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DESSO – Design for survival onboard

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SUMMARY

The DESSO (Design for Survival Onboard) project started December 1, 2003 and finished in March 2006. The main partners in the project were SSPA (project manager), Chalmers University of Technology, Globtech Marine AB, SP Swedish National Testing and Research Institute Fire Technology and Kockum Sonics AB. In addition to these partners the consortium consisted of four collaborating partners: Stena Line, Silja Line, Lloyd's Register of Shipping and The Swedish Club. Significant work was also carried out by three subcontractors: NAOS, MarDeQ, and Kattegatt Design. Besides VINNOVA, who was the major funding party of DESSO, significant funding also came from the Swedish Maritime Administration and the Swedish Mercantile Marine Foundation, as well as from collaborating partners. The total budget was approximately 1 million EURO.

The main objectives of the work were:

- to create a template for the conceptual design of a roll-on/roll-off passenger ship that demonstrates the possibilities of "the ship serving as its own lifeboat",
- to significantly increase the current understanding of a ship's capacity to remain upright and afloat after suffering structural damage, fire or terrorist attacks,
- to establish a Swedish/European network of companies, research institutes and interested parties within the public sector,
- to study passenger and crew survival, both regarding moving large numbers of passengers onboard and accommodating passengers for extended periods in an emergency situation.

Some important features developed for the DESSO ROPAX concept ship are as follows:

- Wide side casings to keep the vessel upright and afloat if severe structural damage occurs.
- Interior materials that have been selected to minimise the growth and spread of fire.
- Systems to ensure rapid and effective fire detection and suppression.
- Onboard decision support system.
- High degree of redundancy

Another important finding of the safety assessment portion of the DESSO project was that a well organised safety management system and a highly skilled crew is probably the most cost-effective way to avoid or limit the severity of ship accidents.

1 INTRODUCTION

1.1 Background

In March 2003, VINNOVA, the Swedish Governmental Agency for Innovation Systems, opened a call within 'MARITIME SAFETY 2003-2005 - a new step towards a zero vision'. The goal of this call, 'a ship which is its own lifeboat', was to initiate projects that would contribute to:

- establishing networks of companies, researchers and other interested parties to stimulate international development of an innovation system leading to 'the ship being its own lifeboat'.
- presenting results that show how the ship should be designed to fulfil the safety criteria to 'serve as its own lifeboat' for as long as possible.
- significantly increasing the knowledge regarding selected critical issues that influence the ship's ability to survive after a collision, grounding, fire or terrorist attack.

A consortium was established in the spring of 2003 to form a proposal. When selecting partners it was natural to choose those who were already active in the field of maritime safety. It was soon clear that the most interesting ship type to work with was the ropax. A modern ropax can carry in the order of 3000 people, mostly passengers. It was thus important to select partners who also had experience with ropax design. The DESSO consortium includes two of the biggest ropax operators in Scandinavia.

The DESSO project started December 1, 2003 and initially had a planned duration of 25 months, but this was extended to 28 months. Besides VINNOVA, who is the major funding party of DESSO, significant funding also came from the Swedish Maritime Administration and the Swedish Mercantile Marine Foundation, as well as from collaborating partners. The total budget was approximately 1 million EURO.

1.2 Project participants

Initial discussions regarding the proposal and the partnership were carried out by SSPA, Chalmers University of Technology, and Globtech. In 2003 Chalmers was represented by two different units: Chalmers Lindholmen, which focused on ship safety, and Chalmers University of Technology, which represented the more general ship technology. Today there is only one common unit called Chalmers, Department of Shipping and Marine Technology. It was decided that SSPA should act as Project Manager.

SSPA, Chalmers and Globtech are three out of a total of five partners. To strengthen the knowledge within decision support for the consortium, Kockum Sonics AB was invited as a partner. SP Swedish National Testing and Research Institute Fire Technology was invited to be the partner responsible for fire safety. In addition to these partners the consortium consists of four collaborating partners: Stena Line, Silja Line, Lloyd's Register of Shipping and The Swedish Club. These four partners contributed with their own work, while the other partners received financial support.

Significant work was also carried out by three subcontractors: NAOS, MarDeQ, and Kattegatt Design. NAOS is a design office for ropax located in Trieste, Italy, while the other two subcontractors are consulting companies located in Göteborg, Sweden. The contact persons for the partners, collaborating partners and subcontractors are provided below.

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Table 1.1 Partners, collaborating partners and major subcontractors in the DESSO project.

1.3 Objectives and structure of the work

At the proposal stage, a number of objectives for the work were presented:

- To create a template for the conceptual design of a passenger ship that demonstrates the possibilities of “the ship serving as its own lifeboat”. This means that the ship shall have floatability and fire safety better than state-of-the-art.
  - If there is a severe fire, “safe havens” for prolonged survival of passengers and crew will be available.
  - If the ship sinks, capsize will be prevented and it will be possible to evacuate in an orderly fashion.
- To significantly increase the understanding of the ship’s capacity to remain afloat after suffering structural damage, fire or terrorist attacks.
- To investigate different means of integrating the idea of a “safe haven” into a commercial, competitive passenger ship design.
- To establish a Swedish/European network of companies, research institutes and interested parties within the public sector with the aim of stimulating further development and application of the findings of the project.
- To investigate the human elements influencing the movement of large numbers of passengers onboard
- The findings of the project will be demonstrated in the concept ship: “the ship serving as its own lifeboat”.

These objectives more or less formed the structure of the work. The work was carried out as a number of separate workpackages (WP), similar to most EU research projects. The workpackage topics, leaders, and partners were as follows:

WP	Title	WP-leader	Partners
1	Project Management	SSPA	SSPA
2	Safety assessment of ships, concept generation and evaluation	Chalmers	SSPA, SP, Globtech, Stena, Silja Line, LR, SC
3	International Workshop and External Expertise	SSPA	All
4	Ropax Ship Design	Globtech	LR, Stena, Silja Line
5	Staying Upright and Afloat	Chalmers	Globtech, SSPA, Silja Line, Stena, LR
6	Decision Support	KockumSonics	Chalmers, SP, Silja Line, Stena, SSPA
7	Passive and active fire protection	SP Fire Technology	Globtech, Silja Line, Stena
8	Passenger and Crew Survival	Chalmers	SSPA, Globtech, Silja Line, Stena, SP
9	Concept Ship	SSPA	All

Table 1.2 Structure of the DESSO project.

Over the course of the project only one objective was slightly modified: the work addressing ‘safe haven’. Regarding fire it was soon obvious that onboard ships the term ‘safe areas’ is preferred to ‘safe haven’. Instead of focusing on moving a large number of passengers to ‘safe havens’ in case of fire, it is preferred to focus on limiting the area affected by fire and maintaining other parts of the ship as ‘safe areas’. The term ‘safe haven’ was also used to refer to a detachable part of the superstructure that could house approximately 1000 people. In an early stage of the project it was recognised by the consortium that there are major difficulties associated with the ‘safe haven’ solution. These difficulties are described in chapter 6, ‘Float off/fall off capsules’. Following the idea of ‘the ship serving as its own lifeboat’, the work focused on designing a ship that will remain upright and afloat for a long time. In principle, the design follows current rules and regulations, but there are some exceptions. One is that the DESSO ROPAX concept ship does not have any lifeboats. Instead rafts carried onboard are the ultimate rescue device.

1.4 Project reports

This report is the final project report for DESSO. Other reports released previously include a number of public reports describing the work carried out in the different workpackages. These reports are as follows:

WP	Report Title
WP2	DESSO WP2 Report: Chain-breakers – A survey of fatal ship accidents with the event- tree method
WP3	DESSO WP3 Report No. 1: DESSO Workshop June 15-16, 2004
WP4	DESSO WP4 Report: DESSO ROPAX Design
WP5	DESSO WP5 Report No. 1: Assessment of the Dynamic Behaviour of Damaged DESSO ROPAX in Waves DESSO WP5 Report No. 2: MSC80 ASSESSMENT DESSO WP5 Report No. 3: Carriage of Dangerous Goods Cargo On Board the DESSO Ropax Ship DESSO WP5 Report No. 4: Staying upright and afloat - Static stability assessment
WP6	DESSO WP6 Report No. 1: Decision support DESSO WP6 Report No. 2: Safety and Cargo System (SCS) for the DESSO ROPAX
WP7	DESSO WP7 Report No. 1: Fire safety approach on the DESSO ROPAX
WP8	DESSO WP8 Report No. 1: Technical support for emergency evacuation of passengers DESSO WP8 Report No. 2: Passenger and Crew Survival – planning of ship’s lay-out and safety organisation. DESSO WP8 Report No. 3: Passenger and Crew Survival – study of evacuation equipment.

Table 1.3 Public reports prepared for each of the DESSO workpackages.

An eight-page pamphlet presenting the DESSO project was also produced. This pamphlet is included as Appendix F.

2 SHIP ACCIDENTS

During the initial phase of the DESSO project it was decided by the consortium that a survey of ship accidents was a must to set a proper focus for the work in DESSO. All partners were engaged in this work, which was carried out under the Work Package 2 umbrella. A workshop held in Göteborg in June 2004 was also important for gaining an understanding of essential issues and factors to consider when designing a ship that can serve as its own lifeboat. This workshop was organised in Work Package 3. Full reports from the work in WP2 and WP3 are presented by Ulfvarson and Karlsson (2005), and Allenström (2004).

A number of passenger ship catastrophes were studied in WP2. The majority of these were from the 1990s but some older accidents, such as the Stockholm/Andrea Doria collision, were also included. Event trees were created for each case study. A complete event tree has the capacity to cover many different series of events that lead to a range of outcomes, including one that represents the actual accident considered. One branch of the event tree describes the chain of events for the actual accident and this branch has a very high degree of relevance because it is based on an actual case. 'Chain-breakers' were identified along the chain of events for each case considered. These 'chain-breakers' are points along the tree where a different action or occurrence could have changed the course of events, preventing casualties and other losses. The identified chain-breakers were categorised and analysed. The figure below shows the number of chain-breakers that were identified for each of the different accidents investigated. As can be seen, normally there are several occasions to prevent an accident.

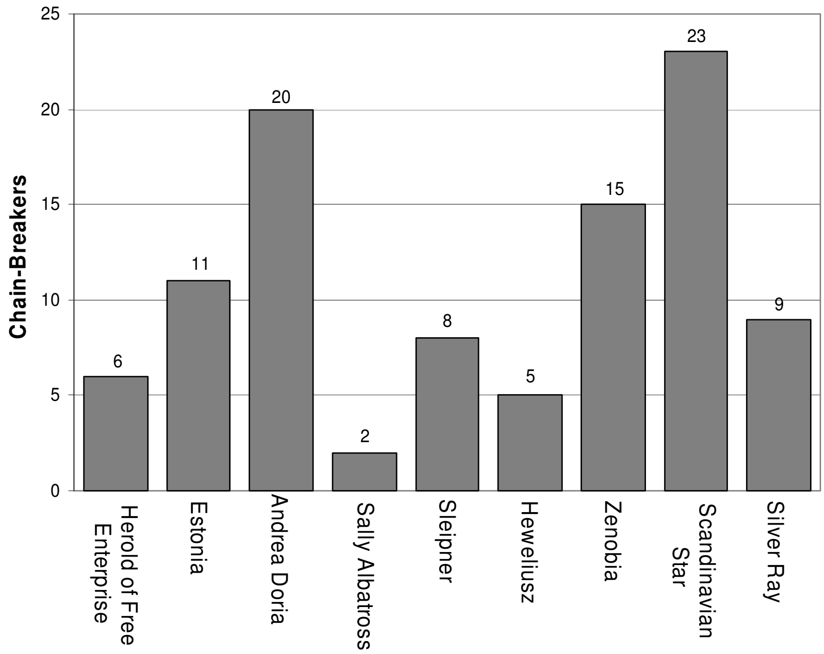

Figure 2.1 Number of chain-breakers for each accident investigated.

In general, it was found that 'management' was the initial cause of most incidents. 'Management' was also often the reason for the continuing or worsening of developments along the chain of events. 'Design features' were generally considered to act as safeguards that had the purpose of stopping or reducing the consequences of a series of events after they had been initiated. In most cases the purpose of the 'equipment' chain-breakers was to limit the severity of the outcome.

Even though improvements to 'management' would obviously result in significant gains for maritime safety, this wasn't the central focus of DESSO. DESSO has instead focused on 'design features' and 'equipment'. From discussions at the workshop held as part of WP3, two main areas emerged as a focal point for the DESSO work:

- The main effort when designing the DESSO concept ship will be to have it remain upright if damaged, so that passengers and crew can be evacuated in an orderly way. Even if the ship is sinking slowly, it should stay upright and never capsize. Examples of orderly methods of evacuation include moving the ship to a harbour or transferring people directly to another ship.

- Fire should never have to be the reason for abandoning the ship. The concept ship will be designed in such a way that a fire will either not spread or will spread very slowly, allowing passengers and crew to stay onboard until they can be evacuated in an orderly way.

