STCW tables A-II/1 and A-II/2 set a minimum standard of competence concerning damage stability at operational and management level, respectively, ref. table 2 and table 3.

  Standard of competence is the level of proficiency to be achieved for the proper performance of functions on board ship in accordance with the internationally agreed criteria as set forth herein and incorporating prescribed standards or levels of knowledge, understanding and demonstrated skills. (IMO, 2018).

  The very basis for the establishment and development of IMO codes and conventions is experience gained as a result of ship accidents. One example is the SOLAS convention, which was originally established as a treaty in 1914 in response of the loss of the Titanic. The SOLAS convention chapter II-1 concerns international requirements regarding survivability, i.e., construction and design considering watertight integrity [43]. This convention affects the standard of competence required by naval architects and ship designers.
- Sharp end influence – For the Titanic, there were no measures that could be carried out regarding recoverability because of the mismatch between ship design due to survivability (bulkhead design) and degree of hull damage, i.e., the ship was doomed to sink [44]. According to the NSIA Part 2 report concerning the HI, there were measures that could have been taken at the sharp end which could have affected the recoverability of the ship. The report states the following regarding recoverability measures that should have been taken:

  Doors, hatches and other openings in the frigate that were supposed to be closed to maintain stability and buoyancy were not closed at the time of evacuation. A shutdown of the frigate could have prevented her from sinking [10].

  It should be noted that openings in the bulkheads should at all times be closed, to ensure that the damage stability, intended to be ensured by the bulkheads, will at all times be functioning.

Table 2. Minimum standard of competence at operational level (table A-II/1. STCW/CONF.2/34)

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Maintain seaworthiness of the ship	Ship stability Working knowledge and application of stability, trim and stress tables, diagrams and stress-calculating equipment. Understanding the fundamental actions to be taken in event of partial loss of intact buoyancy. Understanding the fundamentals of watertight integrity. Ship construction General knowledge of the principal structural members of a ship and the proper names of the various parts	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, where appropriate 4 approved laboratory equipment training	The stability conditions comply with the IMO intact stability criteria under all conditions of loading. Actions to ensure and maintain the watertight integrity of the ship are in accordance with accepted practice

Table 3. Minimum standard of competence at management level (table A-II/2. STCW/CONF.2/34).

Column 1	Column 2	Column 3	Column 4
Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Control trim, stability and stress	Understanding of fundamental principles of ship construction and the theories and factors affecting trim and stability and measures necessary to preserve trim and stability. Knowledge of the effect on trim and stability of an ship in the event of damage to and consequent flooding of a compartment and countermeasures to be taken. Knowledge of IMO recommendations concerning ship stability	Examination and assessment of evidence obtained from one or more of the following: 1. approved in-service experience 2. approved training ship experience 3. approved simulator training, were appropriate	Stability and stress conditions are maintained within safe limits at all times

5 DISCUSSION

The focus of this study was to take a closer look at possible similarities vs. differences between the loss of Titanic and HI when it comes to damage stability aspects and based on this discuss what we have possibly learned or not learned from the Titanic loss. As the study shows, from a damage stability point of view, the Titanic had no recoverability, i.e., was doomed to sink, while the HI had, according to the NSIA investigation-based report, recoverability. Therefore, this discussion focuses mainly on trying to reveal and discuss the investigation basis on which the report claims that the HI had the ability to recover and survive.

It is worth mentioning that both the Titanic and the HI had challenging longitudinal damage zones, followed by subsequent water intrusions, respectively in the front section (bow) and the rear end (stern) of the ship. Such intrusions mean that, in addition to corresponding sinking by the bow and the stern due to lost buoyancy, both ships got trim. Damage zones by the bow or stern, followed by trim, limit the ability to survive, i.e., less water intrusion is required to sink a ship. This can be displayed by the former deterministic damage stability approach, the floodable length curve, cf. figure 9.

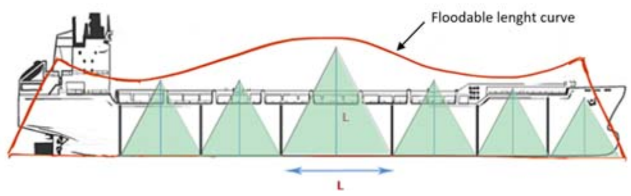


Figure 9. Compliance between damage zones (L) allowance and floodable length curve [45].