Keeping the ship upright and afloat is of course a ‘design feature’. To achieve this, the focus was placed on the General Arrangement (GA) of the DESSO ROPAX. Although the GA is also of utmost importance for preventing severe fires, equipment plays an essential role too. As was concluded in the WP2 work, decision support systems are also very valuable for the safety of a ship. These systems should be categorised as equipment. As stated above, equipment can often limit the severity of the outcome, and this is especially valid for both decision support systems and for systems that limit development and spread of fire.

After careful consideration of the information generated from WP2 and the Workshop, a guiding philosophy for the DESSO work was developed:

Highly skilled management is one of the primary factors for increasing safety onboard. However, even with a very highly skilled crew, incidents will occur. Equipment onboard can effectively limit the consequences and serve as chain-breakers. When a scenario develops that neither management nor equipment can control, the design must be so ‘forgiving’ that even a very severe situation is manageable because the ship remains upright and afloat, and any fires that may be initiated onboard do not spread.

The DESSO WP2 Report (excluding appendices) is provided in Appendix A.

3 THE GENERIC ROPAX DESIGN

As early as the project proposal stage, discussions were taking place on how the DESSO ROPAX design should be developed and compared with state-of-the art ropax vessels. Using an existing ship can result in complications with the ship owner. Ship owners are almost never willing to disclose design details such as hull lines. If questions regarding safety issues on an existing ship arise during the research work, a complicated situation can develop. To avoid this issue in the DESSO project, a ship that had been designed but not built was selected as a basis for the study. This ship, the EuRoPax 3000, designed by NAOS, originally has a capacity of 850 passengers. In the initial phase of the DESSO project the consortium discussed the passenger capacity of the DESSO ROPAX and selected 1500 passengers as a sort of compromise.

3.1 EuRoPax 3000

The generic ropax design EuRoPax 3000, which fulfils all present rules, constituted the basis for the safety engineering work carried out within the DESSO project. As mentioned above the ship has a capacity of 1500 passengers (1000 beds) and 3000 lane meters for trailers, a capacity rather typical for many European short sea routes. The design is truly generic as a wide range of cargo access modes, capacities and passenger facilities can be adopted without changing the basic safety principles in the design. The same paradigms were then adopted for the DESSO ROPAX.

3.2 Safety features

The EuRoPax 3000 has very good ‘upright and afloat’ properties for a wide range of damages. The spatial arrangements below the freeboard deck of the EuRoPax 3000 are such that the engine compartments are located outside the B/5 (one fifth of the breadth of the ship) longitudinal bulkheads. With this arrangement the following is achieved:

- Simple solutions for fulfilment of the current rules for floatability after sustaining damage

- Uncomplicated arrangement for symmetrical flooding for increased safety in case of damage. Symmetrical flooding results in small heeling angles, which is a requirement for safe evacuation
- A very good utilisation of the lower hold, which has the desirable features of straight lanes and straight access.

The EuRoPax 3000 also has closed side casings from the freeboard deck up to the passenger accommodation. This does not receive any bonus from the rule point of view, but does provide additional safety against rip-up and minor structural damages.

3.3 Commercial features

Cargo areas are designed with straight lanes and there is the possibility to arrange straight entrances to the lanes. These arrangements result in the following benefits:

- Fast and safe cargo handling.
- Possibilities for automatic or semiautomatic securing of the cargo.
- Possibility to have structural pillars placed on the decks, which in turn results in a lighter deck structure and is also helpful for reducing consequences of solid cargo shift.
- The “outside B/5” arrangement of the engine rooms facilitates a very good utilisation of the lower hold.
- The EuRoPax 3000 concept has the flexibility to accommodate the most common methods of handling rolling cargo and to allow passengers to embark and disembark on more than one level. It also allows through-driving on one or more levels including the lower holds or a combination thereof including vehicle turnaround.
- The accommodation areas have full flexibility to be adapted to the trade requirements.

A sketch of the EuRoPax 30000 is shown on next page (Figure 3.1). To summarise, the EuRoPax 3000 is a modern ropax that meets today’s high safety and efficiency standards. The goal within the DESSO project to present an even better design was therefore quite a challenge.

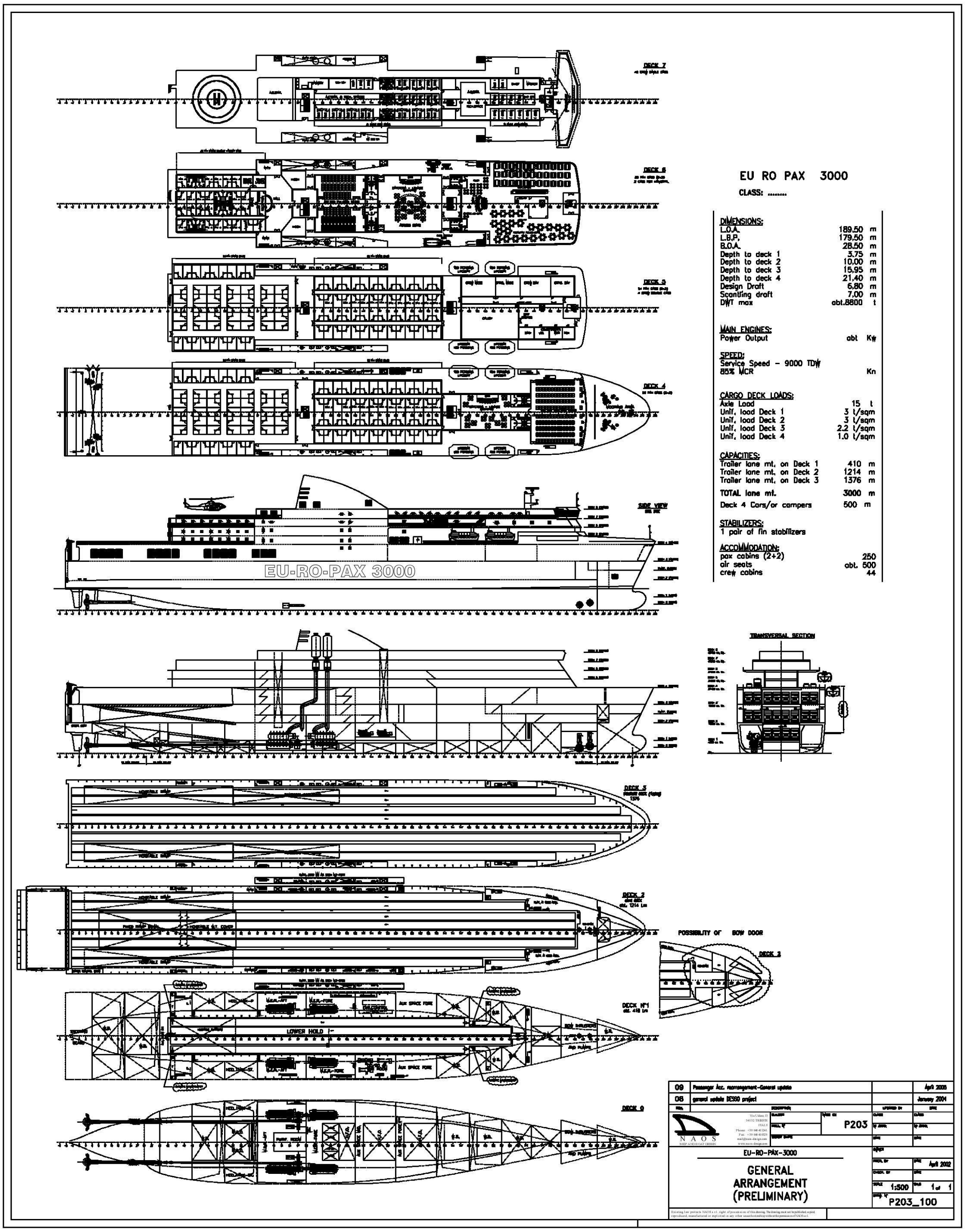

Figure 3.1 A sketch of the EuRoPax 3000.

4 STABILITY IN CASE OF STRUCTURAL DAMAGE

As mentioned previously, a workshop was held during the initial phase of the DESSO project. Results of workshop discussions, considered together with findings from Work Package 2, showed that ‘upright and afloat’ are key words for survival after sustaining severe damage. The interpretation of the ‘upright and afloat’ concept in the DESSO project was as follows:

> According to an old ‘rule of the thumb’, when the heel angle reaches 12 degrees, panic can break out among the passengers onboard. More modern studies indicate that passengers experience difficulties moving around the ship long before the heel angle reaches 12 degrees. One goal in the DESSO project was to limit the heel angle to 10 degrees, but in the initial phase of severe damage this is not always possible. However, the DESSO ROPAX is equipped with a decision support system that will inform the crew of how to best ballast the ship in an emergency situation. For this reason, heel angles exceeding 10 degrees should not be experienced for any significant length of time.

The expression ‘severe damage’ is used in the previous paragraph. What is severe damage and how can it occur? The latter part of the question has not been dealt with by the consortium in detail. Because the call for proposals indicated that the ship should survive incidents such as collision, grounding, fire, and terrorist attacks, any detailed description of how the damage was caused seems unnecessary. However, Figure 6 in Appendix C shows that very severe damage has occurred in collisions. As a definition of ‘severe damage’, the DESSO project has adopted the 3 compartment MCA (Maritime and Coastguard Agency, UK) damage. In plain language this means that the DESSO ROPAX would sustain damage from the ship side that extends into more than half of the ship breadth, and in the longitudinal direction of the ship three water tight compartments would be damaged (see Figure 7 in Appendix C). The consortium knows of no existing ropax that can remain upright and afloat after sustaining such damage. Ropax operating today will probably capsize and sink within minutes after sustaining this type of damage. A high-speed collision with another ship, or perhaps a terrorist attack, would cause this type of damage. The necessary speed required for the striking ship to cause severe damage was not determined in the DESSO project, but according to statistics mentioned above these types of damages have occurred. The possibility of designing a ship that structurally could survive such a collision was discussed within the consortium, and also investigated in some minor studies.

The second key word is 'afloat'. In the DESSO project one meaning with the word is that the ship is possible to accommodate all the 1500 passengers when damaged and until rescue is possible. The goal within DESSO was to design a ship that would stay afloat long enough to allow it to be abandoned in an orderly way, meaning that passengers should be able to abandon the ship by walking across a gangway to shore or to another ship. In the DESSO project it was decided that 24 hours was a reasonable length of time for the ship, if possible, to return to port or be assisted by other ships. A ropax trafficking European waters is seldom many hours away from a port or a route with other ship traffic nearby. 24 hours was therefore regarded as a plausible time frame, but 24 hours plus/minus 6-12 hours is also probably relevant. In other words, the DESSO ROPAX is not unsinkable, but it should stay afloat (and upright) long enough to be able to steam to port or to be assisted by other ships. If the same design philosophy is applied to a cruise ship, the target time frame may have to be adjusted. It should, however, be mentioned that no detailed calculations were carried out to estimate the length of time the DESSO ROPAX will stay afloat after being severely damaged. For the damage case studied within DESSO, the ship will theoretically stay afloat forever, but in practice one can imagine that minor leakage can eventually lead to foundering.

The stability study is presented in Appendix C. The two main parameters for staying upright and afloat are very easy to describe: one needs reserve buoyancy and residual stability. For the DESSO ROPAX the goal was to design a ship that was better than state-of-the-art. This also meant that it should be commercially competitive. To meet this requirement, the lane meters and other revenue-generating areas should be the same or possible larger than the generic ship (also referred to as the template ship). Other requirements for the design was that the DESSO ROPAX should have full redundancy regarding powering as well as cross flooding in the event of damage. Of course these two latter requirements have had a certain influence on the general arrangement, but it was mainly the requirement for maintaining the lane meters that had the most obvious impact on the DESSO ROPAX. It was found that the best solution for getting the reserve buoyancy and reserve stability, without reducing lane meters, was to introduce wide side casings. The DESSO ROPAX can, therefore, more or less be compared with a floating dock.

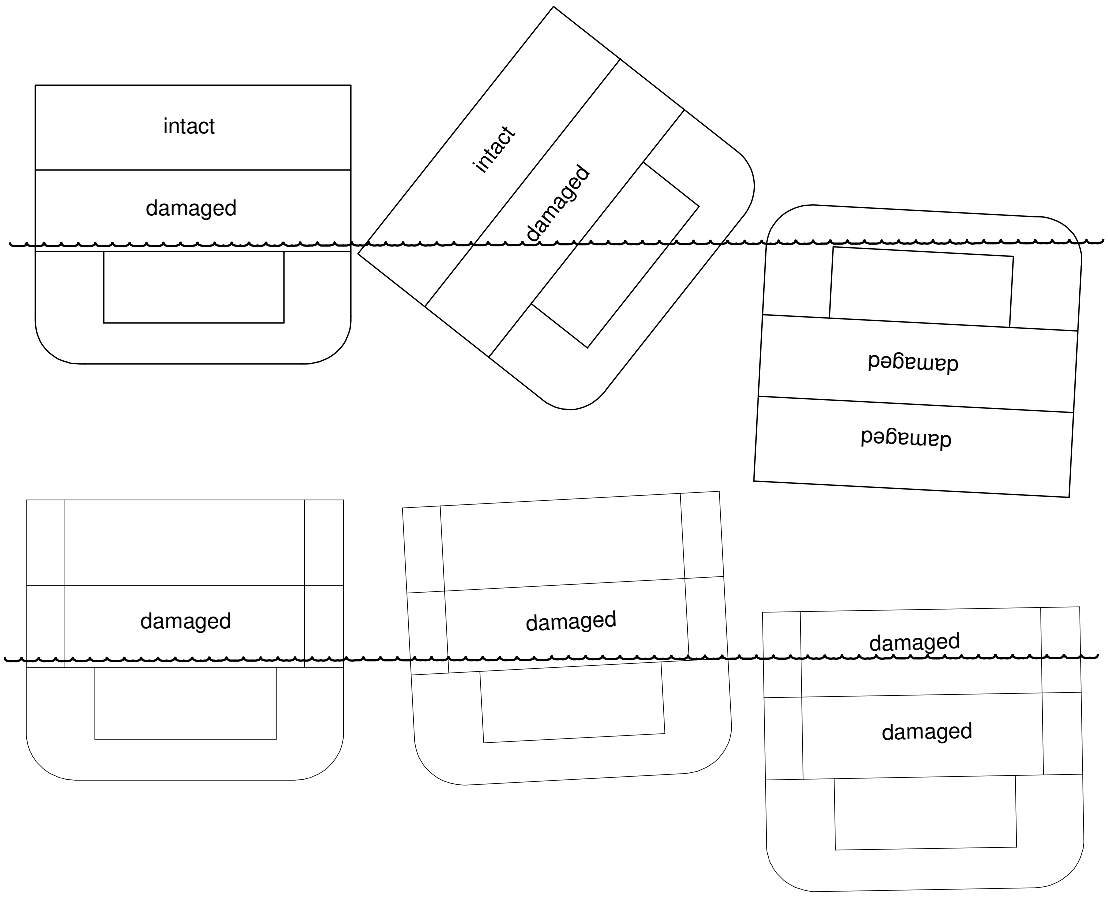

Figure 4.1 Effect of severe damage on vessel designed with wide side casings (lower pictures) compared to state-of-the-art design.

One result of introducing the wide side casings is of course that the whole superstructure part of the ship became wider to maintain the same the lane meters. The underwater body, however, gradually increases in breadth from bottom to waterline and then curves out to the maximum breadth. This was done to avoid having a too-stable ship that could develop unpleasant roll motions. The proposed hull shape needs further study, especially from a hydrodynamic point of view. A softer transition from maximum breadth down to breadth at bottom may possibly have better performance. When launching fast rescue boats it is frightening to risk having one caught under the side casings. A significant improvement with the DESSO ROPAX design, however, is that the fast rescue boats can be placed very low because of the wide side casings.

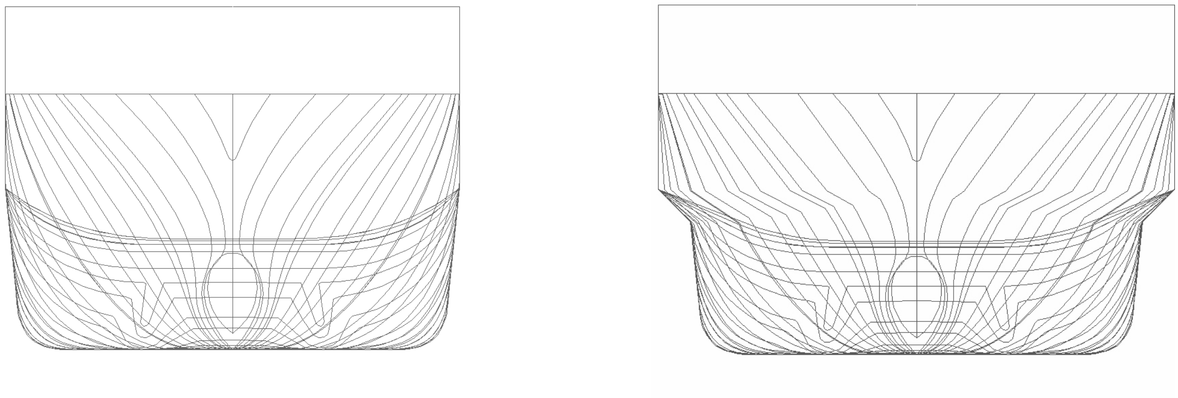

Figure 4.2 Generic ropax design (on the left) compared to the DESSO ROPAX.

As mentioned above the report on stability and floatability (excluding appendices) is included in Appendix C.

5 FIRE SAFETY ON THE DESSO ROPAX

Fires are a serious hazard on ships; several studies have shown that for crew and passengers the hazard of fire is second only to foundering. A main goal of the DESSO project was to design a ropax vessel with fire safety that is better than "state of the art". To achieve this, the fire safety work carried out under WP7 of the DESSO project focused on measures that would minimise the growth and spread of fire from its point of initiation, and maximise the time one can survive on the burning ship. This also relates to the overall project goal of designing a ship "that is its own lifeboat", by aiming to reduce the need to evacuate due to fire.

The basic starting point with respect to fire safety for the DESSO ROPAX was to fulfil all the prescriptive requirements set out in the relevant regulations, including SOLAS Chapter II-2, the International Code for the Application of Fire Test Procedures (FTP), and the International Fire Safety Systems Code (FSS). It was important that the measures proposed for improving fire safety beyond the level provided by the regulatory requirements be:

- realistic,
- simple and achievable, and,
- cost effective.

Fire safety improvements have been achieved through an astute design and lay-out of the ship, judicious selection of materials in order to minimise the growth and spread of fire, and rapid fire detection and response, coupled to fire mitigation or a combination of these activities. It is imperative that the reliability of active fire protection measures, such as fire detection systems or sprinkler systems, is high. Redundancy and reliability beyond the present regulatory requirements has therefore been sought.

Part of the work to identify measures for improved fire safety included an analysis of previous accidents. In DESSO WP 2 (Ulfvarson and Karlsson, 2005), an analysis of the damage due to fires, the risk for fire spread and consequences of such spread for two disastrous ship fires, the fire on board Scandinavian Star in 1990 and the fire on board Silver Ray in 2002, was carried out. The goal of this analysis was to identify key event chain breakers that could provide the greatest potential benefit for improvements.

Safety analysis and development of measures to improve fire safety was focused on three main categories of spaces on board a ropax ship, namely the:

- accommodation and service spaces,

- machinery spaces, and,
- ro-ro cargo decks (defined as “special category spaces”).

Work carried out for each of these space categories is summarised below. Further details of the work can be found in Appendix D. However, the full report presented in Appendix D contains appendices, but they are not included in the present report.

5.1 Accommodation and service spaces

Fire within the accommodation and service spaces on board a ship will put many passengers in immediate danger. The suggested fire safety approach for these spaces on the DESSO ROPAX can be summarised as follows:

- The first and foremost objective was to improve the fire characteristics of combustibles as compared to the present regulatory requirements. All bedding material and all electrical cables fulfil requirements in excess of present requirements.

- The means for escape has been improved through a simplistic lay-out of the cabin and corridors and all stairways lead directly to the internal assembly stations at the deck above the accommodation spaces. These spaces are considered ‘safe areas’ and can safely accommodate all the persons onboard to protect them from hazards to life or health and provide them with basic services.

- The active fire protection systems, i.e. the fixed fire detection and fire suppression systems have been enhanced through improvements to design, performance, reliability and redundancy.

- The use of an active smoke control system in the spaces will limit the spread of smoke and improve the possibilities for manual fire fighting.

Mattress fire tests

To achieve the objective of improving the fire characteristics of combustibles, fire tests were carried out on a number of mattresses currently approved for use on board passenger ships. Mattresses were chosen as a subject for testing because they probably constitute the highest fire load of all items inside passenger and crew cabins. It is therefore important that these components have as high resistance to ignition and flame spread as possible. The fire tests described in the report by Arvidson et al. (2006) indicate that compliance with the present regulatory requirements is not a guarantee that mattresses will not burn severely when ignited with a larger fire ignition source. Figure 5.1 illustrates the test performance of two different mattress types.

Figure 5.1 The difference between the fire performance for two mattress types is illustrated in the above photographs. The mattress on the upper picture has high resistance to ignition and exhibits other good fire performance properties, while the mattress on the lower picture clearly has much worse fire performance properties.

For the DESSO ROPAX “fire-resistant” mattresses were chosen - mattresses that fulfil the requirements of SS 876 00 10, “Health care textiles - Fire requirements - Extra high resistance to ignition of mattresses intended for special purposes” (Swedish Standards Institute, 2001) and therefore provide high protection against arson and decreased risk of rapid fire development in the cabin.

Smoke control system

If a fire does develop in the accommodation and service spaces of the DESSO ROPAX, an active smoke control system will limit the spread of smoke and toxic gases. The philosophy for the active smoke control system for the passenger accommodation spaces is that smoke should be extracted from the escape routes, i.e. the corridors, to keep them sufficiently free from smoke and toxic gases. Stairway enclosures and surrounding areas should be kept under overpressure by the ventilation supply air system in order to prevent smoke from spreading to these areas.

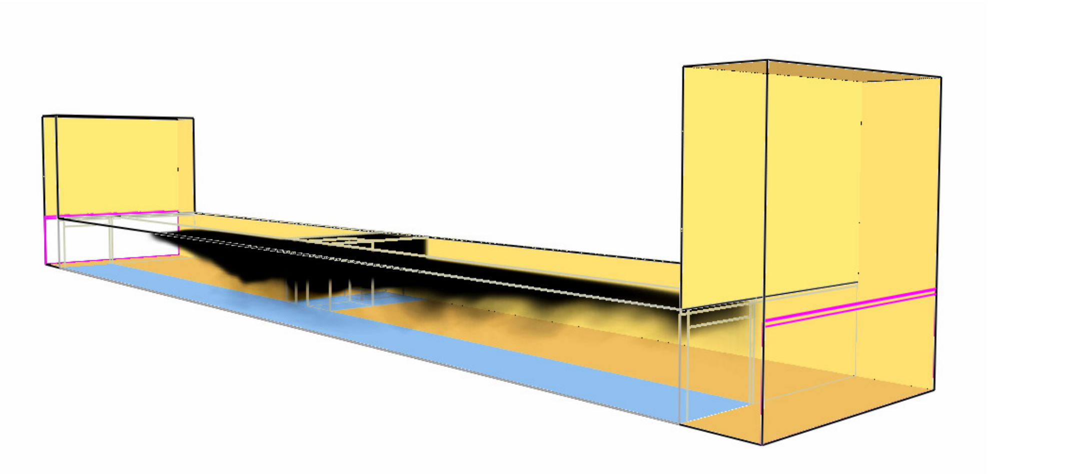

Figure 5.2 An active smoke control system can keep corridors free from smoke and toxic gases. This is an advantage for evacuation of the affected areas and for manual fire fighting. Specifications for the system on the DESSO ROPAX were developed using CFD (Computational Fluid Dynamics) calculations.

5.2 Machinery spaces

About two-thirds of all fires on board ships start in the machinery space (Det Norske Veritas, 2000). These fires can result in costly damages to the ship, and they also represent a hazard for crew members and fire fighters and may lead to a situation where passengers need to be evacuated from the vessel. For the DESSO ROPAX, a number of measures have been taken to improve the fire safety of the machinery spaces. First and foremost, the use of separate machinery space compartments represents an improvement. The DESSO ROPAX is equipped with four main diesel engines located inside four separate compartments, two compartments on each side of the ship. However, the two fore compartments are in open connection due to cross-flooding reasons.

Several different fire detection techniques are specified for use in the machinery spaces, with the intention to detect a fire at an early stage, in a reliable fashion. The choice of fire detection techniques allows rapid detection of both flaming fires (flammable liquid spray fire or spill fires) and smouldering fires.

The high-pressure water mist system protecting the machinery space compartments will activate automatically during a fire, and a foam additive, of a film-forming type, will be mixed with the water using a foam proportioner, in specific sections of the system. The use of a foam additive enhances the performance on, for example, flammable liquid fires.

5.3 RoRo cargo spaces

Fires on ro-ro cargo decks are rare and, historically, have not represented a major risk for passengers and crew. However, the property loss can be large if the fire is not manually extinguished or if the fixed fire-fighting system fails to control the fire. There are cases where a fire has spread throughout the ship (Det Norske Veritas, 2005).

The ro-ro cargo spaces on the DESSO ROPAX are considered “special category spaces”, i.e. enclosed spaces on a deck intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion and to which the passengers have access. Therefore, SOLAS Chapter II-2, Regulation 20 requires that the deck shall be protected with an approved deluge type sprinkler system. Other types of fixed fire-fighting systems are in principle not allowed, due to the safety concerns for the passengers.