The floodable length curve represents the maximum allowable longitudinal floodable length (L) at any point along the length of the ship, which can be flooded without immersing any part of the margin line [17]. Although this represents an aspect of a former damage stability approach, it can still visualize that a ship can withstand less water intrusion at the bow and stern compared to midships.

Considering the lessons learned from the Titanic's recoverability, a similar accident occurred in 1989, in which resourcefulness, communication, and prudence, combined with destiny and luck, meant that the outcome was different. The Russian cruise ship M/S Maksim Gorkiy (MG) accident west of Svalbard, on 19 June 1989, was significantly similar to the Titanic accident, in the fact that both ships were passenger/cruise ships that suffered hull damage in the bow section, followed by subsequent water intrusion, as a result of a collision with ice. Despite the cold climate and remote area, followed by consequent poor infrastructure, the ship and passengers survived as a result of a successful joint rescue operation between the crew of both the MG and the Norwegian coast guard ship, KV Senja (KVS) and two rescue helicopters (Sea King) from Longyearbyen, Svalbard [46]. The recovery, leading to the survival of the MG was made possible due to the performance of appropriate measures by the crew of the KVS, more specifically the installation of external pumps to bilge the ship and of leakage mats to seal or limit water intrusion, cf. figure 10. The successful survival of the MG was based on the fact that, fortunately, the KVS was close enough to come to the rescue, and that the crew of the KVS showed wisdom and determination. How the successful outcome of this accident was made possible should be an example to follow and should be included in MET.

Figure 10. Installation of leakage mats MG [46].

6 CONCLUSION

According to the NSIA Part 2 report, HI had recoverability if the right decisions had been made. In this investigation report, the NSIA has mapped the sequence of events after the collision, which shows that a number of both organizational and systemic level factors affected the outcome of the accident (ship loss).

The investigation identified and submitted 28 areas of safety recommendations for improving safety to the Ministry of Trade, Industry and Fisheries and the Ministry of Defence. The following five main measures apply to matters at organizational and systematic levels, covering the most important content of the 28 submitted areas of safety recommendations.

– The Ministry of Defence must take steps to clarify the regulatory framework for the sector for the purpose of ensuring ship safety. This includes clearly defining the roles of authorities, avoiding dual roles and establishing an overall, independent supervisory function for naval activities in the defence sector.
– The Norwegian Defence Materiel Agency must ensure correct prioritization to be able to balance tasks and resources relating to the technical operation of the frigates.
– The Norwegian Armed Forces must establish mechanisms for organizational learning from undesirable incidents and accidents and to meet the Navy’s need for better system support in the operation of the frigates.
– The Royal Norwegian Navy must review and conduct a risk assessment of the manning concept for the frigates and take steps to clarify the prerequisites for the concept and how these are to be followed up. The Navy must evaluate and implement measures in its own training and exercise programmes to ensure that the frigate crews have the competence required to handle complex damage control scenarios. They must also take steps to ensure that the Navy has an overview of the risks associated with nonconformities, with a view to ensuring safe operation of the frigates.

- The Norwegian Armed Forces Materiel Safety Authority must conduct supervisory activities of the Norwegian Defence Materiel Agency and the Royal Norwegian Navy to ensure safe operation of the frigates through long-term good configuration management and updated technical documentation [10].

The report pinpoints deficiencies in the training of the operational personnel on board the HI. The Royal Norwegian Navy is recommended to, e.g., implement measures in its own training and exercise programmes to ensure that their crews have the competence required to handle complex damage control scenarios. Further, the report pinpoints recommendations for the Norwegian Armed Forces to establish mechanisms for organizational learning from undesirable incidents and accidents. These measures represent parts in the establishment of important aspects of a comprehensive seamanship-oriented competence. Seamanship competence is complex in that it concerns all aspects of handling and sailing a ship under all conditions. According to Kemp [47], the manifestation of seamanship competence is considered by the following as an art:

> *The art of sailing, manoeuvring, and preserving a ship or a boat in all positions and under all reasonable conditions.*

The demonstration of proper seamanship competence depends on which MET has been reviewed and experience gained in, in accordance with practice. The term “competence” is linked to the learning of skills, knowledge and attitude by the following:

> *Competence is measured by the ability to put into practice the knowledge, skills and attitudes which have been learned and understood. It is this integration in practice which is the crucial part, not simply the acquisition of knowledge and skills [48].*

According to both Kemp [47] and Callman [48], the concepts of seamanship and competence, both individually and in conjunction, concern a comprehensive knowledge and understanding of all aspects of seafaring, including damage stability. In the concluding section of the NSIA Part 2 report, it is claimed that the assessment of alternative actions to those which were implemented would have required further competence, instruction and training of the crew, as well as better decision support tools than were available [10]. According to this claim, the crew of the HI might not have been given the opportunity to acquire the proper prerequisites to act in accordance with the required seamanship-based competence.