The main improvement on the DESSO ROPAX has been made by sub-dividing the ro-ro cargo spaces into smaller volumes by active fire-resistant smoke and fire barriers (traditionally known as fire curtains). These fire barriers are shut upon completion of loading and open during loading and unloading of the deck. Furthermore, the fire resistance between the individual ro-ro cargo decks and the ro-ro deck and the division between the upper ro-ro deck and the accommodation spaces above this deck has been improved.

In addition, it is possible to remotely close the aft port and the internal hoistable ramps in case of fire. The reason for the measures described above is to limit the availability of air to a fire and thereby reduce its size.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems, have been enhanced through improvements to design, performance, reliability and redundancy. The high-pressure water mist system is automatic and the pump capacity is sufficient to activate all the nozzles within the sub-divisions.

5.4 Application of the "safe area" concept on the DESSO ROPAX

An important measure to achieve improved survivability on passenger vessels is the "safe area" concept. It should be underscored that the "safe area" is not intended to be a single area or space outside the main vertical zone affected by the fire; it is, rather, any area outside the main vertical zone(s) in which a fire has occurred that can safely accommodate all the persons onboard in order to protect them from hazards to life or health and provide them with basic services. In the event of a casualty, the "safe area" should allow passengers and crew members to stay safely on board as the ship proceeds to port.

The overall fire safety approach on the DESSO ROPAX is in line with the safe area concept; if a fire occurs, its growth and spread should be as limited as possible and the spread of smoke should be limited. In addition, improved means for rapid fire detection, manual fire-fighting and the fixed fire-fighting system is suggested.

6 FLOAT-OFF / FALL-OFF CAPSULES

Although the goal of the DESSO project was to design a ship that can serve as its own lifeboat, the project scope included an investigation into evacuation systems. This work focused on two means of abandoning ship: a float-free module and float-free, free-fall lifeboats connected with a fire-safe assembly station. The feasibility of implementing these systems on the DESSO ROPAX was investigated as part of work package 8.

6.1 Float-free module

The float-free module considered for the DESSO ROPAX was a watertight structure that would be located on top of the ship (see Figure 1 for a general representation). If the "mother" ship sinks, this float-free structure would be released from the superstructure to float on the water surface.

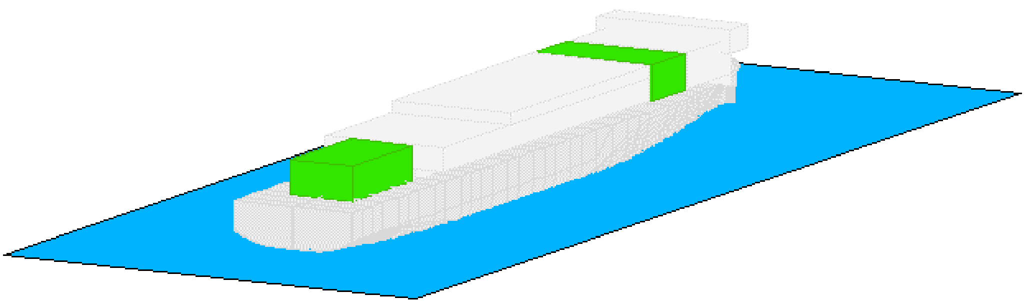

Figure 6.1 Principal location of float-free units (green) on the ship. 2 capsules with capacity of 1500 occupants each.

Advantages of using a float-free system are as follows:

- Two phases of evacuation, assembling at the assembly station and boarding the equipment, are combined in one step.
- The system is easy to board.
- A comfortable and safe waiting area is available for passengers and crew.
- The occupants don't need to be moved if there is a need to abandon ship.
- The abandon capsule can be used for regular onboard activities.
- Separate equipment for abandoning ship is not required.
- The system is suitable for all crew and passengers including the disabled, elderly, and children.

The main disadvantages of the system are:

- The cost is high.
- The ship can't be abandoned before it sinks. The system can't be used to abandon the ship during a grounding incident.
- Placing a large number of people in two units results in a higher risk and more serious consequences if the evacuation procedure with this system goes wrong.
- When launched, there is a risk of collision between ship and capsule.
- A high water depth is needed, up to 30 m, for the system to work.

6.2 Float-free, free-fall lifeboats

The focus of the study on float-free, free-fall lifeboats was to examine the launch of large free-fall lifeboats from a passenger ship and to present launch setups that provide successful launching. These investigations were carried out using a numerical program developed by Wisniewski (Wisniewski 1999 and 2003). This program was carefully verified against experiments for a regular-sized lifeboat with a length of approximately 6 m. The results from the regular-sized lifeboat tests were used as reference data for simulations of the larger free-fall lifeboat.

For the DESSO study, the criteria for a successful launch were considered to be the following:

- The maximum acceleration at water entry must be < 7 g (≈ 70 m/s^2).
- The lifeboat must make positive headway from the mother ship after water entry.
- The lifeboat must not capsize.

Several numerical simulations were performed with both a regular-sized free-fall lifeboat and a large free-fall lifeboat, and the criteria presented above were used to determine if the launch was successful. The results from these numerical simulations were used to specify allowable ranges of launch parameters for large free-fall lifeboats. The influence of each of the following parameters was investigated:

- Launch angle
- Launch height
- Ramp length
- Location of center of gravity
- Moment of inertia

The possibility of launching a free-fall lifeboat from a ship with a 20° list was also investigated.

Conclusions regarding the launch of a large free-fall lifeboat (length 16 m) from a passenger ship are as follows:

- Launch angles in the range of 20°-70° are safe for an upright ship. A launch angle of 10° may also be acceptable but this is somewhat uncertain.
- Launch heights up to 20 m are acceptable.
- A longer ramp provides lower accelerations at water impact. A ramp length ratio (ramp length / boat length) of 1.15 was successfully used in the study.
- The center of gravity must not be located far forward or aft, or very low or high. Placing the center of gravity at these positions may cause the lifeboat to capsize after water entry.
- Given that IMO resolution A.687 (17) requires that it should be possible to launch a free-fall lifeboat from a ship with a 20° list, the allowable launch angles are limited to 40°-50° (possibly 30°).
- The moment of inertia affects the level of accelerations at water entry. A higher moment of inertia will provide lower accelerations.

The results and conclusions presented above are valid for the large lifeboat investigated in this study. The use of large free-fall lifeboats with different hull designs may result in slightly different conclusions but it is believed that no substantial changes would be required.

7 HAZARDOUS CARGO ONBOARD THE DESSO ROPAX

Carriage of dangerous goods on a ropax vessel can be a risk for passengers, the vessel and other cargo. The goal of the DESSO project was to design a ship that is "safer than state of the art". To ensure that carriage of dangerous goods on the DESSO ROPAX was in line with this goal, a review of current regulations, information on risks, and previous incidents with dangerous goods transport was carried out to develop recommendations for the DESSO concept ship. The goals were to ensure that as a minimum the current standards were met and to attempt to identify potential areas where safety could be improved.

A search for information on previous dangerous goods accidents on ropax vessels did not identify any reports of major accidents attributed to dangerous goods transport on passenger ships. Within the Baltic Sea and Swedish waters, one minor dangerous goods accident has occurred in recent years (in 1999). It had minor consequences and was the result of undeclared dangerous goods (charcoal) that had not been cooled properly prior to transport.

Within the DESSO project, discussions were held with ropax operators on the project team to identify major issues and concerns related to dangerous goods transport. The carriage of undeclared dangerous goods was mentioned as a significant concern. Dangerous goods that are properly declared and transported according to the regulations (IMDG and SOLAS) were not thought to pose a problem. Although Customs, Coast Guard, and the shipping companies themselves carry out spot checks of transport units, it was considered that these were insufficient to stop all undeclared goods. The fact that undeclared dangerous goods have been discovered during these checks shows that it is valid concern. The most appropriate way to deal with this problem is goods handling and management procedures such as increased screening and inspections or increasing awareness about dangerous goods regulations.

Regarding carriage of dangerous goods on the DESSO ROPAX, it was considered appropriate to carry goods both on a "weather deck" and under deck in "closed ro-ro spaces". The weather deck of the DESSO ROPAX would be the only deck where all classes of dangerous goods permitted for carriage on passenger vessels could be carried. The designation of a weather deck means that a wider range of dangerous goods classes may be carried. Decks 2 and 3 would be designated as "closed ro-ro spaces" for the carriage of dangerous goods, but would not be designated for carriage of classes 1.1 to 1.6, flammable gases (class 2.1) and liquids with a flashpoint less than or equal to 23 degrees Celsius (Class 3, 6.1, or 8). Deck 1 was not designated for dangerous goods carriage simply to add an additional factor of safety adjacent to the machinery spaces. Table 7.1 lists the classes of dangerous goods that would be carried on the DESSO ROPAX.

Hold / Class	1	2	3	4		
1.1 – 1.6		X	X	P		
1.4 S		P	P	P		
2.1		X	X	P		
2.2		P	P	P		
2.3		P	P	P		
3 FP <23°C c.c.		X	X	P		
3 FP >23°C c.c. -≤61°C c.c.		P	P	P		
4.1		P	P	P		
4.2		P	P	P		
4.3		P	P	P		
5.1		P	P	P		
5.2		X	X	X		
6.1 liquids		P	P	P		
6.1 liquids FP < 23°C c.c.		X	X	P		
6.1 liquids FP≥23°C≤61°C c.c.		P	P	P		
6.1 solids		P	P	P		
8 liquids		P	P	P		
8 liquids FP < 23°C c.c.		X	X	P		
8 liquids FP≥23°C≤61°C c.c.		P	P	P		
8 solids		P	P	P		
9		P	P	P		

Table 7.1 Dangerous Goods Classes Proposed for Carriage on the DESSO ROPAX, where P indicates PACKAGED GOODS PERMITTED and X = NOT PERMITTED.

In the DESSO ROPAX Deck 2 and 3 are designated as closed ro-ro spaces. Deck 4 is designated as a weather deck. There are no special requirements in SOLAS II-2/19 for the carriage of dangerous goods of classes 6.2 and 7, therefore they are not shown on Table 7.1.

8 DECISION SUPPORT SYSTEMS

A relatively advanced Decision Support Systems (DSS) was proposed for the DESSO ROPAX. The general opinion is that an advanced decision support system can be a decisive factor for minimising consequences of a severe accident. For a ship to remain upright after sustaining 3-compartment MCA damage, however, it must have quite a 'forgiving' design, such as the DESSO ROPAX. For less severe damage the DSS can be extremely valuable for helping the bridge officers onboard to make the right decisions.

DSS may have different focus and objectives. DSS that primarily provide support to the bridge officers can, for example, provide guidance with the following:

- Manoeuvring the intact or damaged ship in congested waters or in complicated traffic situations.
- Reducing pollution risks and minimising consequences of spills and other environmental accidents.
- Handling the ship in an accident situation such as water ingress, fire and/or cargo shift.

The DESSO DSS is a system for crisis handling of the third type. The DESSO DSS can provide:

- Early warnings of water ingress, cargo shifting, smoke and fire.
- Prediction of the final ship state (floating condition, capsizing or sinking).
- Prediction of the time to reach the final state.
- Assistance in decision making regarding ship handling (manoeuvering, water pumping, fire fighting).
- Assistance with decision making regarding evacuation, if necessary.

The DESSO DSS would be connected to the video camera system and the fire alarm system onboard, and would provide data to the shipping office work station. The system has a simulation mode for hands-on training to practice handling critical situations.

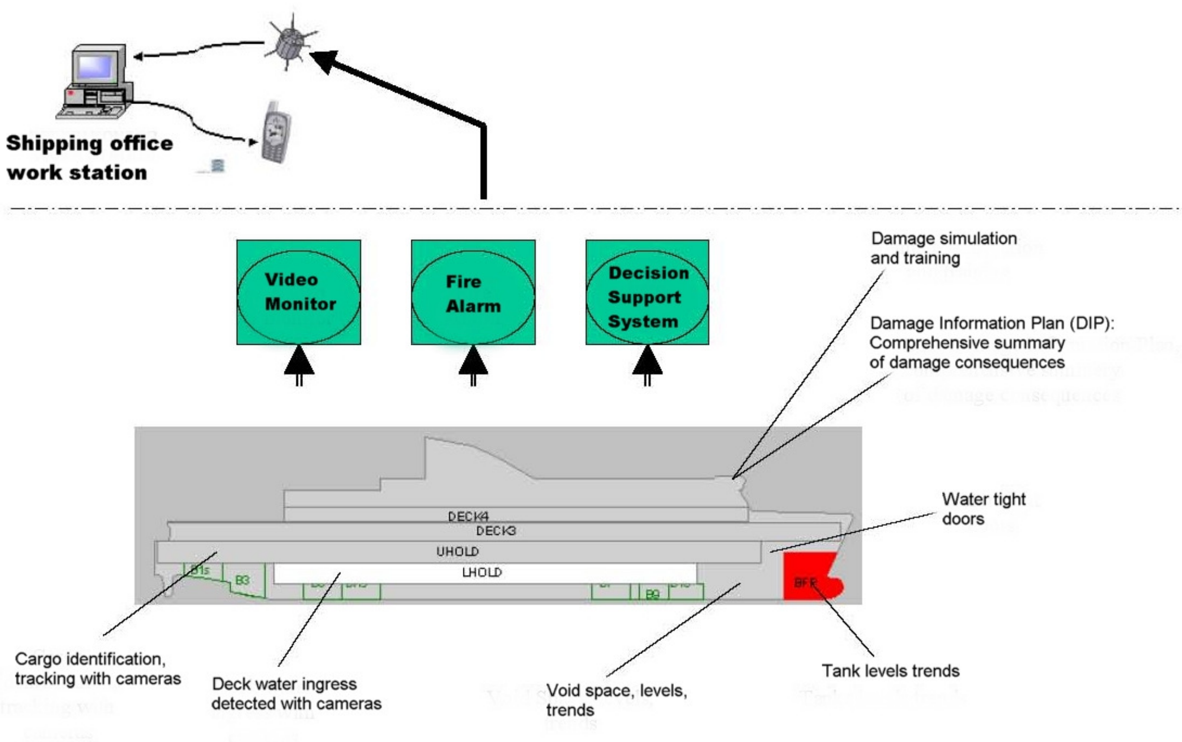

Figure 8.1 Principle inputs to and functions of the DESSO Decision Support System.

Note that the DESSO DSS was designed as part of DESSO, but it was not possible to implement it within the project. However, parts of the system were implemented and tested in the Kockum Sonics “Safety and Cargo System SCS” installed onboard MS Skåne.

9 HUMANS ONBOARD

In an emergency situation, passengers onboard the DESSO ROPAX will need to be evacuated to safe areas of the vessel to protect them from dangers such as fire and smoke or to prepare them for an eventual evacuation of the ship. In cases of extreme damage there may also be the need to abandon ship over a shorter period of time. The “humans onboard” component of the DESSO project focussed on:

- facilitating and improving evacuation and movement of passengers in an emergency situation, through technical and management means
- planning and arranging the ship’s passenger-accessible areas and assembly stations to ensure a safe and comfortable wait during an emergency situation that may last up to 24 hours.

9.1 Supporting emergency evacuation of passengers

A review of information from selected passenger ship and ropax accidents was carried out to identify problems related to the time-limited evacuation of passengers. Problems identified included the following:

- Breakdown of the ship’s safety organisation due to heavy workload and stress caused by the accident
- Escape route identification difficulties caused by complex interiors and confusing signage
- Difficulties with radio communication within the safety organisation
- Difficulties searching cabins and public spaces
- Public address system malfunctions and sound quality issues
- Evacuation in smoke
- Evacuation in a condition of large heel angle

Improvements to the design of evacuation routes and technical support systems were suggested to help prevent these problems. A summary of these improvements is as follows:

- Interactive information system that supports passenger education and preparation for an effective evacuation. It can also support the passengers by providing information during an accident and be a complement to other sources of safety information, such as information broadcast over the PA system.

- Improvements to signing and emergency lighting that take into account human factor aspects and evacuation strategies in smoke.
- Use of directional sound as a complement or alternative to low location lighting.
- Emergency Escape Breathing Devices (EEBD's).
- Digital mobile communication system covering all communication needs including internal and external communication on a normal daily basis, as well as safety related and emergency communication.
- System for passenger surveillance using RFID (radio frequency identification) that can facilitate search tasks and give management the ability to identify bottlenecks and uneven distributions of passengers during evacuation.

Figure 9.1 Example of signs indicating emergency evacuation route. The low location light is at the height of the handrails that support an up-right escape. The handrails are equipped with tactile signs that support evacuation in smoke and aid people with impaired vision.

Further details on suggested systems to facilitate evacuation on the DESSO ROPAX can be found in the report by Wilske and Ellis (2005).

9.2 Provision of safe and comfortable passenger areas during emergency situations

The focus of this portion of the work was to provide recommendations on how to keep passengers and crew of the DESSO ROPAX safe and comfortable while waiting for rescue and evacuation. Because the DESSO ROPAX is designed to serve as its own lifeboat and should stay afloat for at least 24 hours after sustaining damages, passengers and crew may need to be accommodated in designated safe areas for long periods during an emergency situation.

Factors that could influence human behaviour during an extended waiting period were investigated and considered when specifying the layout of accommodation and public spaces. Stress reactions, group behaviour, effects of waiting, and communication were considered throughout the design process. To enable a sequential clearing out of accommodation and public spaces during an emergency situation, passenger accessible areas were divided into three zones. These zones were specified as yellow, orange, and red alert areas and the appropriate level of alert will be designated during an incident by the crew based on the seriousness of the situation. A description of each alert level is as follows:

- **Yellow alert:** As long as the crew estimates the situation to be safe, passengers will be allowed to stay in all areas.
- **Orange alert:** A change of the situation to a more serious state will cause the alert level to be raised to orange. Passengers will have to be awakened and moved from cabins and family rooms, but will be allowed on the leisure and evacuation decks. The cabin decks will be searched by crewmembers and then closed.
- **Red alert:** An even more serious development of the situation will trigger a clearing out and closing of the leisure decks. When all passengers are gathered on the evacuation deck an evacuation will be initiated.

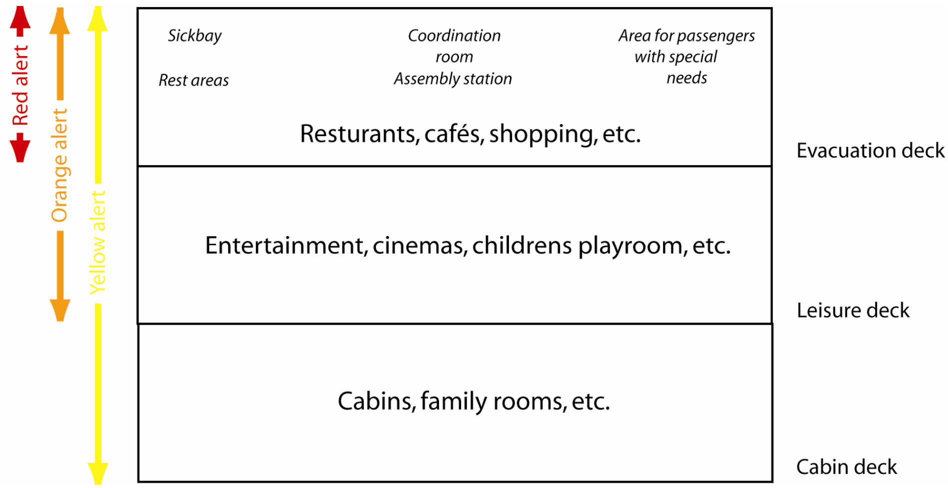

Figure 9.2 Designation of passenger spaces for emergency alert levels.

The sequential clearing out of the accommodation areas and public spaces will provide the time necessary to inhibit crowding and to prepare passengers. If crowding is prevented most factors which risk triggering violent behaviour within the group are eliminated. The additional time will also give passengers the opportunity to group with family and friends, dress properly, receive information and mentally prepare themselves to evacuate the ship.

Regardless of which zone has been designated, passengers must have access to a minimum level of facilities. This implies redundancy when it comes to the rest areas, the sickbay, coordination room and the areas for passengers with particular needs. A more detailed description of the layout of accommodation and public areas is provided in the report by Rutgersson et al. (2005), which is included as Appendix E.

9.3 Communication and ship's safety organisation

Effective communication is very important during an emergency. The provision of sufficient information will help keep the passengers calm and will lessen their worries. The crew must at all times be updated on the most recent developments. The continuous display of information on screens, etc., is important for making sure that each passenger can get information on the situation whenever they want.

The additional demands placed on members of the ship' safety organisation will require further training and education. More crewmembers will require medical training as well as training in handling crowds. New functions have also been added - the responsibility of providing crewmembers and passengers with continuous information must be delegated to separate members in the safety organisation.

10 THE DESSO ROPAX

The design of the DESSO ROPAX is the main result of the DESSO project. The DESSO WP4 Report: DESSO ROPAX Design is therefore given in full in Appendix B. As a complement to this report, the DESSO pamphlet (Appendix F) presents the features of the ship.

11 CONCLUSIONS

One of the objectives of the project was to 'significantly increase the understanding of the ship's capacity to remain afloat after suffering structural damage, fire or terrorist attacks'. Without a doubt this objective has been achieved. Furthermore it must be concluded that the overall understanding of ship safety, and of course safety of ropax in particular, has been significantly increased for all participants in the project. The almost perfect mix of companies, ship owners, research institutes and universities, each drawing on different skills and areas of expertise such as ship design, fire protection, stability, support systems, human behaviour, etc., has resulted in a distribution of knowledge of safety problems and methods to increase safety to a very high extent. Support from authorities has also been very valuable, as has the influence and cooperation with European experts.

One important finding of the safety assessment portion of the DESSO project was that a well organised safety management system and a highly skilled crew is probably the most cost-effective way to avoid or limit the severity of ship accidents. However, as long as we have a human crew onboard there will be human errors. Therefore a 'safe design' must be a 'forgiving design'. This is what we claim we have accomplished in DESSO. The main features of the DESSO ROPAX that make it a safe and forgiving design are:

- Wide side casings to keep the vessel upright and afloat if severe structural damage occurs.
- Interior materials that have been selected to minimise the growth and spread of fire.
- Systems to ensure rapid and effective fire detection and suppression.
- Onboard decision support system.
- High degree of redundancy

For the people onboard, the greatest achievement of the DESSO ROPAX is probably a significant gain of time before the vessel sinks, making it possible to abandon the ship in an orderly way. This means that the ship should be able to return to port or at least to sheltered waters. Still, however, there is one task to address: how to move a large number of passengers safely from one ship to another not using rafts or boats. This task has not been within the scope of DESSO, but has been studied elsewhere, for example within the EU project SAFECRAFTS.

12 ACKNOWLEDGEMENTS

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We are also indebted to Olle Thomson, former head of Lloyd's Register's office in Gothenburg, Honorary Doctor at Chalmers University of Technology, deceased in 2005, who greatly contributed to the outcome of this project.

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14 APPENDICES

A. DESSO WP2 Report: Chain-Breakers – a Survey of Fatal Ship Accidents with the Event-Tree Method (without appendices)

B. DESSO WP4 Report: DESSO ROPAX Design

C. DESSO WP5 Report No. 4: Staying upright and afloat - Static stability assessment (without appendices)

D. DESSO WP7 Report: Fire safety approach on the DESSO ROPAX (without appendices)

E. DESSO WP8 Report No. 2: Passenger and Crew Survival – planning of ship's lay-out and safety organisation

F. DESSO pamphlet

APPENDIX A

DESSO	Design for survival onboard

VINNOVA Dnr 2003-01900	Date: 2004-05-18

Title: Chain-breakers - a survey of fatal ship accidents with the event- tree method

Editors: U. Karlsson (Chalmers), A. Ulfvarson (Chalmers)
Co-ordinator of the project: Björn Allenström, SSPA Sweden AB

Issued by: Chalmers

Abstract: The project 'DESSO' was organised in the autumn of 2003 in order to utilise the research and development resources existing in Sweden and to combine it with international expertise for a radical roro-concept with a focus on safety. The ship research project DESSO aims at improving the safety of roro-ferries. "In order to get a realistic basis of 'working on the right problem' a systematic and in-depth analysis of a few selected significant and well documented disasters was made. The aim was to develop good practise for the early identification of chain breakers that can change the course of events, which may cause casualties or other losses. A literature survey gave relevant references for our work. On the basis of the methods shown to be effective, partners of DESSO contributed by making an event-tree analysis of a selected number of accidents. The complete event-tree has the capacity to cover a lot more than the actual series of events leading to the accident investigated. One branch of the event-tree will cover the actual accident and in this way it has a very high degree of relevance coming from actual realistic cases.

The identified chain-breakers were categorized and analyzed. In general, it was found that 'Management' in most cases is the starting cause of the events. Often 'Management' is also the reason for the continuing or worsening of the events.
The 'Design features' generally act as safety guards, with the purpose of stopping or reducing the consequences of the events after they have started.
'Equipment' has in most cases the purpose of limiting the severity of the outcome.

An attempt at evaluating the chain-breakers was made and the chain-breakers that were found effective have been further analysed and put forward as possible concepts for the concept ship NAOS.

Revision:	date:	description:	pages:	checked:	approved:
0	20 April 2004	DESSO Chain breakers, draft report	abt. 60		
1	18 May 2004	Chain-breakers – a survey of…	43	UK, AU	
2	3 June 2004	Chain-breakers – a survey of…	43	UK, AU	
3	18 April 2005	Chain-breakers – a survey of…	120	UK, AU	
4	12 May 2005	Chain-breakers – a survey of…	120	UK, AU	

Preface

The project 'DESSO' was organised in the autumn of 2003 in order to utilise the research and development existing in Sweden and to combine it with international expertise for a radical roro-concept with a focus on safety. Special funds have been allocated by the Swedish government to pursue safety research in shipping. The main funding comes from VINNOVA, Stiftelsen Sveriges Sjömanshus and The Swedish Maritime Administration.