It is worth mentioning that all frigates in the Fridtjof Nansen class are ordered to operate at a certain level of preparedness that refers to a given degree of material safety. In general, a vessel's survivability in a crisis depends on compliance with a sufficient degree of material safety. An important part of the degree of material safety is shutdown (the closing of watertight devices like doors, hatches, valves, etc.) to prevent the spread of water intrusion. The mentioned closing devices refer to specific equipment protection levels marked with the following letters, X, Y and Z, which indicate the vessel’s ordered safety level regarding the required position of the specific closing device (open/closed). The HI was sailing at equipment protection level Y on the day of the collision. This equipment protection level refers to use alongside quay in wartime and at sea in peacetime. Subsequent investigations have shown that the HI had some breaches regarding this level of equipment protection, i.e., allowing doors between watertight compartments 12 and 13 to be open. These doors were supposed to be closed in accordance with equipment protection level Y.

Design and construction regulations are ratified and developed as a result of experience gained through accident investigations. The Titanic had no concrete regulations or adequate experiences to follow up in the design and construction phase regarding survivability, besides the aforementioned recommendations by the Merchant Shipping Act of 1854. Although the designers tried to design and build an almost "unsinkable" ship, it later turned out to have serious flaws in terms of survivability. The investigation into the loss revealed these serious flaws, which had direct consequences for the design and construction of new ships and the modification of existing ships. A concrete example is the modification of the Titanic's sister ship, the Olympic. Six months after the loss of the Titanic, the Olympic returned to the Harland and Wolff shipyard to undergo changes, as a result of the loss. These modifications involved making her watertight bulkheads higher, fitting significantly more lifeboats, and, in addition, the ship was given a double skin [49].

The HI had better prerequisites in relation to design and construction for survivability, due to regulations, recommendations, and experiences gained in the approximately one century since the loss of the Titanic. However, the ship’s design proved to have a lack of waterproof integrity between the watertight bulkheads, i.e., there was water intrusion through hollow propeller axle sleeves from compartment 10 to compartment 8 and further into compartments 9 and 7 through stuffing boxes in bulkheads 7 and 8. The NSIA Part 2 report states that this flaw did not have a direct and decisive impact on the loss, but errors of this nature normally represent an important contribution to such losses. Like the Titanic`s sister ship, the Olympic, the HI`s sister ships in the Fridtjof Nansen class have been redesigned for improved survivability regarding watertight integrity, i.e., the propeller shaft sleeves have been made watertight [10]. The message to ensure the integrity of the bulkheads has to be conveyed to students and all designers and fabricators.

Warships are in general supposed to be designed to withstand challenges beyond what applies to merchant ships. Therefore, according to Liwong & Jonsson [21], it is crucial that measures to reduce the vulnerability of warships are implemented early in the design process. This is to create conditions for survival and recovery during the design and construction process of naval vessels. A challenge regarding keeping vulnerability to a minimum is separate rules applicable to warships, which can be confusing for the classification societies which normally follow the building processes and classify ships in accordance with the IMO conventions.

According to Riola & Perez [50], this confusion can be misinterpreted and may represent a drop in safety standards, i.e., contribute to increased vulnerability.

The Accident Investigation Board of Norway (SHK), which prepared the NSIA Part 2 report, gained access to and used Norwegian defence sector safety-graded information as part of the investigation. Such information included organizational structures, crew perspectives, sequences of the events, detailed drawings and stability manuals, etc. Through access to such primary information, SHK had the best prerequisite for their investigation that formed the basis for the content of their report. The report pinpointed both blunt end and sharp end factors that led to the loss of the HI. However, in this paper, information about the HI was based on secondary information, i.e., collected from the NSIA report, considering the lack of access to graded primary information. For example, figures 7 and 8 are based on the content of the NSIA report and not on the mentioned primary sources. Thus, these figures could probably deviate from the real loss of the HI.