The partners of the project come from SSPA, Globtech, SP, Kattegatt Design, Chalmers Sjöfartshögskolan, Chalmers Dept. of Naval Architecture, Silja Line, Stena, The Swedish Club, Lloyd's Register and Kockum Sonics.

The project contains nine work packages.
WP2: Safety assessment of ships, concept generation and evaluation, Marin Teknik Chalmers.
WP3: International Workshop and External Expertise, SSPA.
WP4: Ro-pax Ship Design, Globtech.
WP5: Staying Upright and Afloat, CHL.
WP6: Decision Support, Kockumsonics.
WP7: Passive and active fire protection, SP.
WP8: Passenger and Crew Survival, CHL.
WP9: Concept Ship, SSPA.

This report is about WP2 and is based mainly upon the assessment of accidents in the past.

Contents:

Definitions and abbreviations:

Concept ship	The concept ship in this project is the generic ship developed by NAOS.
Generic ship	A generic ship is a ship that can be used as the basis for new designs.
Concept (idea)	A concept is an idea with a potential for development.
Damage stability	Damage stability is stability in a damaged condition; usually rule-based criteria.
Chain breaker	Chain breaker is a function that can stop a chain of events from continuing.
Systems Engineering	Methods, with which to engineer complex systems, www.incose.org.
Stakeholder	A person or organisation that should influence the development.
User	A user of a product or a system developed (usually pays for the use).
FTA	Fault-Tree Analysis, analysis with a graphical representation of system.
FMECA	Failure Mode, Effect and Consequence Analysis, matrix representation
Event tree	Analysis of events, analysis with a graphical representation of a system.
Freeboard deck	Deck that should be considered watertight for the purpose of safety.
Bulkhead deck	Deck that seals off the compartments below to create watertight rooms.
'One compartment'	A ‘one-compartment’ ship must be shown to survive the filling of one compartment.
'Two-compartment'	A ‘two-compartment’ ship must be shown to survive the filling of two compartments.
A60	A class of insulation. A60 has been demonstrated to protect a bulkhead or deck from a 60-minute standard fire without a dangerous temperature increase.
Inherent safety	Passive safety, safe by itself, robust.
Safety by action	Safety achieved by an operator’s continuous supervision and interference.
ISM	International Safety Management – international code for safety management.

1. Introduction.

1.1 Background and Aim of Study.

The ship research project DESSO aims at the improved safety of roro-ferries. "In order to acquire a realistic basis of 'working on the right problem' a systematic and in-depth analysis of a few selected significant and well documented disasters has been made. The results are presented in such a way that conclusions can be drawn for how to design and organise in order to break fatal chain of events."
The purpose of this is to come forward with relevant conceptual solutions at a pre-design level in order to improve safety. If safety is built in at the design stage, an increase in safety is usually arrived at without much cost.

Accidents are seen as a result of a series of events where each one may be trivial but when combined will ultimately end in a catastrophe. When such series of events is studied, it is possible to define 'chain breakers', i.e. points in time and space where a different action could halt the development. The task of WP2 is to identify and analyse chain-breakers and to put forward proposals for the concept ship NAOS.
As this to some extent is also the subject of other workshops, the specific purpose here is to try to stay in the early design phases where the interaction between logistics and the GA is developed, i.e., to identify chain-breakers in early stages of project work. This also involves qualitative cost-benefit evaluation. In early stages of development, this can usually not be carefully calculated but needs to be assessed by experienced engineers.

The aim of the DESSO-exercise is, among other things, to assess the structural arrangement, so that the ship will stay afloat for a reasonable period of time after an accident, for instance 24 hours, or in the case of fire create a safe haven for passengers. During the 24 hours, various rescue operations may take place. It is not the aim within the project to define such rescue operations or to evaluate rescue equipment now required by rules and regulations for abandoning the ship.
The aim of this document is to suggest ideas and concepts that may lead to improved floatability and survivability for the damaged vessel. These concepts may than be used, or tested, on the NAOS vessel when applicable in order to indicate possible solutions for achieving the aim in a practical way and not destroying the business idea with a roro-ferry.
The study of major incidents performed (appendix 1-3) forms the basis of the proposed concepts in association with existing rules and regulations.

1.3 Method.

The different selected accidents were distributed between participants who performed literature survey for a first analysis. The descriptive result were short accounts of the accidents, event-trees with chain-breakers and some matrices to clarify what was important. The format of this first description deviated from case to case. It was decided to make a common format for the described series of events in order to simplify communication. In this format, the accidents are described in such a way that chain-breakers are clearly exposed.

The ‘event chains’ were developed to describe each sub-event that lead to the accident and specifically to spot chain-breakers.
The chain-breakers were further categorized in a matrix for their kind and the intended purpose and function.
Further analysis of the chain-breakers was made with the help of DESSO partners and other knowledgeable people within these areas. Finally, concepts and ideas for the concept ship NAOS, were put forward.

2. General Description of some Methods and Arguments for Selection.

Below, are to be found short descriptions of some methods and the arguments for our selective use of these methods.

2.1 Fault-Tree Analysis (FTA).
The fault-tree analysis is a top-down method with which the likelihood of a top event can be analysed. The analyst tries to identify all different paths that start from a single failure at the base and leads to the top event. The logical structure has links and nodes. In a node there may be an 'and'-gate or an 'or'-gate. The 'and'-gate represents some kind of redundancy, i.e. more than one branch needs to contribute in order to pass the gate on the way to the top event.
It is possible to quantify this fault-tree, and thus by numerical evaluation to find out the frequency with which the top event occurs. In shipping, however, statistics on the needed quality is usually lacking. Experts can usually make judgements where precise information is lacking and a reasonable estimate of likelihood can be made. The structuring in a fault-tree in itself exposes the actual dangers, which can improve safety.

2.2 FMECA.
Failure Mode Effect and Consequence Analysis
This method starts with a long list of components that are part of the system. Each component may fail. The component failure will have consequences that should be described and the likelihood of failure and the consequences should be estimated. This is a 'bottom-up' method. This is all done in a table, one such table for each component. The FMECA is usually combined with the fault-tree analysis.

2.3 Event-Tree.
The event-tree analysis is a less formalised analysis than FTA and FMECA. However, some good practice has been developed and the most common one is to start from an initial event and follow it to its conclusion. Sometimes one initial event will actually develop through different branches to some final events. When applied to an accident that has already happened, usually only one such branch is identified. This method is useful for the identification of a chain breaker, i.e. functions or events that have the ability to stop the road to catastrophe.

2.4 Selected Methods.
In the beginning of the study with the disasters, the participants were asked to make descriptions, event-trees and matrixes to organise the material about the disasters (FMECAs were excluded). The authors of this report still believe that the analysis benefited from this freedom, even if the format came out slightly differently from these contributions. The benefit with the complete fault-tree is that it covers much more than the actual disaster; it shows different paths to the top event. The complete event-tree has the similar capacity to cover much more than the actual series of events. One branch of the event-tree will cover the actual accident and in this way it has a very high degree of relevance coming from actual realistic cases.

The use of these descriptions is facilitated by conforming to a standard format. This has been done, as all of the disasters have been presented with the 'chain breaker staircase', i.e. one branch of a complete event-tree.

3. Short description of ships and accidents.

The ships and the accidents are briefly described below.
The 'event-trees' are to be found in Appendix 1.

The M/S Estonia, sinking as result of the loss of its bow visor on28 September 1994.
The roro-passenger ferry left Tallin after having been inspected by The Swedish Maritime Authorities together with the Estonian authorities in an educational survey. Several deficiencies were found. According to JIAC, the ship met bad weather and lost her visor. The visor disconnected the ramp and the ship was filled from the open bow. The stability was lost and the ship capsized and sank in a very short time. 760 persons followed the ship down, 93 dead bodies were recovered from the sea and 137 persons were rescued.

The MV Estonia, i.e. The VIKING SALLY, was built as a development from previous roro-ferry designs. She was classified in shipping registers as a passenger/cargo roro-ferry. She was built with a continuous vehicle-carrying space on the main deck (A-deck). Below the main deck an economy accommodation area was arranged on deck number 1 (tween-deck) and an extensive sauna and pool area on deck 0 (tank-deck). The main passenger accommodation areas were on decks 4 (C-deck), 5 (D-deck) and 6 (E-deck). The crew accommodation was generally on decks 7 (F-deck) and 8 (G-deck) and the navigation bridge was on deck 9 (H-deck).
The ship was built with one bow loading ramp on the car deck, enclosed by a hinged bow visor that opened upwards, and two stern loading ramps. Passenger entrance doors were arranged on decks 4 and 5 and pilot and bunkering doors on the car deck.
The ship had the following main particulars according to building specifications and certificates:

L_{OA} 155.4 m
L_{PP} 137.4 m
B_M 24.2 m
Depth to bulkhead deck, moulded 7.65 m
Depth to bulkhead deck, moulded 7.65 m.
Maximum draft 5.60 m.
Deadweight at max. draught 3,006 dwt.
Propulsion power 4 x 4,400 kW.
Maximum number of passengers 2,000.
Maximum service speed 21 knots.

The Herald of Free Enterprise, water intrusion through the open bow-door, capsized on 6 June 1987.
The Herald of Free Enterprise left the inner harbour of Zeebrugge with a crew of 80 hands with 81 cars and 47 freight vehicles plus three other vehicles. Approximately 459 persons were onboard for a voyage to Dover. Good weather. With an open bow-door she shipped water over her threshold onto the car deck and capsized. 150 passengers and 38 crew died in the accident.

LOA 131.9 m
LPP 121.1 m
BM 22.7m
Speed 22 knots
Tmax C1 condition 5.5 m
Tmax C2 condition 5.7 m
Max. no. of passengers C1 condition 630
Max. no. of passengers C2 condition 1,400
Welded steel construction
8 decks above tank top
H-deck subdivided by 13 watertight bulkheads and there were 9 watertight doors.

The Andrea Doria/Stockholm, collision between ships, July 25 1956.
Collision in darkness west of Nantucket lightship outside New York.

MV Stockholm, 1948, Swedish American Line
12,644 tons
525 feet
Beam 69 feet
Draught 25 feet
Speed 19 knots
Crew 216
Passengers onboard 534 (max 548)

T.S. Andrea Doria, 1953, Italian Government
29,083 tons, 700 feet, beam 90 feet, draught 30 feet
speed 23 knots
crew 572
1134 passengers onboard (max 1221)

The Andrea Doria, heading for New York, had followed the North Atlantic route for westbound vessels, passing by the Nantucket light ship. She was travelling in fog and the fog precaution of closing watertight doors had been taken, but the reduction of speed was only notional, from 23 knots to 21.8 knots.
The Stockholm was outward-bound from New York to Gothenburg. She showed a lofty disregard for shipping lanes, although these were not mandatory yet, and chose to close in on the Nantucket light ship, which took her into a normal westbound lane. The eastbound lane was 17 miles further south. Speed 18 knots. Her watertight doors were not closed. Visibility: 5-7 nm. At the time of collision the visibility was 1.8 nm.
The ships had radar contact. The Andrea Doria altered her course to port for a safe port-to-port meeting, while the Stockholm yawed to starboard for a safe starboard-to- starboard meeting. Thus the ships were heading towards each other and collided.

The M/S Sally Albatross Grounding on 4 March 1994.
The Sally Albatross was built in 1980 for the Viking Line. The vessel burned in 1990 while undergoing a refit in Stockholm and was considered a total loss. She was reconstructed and considered a new build in 1992.
The ship was built with 16 watertight compartments. The vessels fulfilled the stability demands for 2 compartments according to the latest SOLAS 90 stability rules. The ship showed good stability and it is considered that it would even manage with most 3-compartment damage situations.

On 4 March 1994 in open sea during the crossing from Tallinn to Helsinki, the M/S Sally Albatross struck ground and sustained damage. The vessel began taking in water, and began listing and heeling. After it was determined that the vessel could not continue the voyage, the order was given to evacuate passengers to an icebreaker that had responded to the call for help. All 1,101 passengers were evacuated safely and without injury. The vessel continued to list and heel, and when it was determined that there was a risk of the ship capsizing, the crew of 159 were evacuated, also without injury. The vessel was towed to shallow water and water was pumped out. The vessel was eventually towed to a shipyard and repaired.

Accident investigations determined that the accident was a result of a navigation error. This error occurred because the first officer and master were relying on a new radar-map navigation system, and they were not sufficiently familiar with the use of this system.

Ship Particulars:

Length:	158.9 m	
Beam:	25.2 m	
Draught:	5.9 m	
Speed:	21 knots	
Ice Class:	1 A	
Tonnage:	25076 Grt	12407 net tonnes
Passengers:	1400	

The Jan Hewelius, capsized on 4 January 1993.
The M/S Jan Hewelius had a history of stability incidents.
She was delivered in July 1977 from Norway to Polskie Line Oceancizne in Gdynia Poland.