According to the damage stability relationship between the Titanic and the HI, there were certain similar aspects of damage stability, e.g., both ships were designed and built for water spread between bulkheads, which led to uncontrolled water flooding. Another similar aspect was that this water flooding resulted in both ships being lost. Literally, one could say that the damage stability design lessons of the HI were not learned, but this aspect has not been tried in court yet. Therefore, this paper will not conclude any further in relation to this aspect, although the NSIA Part 2 report documents how the water spread into the ship.

In accordance with Boulougouris & Papanikolaou [22], both designers and operators of naval ships seem in general to lack an appropriate understanding of risk-based design and operational aspects regarding damage survivability performance. Ship design and construction, and organizational challenges like MET leading to appropriate understanding, represent the blunt end of both ship losses but perhaps more so for the HI, considering the recoverability aspect. The Boulougouris & Papanikolaou's [22] blunt end-based claim can probably be supported on the basis of what emerges in the NSIA Part 2 report.

Regarding the confusing rules for navy ships, maybe navies should adopt merchant and passenger damage stability regulations to ensure that navy ships are built according to well-documented standards. In this way, both designers and operators may have better prerequisites to gain appropriate understanding of all aspects of damage stability.

According to Schröder-Hinrichs et al. [5], the science of human factors first became actualized around and after World War II. Therefore, this aspect was not directly named in conjunction with the Titanic loss in 1912, although the human factors were present. Therefore, the human elements or factors was not directly considered as similarities or differences between the loss of the Titanic and the HI. Although, these elements represent the sharp end of the manifestation of executing proper seamanship competence and will always influence when humans are involved. These aspects certainly contributed to the losses of both Titanic and HI, both in advance and during the actual development of the loss.

REFERENCES

[1] Heath, T, L. The Works of Archimedes. Cambridge University Press, 256 – 263, 1897.

[2] Francescutto, A., Papanikolaou, A, D. Buoyancy, stability, and subdivision: Archimedes to SOLAS 2009 and the way ahead, 2010.

[3] UNCTAD. E-Handbook of Statistics, 2021. https://hbs.unctad.org/merchant-fleet/#Ref_8IVYHP88, 2021. Accessed 9th September 2022.

[4] Allianz Global Corporate Speciality. Safety and Shipping Review 2022. May 2022.

[5] Schröder-Hinrichs, J. U., Hollnagel, E., Baldauf, M. From Titanic to Costa Concordia: a century of lessons not learned. WMU Journal of Maritime Affairs 11, 151-167, 2012.

[6] Woods, D. D., Johannesen, L. J., Cook, R. I., Sarter, N. B. Behind Human Error: Cognitive Systems, Computers and Hindsight, 1994.

[7] Hollnagel, E. Barriers and Accidents Prevention. Aldershot, UK: Ashgate, 2004.

[8] Ludík, T., Barta, J., Navrátil, J. (2013). Design Patterns for Emergency Management Processes. World Academy of Science, Engineering and Technology, International Journal of Economics and Management Engineering Vol:7, No:12, 2013.

[9] Bassett, V. Causes and Effects of the Rapid Sinking of the Titanic. Department of Mechanical Engineering, the University of Wisconsin, 1998.

[10] NSIA. https://havarikommisjonen.no/Marine/Published-reports/2021-05-eng, 2021. Accessed 9th September 2022.

[11] Lu, Y. (2015). A History of Chinese Science and Technology, Volume 3. Shanghai Jiao Tong University Press, Shanghai and Springer-Verlag Berlin Heidelberg, 453-461, 2015.

[12] Plimsoll, S. Our Seamen, an Appeal. Andesite Press. 11 August 2015, 1873.

[13] Barrass, B., Derrett, D. R. Ship Stability for Masters and Mates, sixth edition. Elsevier Ltd, 2006.

[14] IMO. SOLAS-International Convention for the Safety of Life at Sea; IMO: London, UK, 2009/(2020).

[15] ICLL. International Convention on Load Lines 1966 (MSC. 172 (79)), 1966.

[16] Vassalos, D., Guarin, L. Designing for Damage Stability and Survivability – Contemporary Developments and Implementation, 2009.

[17] Birian, A., Lopez-Pulido, R. Ship Hydrostatics and Stability, second edition, 2014.

[18] Goulielmos, A. M., Goulielmos, M. A. The accident of m/v Herald of Free Enterprise, a failure of the ship or of the management? Disaster Prevention and Management 14 (4), 476-492, 2005.

[19] Eliopoulou, E., Papanikolaou, A., Voulgarellis, M. Statistical analysis of ship accidents and review of safety level. Safety Science 85, 282-292, 2016.

[20] Lee, B. S. Hydrostatics and Stability of Marine Vehicles. Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping 7, 2019.

[21] Liwong, H., Jonsson, H. Comparison between different survivability measures on a generic frigate. Trans RINA, Vol 157, Part A2, intl J Maritime Eng, 2015

[22] Boulougouris, E., Papanikolaou, A. Risk-based design of naval combatants. Ocean Engineering 65 (2013) 49-6, 2013.

[23] Grech, M. R., Drohan, D., Warren, R., Gamble, G. I. Ship recoverability: How important is the human factors input, 2012.

[24] Nagarajan, K. V. The Code of Hammurabi: An economic interpretation. International Journal of Business and Social Science 2 (8), 2011.

[25] Gordon, C. H. Hammurabi's Code. New York: Holt, Reinhart and Winston, 1965.

[26] Tupper, E. C. Introduction to Naval Architecture, fifth edition. Elsevier Ltd, 2013.

[27] Lancaster, J. Engineering Catastrophes: Causes and Effects of Mayor Accidents. Abington, USA: Abington Publishing, 1996.

[28] IMO. Guidelines for verification of damage stability requirements for tankers. MRC. 1/Circ. 1461, 2013.

[29] de Vos, J., Hekkenberg, R. G., Koelman, H. J. Damage stability requirements for autonomous ships based on equivalent safety. Safety Science 130, 2020.

[30] Vassalos, D. The Role of Damaged Ships Dynamics in addressing the Risk of Flooding. Ships and Offshore Structures. Maritime Safety Research Centre, Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, Scotland, UK, 2020.

[31] Boulougouris, E., Winnie, S., Papanikolaou, A. Advanced damage stability assessment for surface combatants. Ocean Engineering 120, 305-311, 2016.

[32] Allied Naval Engineering Publication. ANEP-77 Part 1. Naval ship code: goals, functional objectives and performance requirements. Edition G Version 3, 2019.

[33] INSA. (2021). International Naval Safety Association. https://www.navalshipcode.org, 2021. Accessed 9th September 2022.

[34] Bassett, V. Causes and Effects of the Rapid Sinking of the Titanic. Department of Mechanical Engineering, the University of Wisconsin, 1998.

[35] Vassalos, D., Boulougouris, E., Paterson, D., Kanerva, M. Designing for Damage Stability beyond Design Level. Conference: 6th Conference on Design for Safety, Hamburg, 2016.

[36] Newworldencyclopedia. https://www.newworldencyclopedia.org/entry/RMS_Titanic, 2021. Accessed 9th September 2022.

[37] Stettler, J. W., Thomas, B. S. Flooding and structural forensic analysis of the sinking of the RMS Titanic. Ships and Offshore Structures 83(-4), 346-366, 2013.

[38] Hahn Titanic-Plans. http://www.titanic-plan.com/start_e.html, 2021. Accessed 9th September 2022.

[39] Gannon, R. What really sank the Titanic. Popular Science 246 (2), 49-55, 1995.

[40] Ball, R. E., Calvano, C. N. Establishing the fundamentals of surface ship, survivability design discipline. Naval Engineers Journal, Issue 1, 1994.

[41] Merchant Shipping Act. An Act to Amend and Consolidate the Acts Relating to Merchant Shipping. Reprinted by Theos Jones, 1854.

[42] IMO. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, 2018.

[43] IMO. https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of- Life-at-Sea-(SOLAS),-1974.aspx, 2021. Accessed 9th September 2022.

[44] Marshall, L. Sinking of the Titanic: Great Sea Disasters. Iboo Press. EAN/UPC 9781641812016, 1918.

[45] MySeaTime. https://www.myseatime.com/blog/detail/damage-stability, 2021. Accessed 9th september 2022.

[46] Hovden, S. T. Redningsdåden – om Maksim Gorkiy-havariet utenfor Svalbard i 1989, Commentum Forlag, 2012.

[47] Kemp, P. Seamanship: The Complete Illustrated Guide for the Cruising Yachtsman, first American edition, Van Nostrand Reinhold, 1983.

[48] Callman, K. Medical Education: Past, Present and Future, first edition, p. 401. Churchill Livingstone, 2006.

[49] Whitestarhistory. https://www.whitestarhistory.com/olympic, 2021. Accessed 9th September 2022.

[50] Riola, J. M., Perez, R. Warship damage stability criteria case study. Journal of Maritime Research, VI (III), 75-100, 2009.