LPP	125.65 m
BM	17.01 m
T	4.31 m

790 lane metres for trailers
400 lane metres for train

The Zenobia, capsized on 7 June 1980.
The roro passenger and freight ferry Zenobia was manned in accordance with regulations from the Swedish Maritime Administration. The ship got a permanent heel on 2 June 1980 after a demonstration of the ship's autopilot at sea. Passengers were evacuated and she was taken to Larnaca on tow. She sank in the morning of 7 June.

Zenobia was a twin screw roro-passenger and vehicle ship built by Kockums.
The main particulars are:

Length over all	165.2m
BM	23m
Speed	21 knots

Tmax	6.52m as a passenger ship
Tmax	7.92m as a cargo ship
Max. no. of passengers:	175

Class Notation: +1A1 Car Ferry A+NV Ice 1B/1C, E0 each developing 9000BHP at the maximum continuous rating. The ship was of an all-welded construction. She had three decks carrying vehicles.

The MS Sleipner, grounding, November 26, 1999.

The M/S Sleipner was a high-speed catamaran with an almost identical sister, the M/S Draupner. The M/S Sleipner sailed in darkness and heavy rain and wind with a relatively high tide in the evening of 26 November 1999. The speed was 35 knots and significant waves were about 1.5 m at the time (this means that waves of 3 m occasionally appeared). The ship went aground on Store Bloksen at around 19.00 hours with 80 passengers and a crew of 9. A number (58) of survivors gave witness to the accident. The captain of the ship did not survive. The navigator at the chair beneath him survived and has given a detailed witness account from the bridge. All is well-reported in NOU 2000:31 and appendices.

LWL	40.9 m	
BWL	5.52 m	
T	1.6 m	(as built T = 1.68 - 1.73 m)
v	35 knots	
CB	0.40	

202 tonnes (as built 219 - 225 tonnes)

The Scandinavian Star fire with 158 lives lost on 7 April 7 1990.

The Scandinavian Star was built in France in 1971 as a combined passenger ship and ferry for cars and trailer. The ship was built to SOLAS 1960. Classed at BV until 1987, thereafter LR. Bahamian flag.

At 21.45 hours on 6 April 1990, the motorised ferry Scandinavian Star left Oslo bound for Frederikshaven. Several hours later, while the ship was crossing to Denmark, a fire broke out that was to claim the lives of 158 people onboard.

The Silver Ray, fire, 14-23 May 2002.

The fire started on roro-deck no. 6 in the forward part of the ship. The crew could not extinguish the fire, which spread rapidly. The local fire department was alerted but they could not control the fire. One week after the fire started it was still burning. After nine days the fire department assessed that their work was finalised.

Lover all	189 m
GRT:	39,147
Built	1978

Owner: Stamco Ship Management Co Ltd

4. Statistics.

Large accidents resulting in the loss of a ship is, fortunately, a rear events. Consequently, available statistics are more of a descriptive nature rather than something suited for the application of statistical mathematical models. Lloyd's Register/Fairplay issues each year a document called the "World casualty statistics", which is a documentation of all ships in the world that have been declared as "Total losses" on an annual basis. Some information from this document may serve as an indicator of the relative frequency of different types of major incidents. This information may have a bearing on the relative effectiveness of specific efforts to increase safety within this project.
Total losses of all types of ships have for many years decreased in number. One may interpret this as a result of the continued safety efforts within the maritime sector carried out by responsible ship-owners, National Maritime Administrations and the International Maritime Organisation (IMO). The number of total losses for the period from 1998 to 2003 looks as follows:

1998	263
1999	220
2000	206
2001	173
2002	148
2003	144

Looking into the number of ships within each casualty category for the years 2002 and 2003 for all ship types, the following is to be found:

	2002	2003
1. Foundered	69	76
2. Fire/Explosion	30	18
3. Collision	16	19
4. Contact	1	5
5. Wrecked/Stranded	24	24
6. Missing	1	1
7. Hull/Machinery	2	1
8. Other	1	0

The information is self-explanatory and indicates that the most common cause is foundered. Heavy weather resulting in an intrusion of water and the ship capsizing seems to be the most common development of the casualty. No clear tendency for collision and 'wrecked'/'stranded' can be found.
Extracting the roro-passenger ships for the period between 2002 and 2003 (Appendix 4), there were 13 total losses distributed over categories as follows:

1. Foundered	7
2. Fire/Explosion	4
3. Collision	1
4. Hull/Machinery	1

Care has to be exercised when drawing conclusions from the above figures, but it seems that water intrusion and fire are important to consider as the most effective areas for improvement of safety. It is also noted that 'collision' and 'stranding' have very low rates. Regarding 'stranding' one may assume that this should be low, as ferries normally operate on regular routes.

5. Event-Chains.

Official reports from nine accidents, as mentioned in Chapter 3, have been analysed. The sequence of each accident has been broken down into sub-events that lead to the accident, i.e., an event-chain. These events are shown within rectangular frames, see example in Figure 1. In the event-chain, chain-breakers have been identified, i.e., something that would have prevented the event, stopped the event or reduced the consequences of the event, such as a design feature or a management aspect.
The event-chain is in the form of a stair where chain-breakers can be found at the end of each step. For those events a chain-breaker was identified, which of course was not complied with as the event proceeded until the accident, the stair moves down one step. (Event-chains; see Appendix 1)

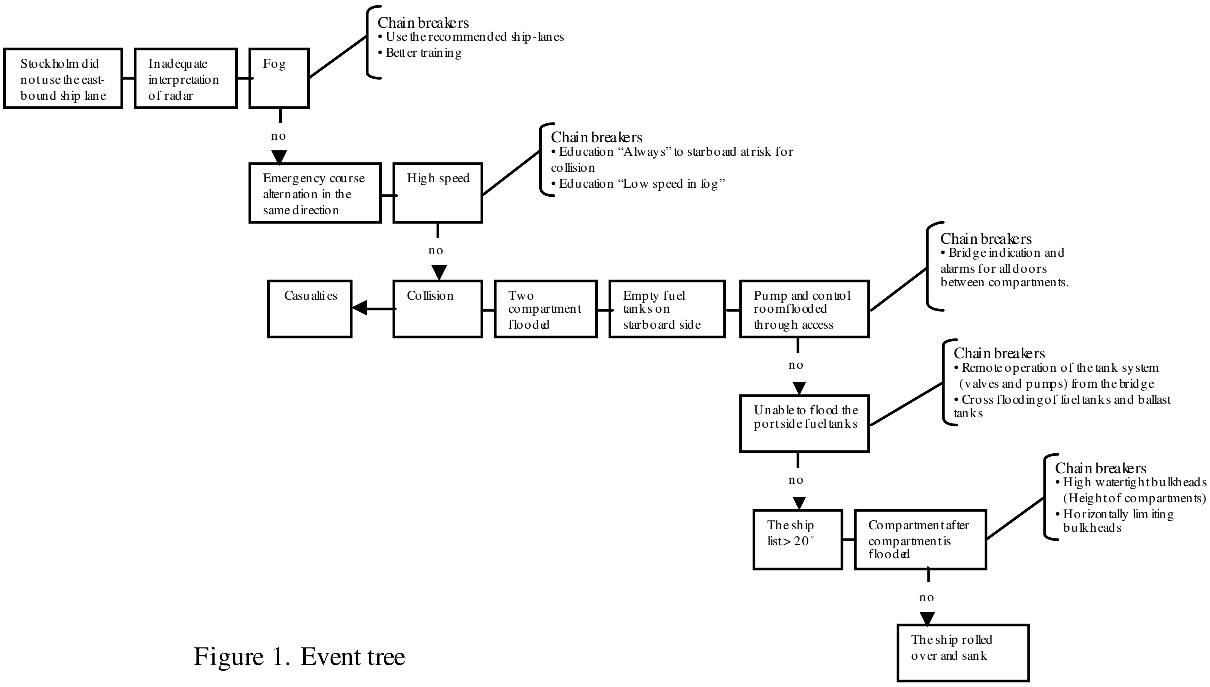

Figure 1. Event tree

6. Categorization of the Chain-Breakers.

Event-chains for nine accidents have been made (Appendix 1). For these, a total of 99 chain-breakers were identified regarding prevention of the event, to stop the event or to reduce the consequences.

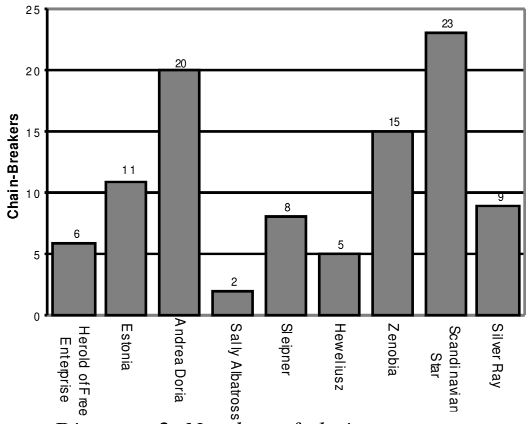

Diagram 2. Number of chain-breakers for each accident.

The number of chain-breakers for each separate event ranges between 2-23, Diagram 2.
The reason for the large difference is partly because there is a different number of chain-breakers in the events but also due to the different levels of detail with which the event- chains have been described and chain-breakers been identified, as they have been made by seven different persons. Variation of robustness of ship systems will also affect the number of chain-breakers as the time span in which the accidents occurred is large and the ships therefore are designed according to different rules.

A categorization of the chain-breakers has been made with the purpose of analyzing the results in general. The chain-breakers identified in the event chains (Appendix 1) have been categorized in a matrix (Appendix 2), for each event, see Matrix 3.

SHIP'S NAME		**Management**	**Support -systems**	**Design, GA**	**Design, other**	**Equipment**
Prevent the event						
Prevent water ingress/progress	Detect water ingress					
	Limit water ingress					
	To facilitate pumping					
Prevent list	Intact stability					
	Damage stability					
	Cargo shift					
Rescue	Evacuation/ Embarkation					
	Other					

Matrix 3. Categorization matrix.

The chain-breakers are categorized into two categorizes, of which the second category is further categorized into a more detailed level. The categorization is as follows:

1. Type of chain-breaker:
- Management (the crew's handling of the ship, even in an emergency)
- Support systems (to inform and guide the crew)
- Design, GA (general design, including major structural design and stability characteristics).
- Design, other (other minor design features)
- Equipment (defined as equipment not attached to the ship)

2. What the chain-breaker is assumed to prevent:
- Prevent the event
- Prevent water ingress/progress (7 events) or fight fire (2 events)
- Prevent list
- Rescue

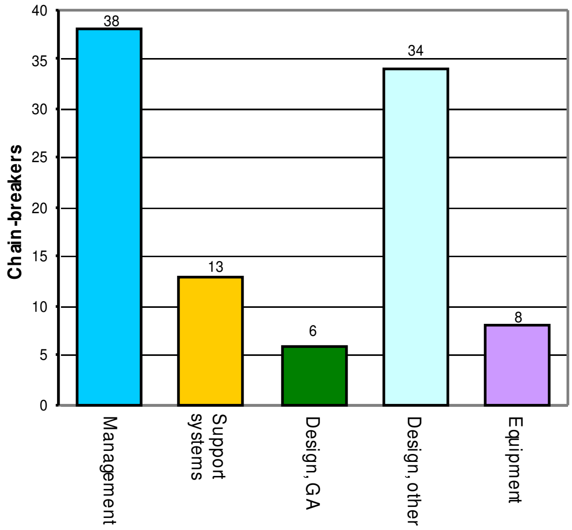

Diagram 4. Total number of categorized chain-breakers.

For the total number of chain-breakers in each category, Diagram 4, we find "Management" and "Design, other" to have significantly more identified chain-breakers than the other three categories. "Management" and "Design, other" with 38 and 34 chain-breakers, respectively, compared to "Support-systems", "Design, GA" and "Equipment", where only between 6-13 chain-breakers were identified.

In Diagram 5 a categorization of the chain-breakers for each event is shown.

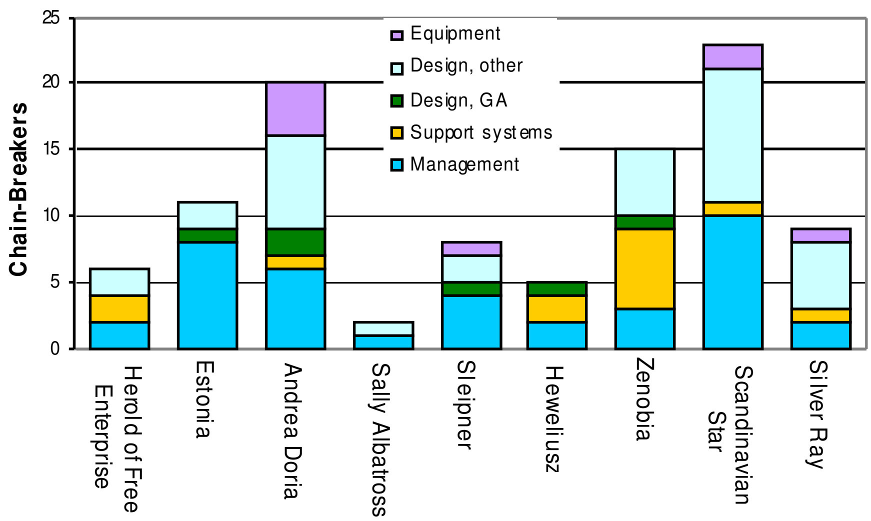

Diagram 5. Categorized chain-breakers for each event.

The chain-breakers in the category 'Management' are highly represented in all events. For the category 'Design, other' the chain-breakers are also highly represented in eight of the nine events. 'Support systems' are represented in six events, but, in general, to a lesser degree and 'Design, GA' and 'Equipment' in five and four events, respectively, to a rather small degree.

In the matrix (Appendix 2), each chain-breaker has also been given a colour depending on what they would have achieved according to:

Green: Chain-breaker that would have prevented the event;
Blue: Chain-breaker that would have stopped the event;
Red: Chain-breaker that would have reduced the consequences.

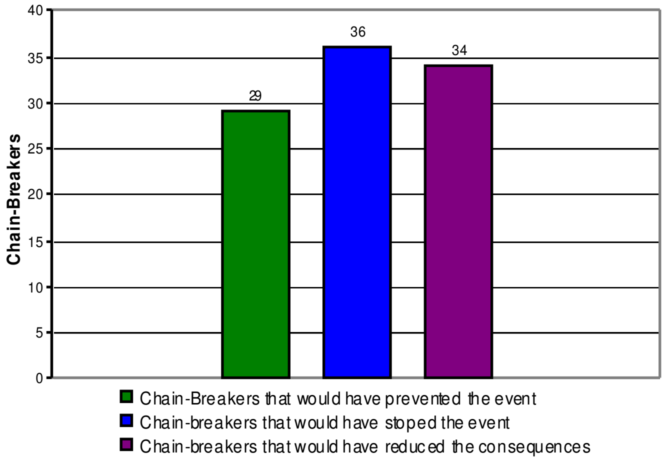

Diagram 6.
Categorization of the chain-breakers depending on what they would have achieved.

The number of chain-breakers in each category is fairly similar, Diagram 6.
If we split the categories into what kind of chain-breaker it is, Diagram 7, the distribution will differ depending on their type.

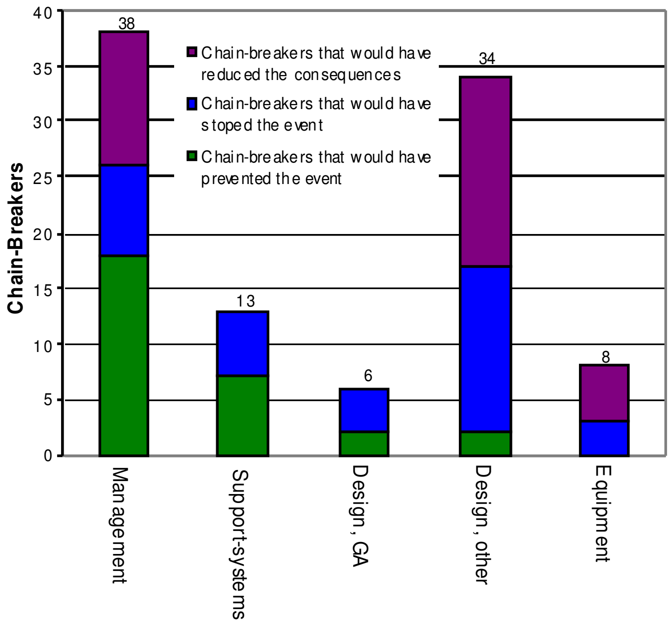

Diagram 7.
Chain-breakers depending on what they would have achieved, categorised into what kind of chain-breaker they are.

For "Management", chain-breakers are mostly found in the early stage of the chain regarding prevention of the event or stopping the event at an early stage, and in the end of the event regarding rescue operations to reduce the consequences.

"Support systems" is coupled to the crew's management and acts as a kind of decision support. Its main function is to inform the crew of the ship's status, to give the alert about events, and to give information for decision-making. These chain-breakers are, in most cases, found at the early stage of the chain as regards preventing or stopping the event.

The chain-breakers for "Design, GA" are generally about stopping the event by limiting the spreading of water and preventing the loss of stability with a structural subdivision of the ship. These chain-breakers are mostly found in the middle of the event-chains.

For "Design, other" the chain-breakers are mainly represented in the middle to the end of the event-chains, merely to stop the development or to reduce the consequences of the event.

The chain-breakers for "Equipment" mostly concern rescue and fire equipment. In most cases, these are to be found in the end of the event concerning reducing the consequences and, for fire, in the beginning of the event as regards stopping the event.

For these events and chain-breakers, the following seems to apply:
In most cases "Management" is the starting cause of the events. Often "Management" is also the reason for the continuing or worsening of the events.
The "Design features" generally act as safety guards, with the purpose of stopping or reducing the consequences of the events after they have started.
"Equipment" has, in most cases, the purpose of limiting the severity of the outcome.

The chain-breakers were searched for in the rules, during which it showed that about half of them are regulated by rules today. In most cases, they were not rules at the time of the accidents, but became rules later. In several cases they become rules due to the accidents in which they where identified in this study.
Some of the rules are adequate and some are not. Usually are the rules concerning design fulfilled. However, rules concerning the management and functionality of equipment are often found not to have been complied with.
In Appendix two, rules and other comments are noted in red text beneath the respective chain-breaker.

7. Evaluation of the Chain-Breakers.

Discussions with the different WP-groups within DESSO and information from the workshop, held with top experts from Europe in July 2004, constitute the basis of the evaluation.

The following categorization has been used for the evaluation:
- Management
- Decision Support
- Fire
- Progressive Flooding and Damage Stability
- Other

7.1 Management.

Of the nine events, wrong management was the starting cause in eight of them. In one case, an arsonist was the starting cause, but management after the fire had started was very poor, contributing heavily to the disaster.

Of the 38 chain-breakers regarding management, 18 concern prevention of the event. Several of these concern the lack of routines onboard the vessels regarding sailing conditions, the securing of cargo and control of open-hull doors. In some cases, bad seamanship was the cause where ships had left harbour while not being seaworthy, travelling with too high speed in bad weather or fog or not turning to starboard at the risk of collision. For two events, the cause of the accidents originated in a lack of knowledge of radar operations. In one of these cases, the crew had not enough knowledge of a newly installed radar navigation system, of which they relied on for navigation. In two cases, a lack of intact stability was the cause, which can be referred to as a lack of routine or knowledge.
Eight of the chain-breakers concern stopping the event after it has started, often at an early stage. Of these, the ongoing problems of open doors between watertight compartments and of fire doors not being closed at fire, are a matter of great concern.
The remaining 12 chain-breakers concern rescue. It is to be mentioned here the crews', often poor handling during evacuation and embarkation, the poor, or lack of, instructions to passengers about emergencies, requesting help at an early stage and the maintenance of alarm systems that in several cases have been found not working. Improved SAR coordination between countries is also a mentioned chain-breaker for reducing the consequences.

Most of these chain-breakers were already at the time of the accidents regulated by rules and as such, rule violations were committed in several cases. The question is why these violations and mistakes were committed. Reasons could be too high a work load as the crews are becoming smaller, the crew's education and training, routines used onboard ships and inspection routines by the crew and representatives of classification societies and maritime authorities.
It should, however, be pointed out that some of the incidents that have been considered happened before the introduction of the ISM-code, which means that improvement in terms of safety-management has taken place. However, the complexity of the ship and its equipment is continuously increasing and consequently the handling of the ship in a critical situation becomes more difficult. Further, it should be pointed out that the ISM code itself mentions in its introduction that the code will need "continued improvement".

From the chain-breakers, we can conclude that education/training and stricter routines would have stopped several of these accidents. Education and training on new vital equipment and means of checking intact stability, as well as damage stability, would also improve safety.

Within the scope of this project, suggestions/proposals regarding crisis management could be considered. This is further regarded as a very cost-effective concept. On the understanding that decisions during the time immediately after an accident is of major importance for the safety of the vessel, two major aspects should be considered:

1) To ensure that the master has adequate training in crisis management.
2) That the master has sufficient information in a crisis situation to be able to make the correct decisions.

In order to meet the above requirements, the following steps should be taken:

1), A simulation program should be developed for the education and training of senior officers at the university. Such programmes should contain simulations of grounding, collisions and fire and be designed in such a way that a high degree of interaction/intervention by the user could be achieved. The chain of events derived in the chain-breaker investigation may be used as input to create as realistic conditions as possible.
2), Two steps are required. As all ships are individually designed in terms of bulkheads, tanks and deck-arrangements, the master should have the possibility of simulating incidences onboard for the training of handling of the ship in crises. The second step is to have a damage-information system, which in case of damage, gives the best possible information of the damage caused and condition-monitoring with regard to the spreading of fire, tank-filling, progressive flooding and damage stability. Such a device could become a very valuable tool for the prevention of wrongdoing in the decision-process during an emergency.

It has also been noted during the analysis of the chain-breakers by ‘officers on the bridge’, that the stability books are not useful for quick decisions in cases of emergencies. These stability books are written by designers for the authorities with the purpose of getting certificates. It would improve safety if the stability book included pages more user-friendly for the officers on the bridge.

7.2 Decision Support.

Thirteen chain-breakers concerning support systems were identified. These are all about preventing the event or stopping the event at an early stage.
Some of the chain-breakers concern indicators for shell doors, i.e., doors through the outer shell, and for the doors between the watertight compartments. Although this today is regulated by rules, watertight doors are often open in ships and this is a major concern.
Having online stability calculations for decision support, regarding intact and damage stability, has been found as being of vital significance.
According to the rules, a ship's GM has to be checked before a vessel leaves quay. The intact stability is then verified as adequate, unless the rules have been violated. The GM is calculated by means of incline gauges and pressure transducers attached on the ship's hull under the waterline measuring the ship's draught. At sea, these cannot be used to predict the ship's stability during, for instance, a cargo shift or a water intrusion, due to the ship's motions.
To be able to calculate the ship's GM at sea, there needs to be gauges of some kind in the different compartments, void spaces, ballast tanks, fuel and oil tanks, etc. Normally, pressure gauges are used for measuring the level in tanks. In a roro-vessel of normal size, there are about 50 of these to manage this function. To cover all spaces that would need to be supervised for damage stability calculations, i.e., to calculate the GM, and for decision support regarding water intrusion, about 50 more gauges would be needed. The cost of a pressure gauge is about SEK 8,000 each, including installation, and they last about 10 years. The cost of this system is obviously high.
A complete support system would include gauges for the indication of water and water level in all relevant spaces and decision support in the form of suggestions of which action to take. The cost of the gauges would constitute 2/3 of the cost and the decision support system about 1/3 of the cost, depending on how advanced the computer programme should be.

An alternative is to use cameras instead of gauges in order to detect water intrusion. These are normal cameras connected to a computer where a program can identify differences in the images. A graded scale could be monitored by the cameras to indicate the water level in compartments, which the computer could read for calculations of the GM.
People would not need to monitor the cameras, as the computer would do this. The computer would raise the alarm for pre-set events and at the same time show the actual camera image on a monitor, at which the alarm could be verified immediately. This would save time, as no manual checking is needed.
Apart from detecting water intrusion and reading water levels in different spaces, cameras could also be used for detecting fire. Confirmation of a fire would be given directly on the monitor, saving time. Supervision of unauthorised persons in different areas, cargo shift, locating people during evacuation and similar situations are other areas of use.
A camera system would be able to solve more tasks than gauges and smoke detectors and is, at the same time, a cheaper alternative.

One concept is to have pressure gauges in tanks and void spaces that are not illuminated and to use cameras for other compartments and spaces that are illuminated. The gauges and cameras should be connected to a computer for analysis, calculations and decision support in the form of recommendations as to which actions to take.

7.3 Fire.

Management.
In the accidents analysed, fire alarms were found not to be working and fire doors not closed during a fire.
Maintenance and inspection of alarm systems and functionality of fire doors is of vital significance for fire-fighting and evacuation. If this does not work, the whole strategy of fighting a fire and evacuating people might fail. To see to it that the functionality of the equipment is adequate also falls under the authorities whose task it is to inspect the equipment.
The crew's training and organization in fire fighting and evacuation was, in the cases studied, inadequate. That this works well is also of vital significance for the outcome of a fire. To instruct passengers of emergencies in a way, in which they can learn it, is also important.
All these items, maintenance of fire alarm and fire doors, training and organization of the crew regarding fire fighting and evacuation and instructions to passengers are very important for increasing and maintaining the safety onboard and are at the same time cheap solutions.

Fire detection systems.
The fire detection systems used today mostly give false alarms. Therefore, if the alarm goes off, one person is sent to check if the alarm is false or not before the fire-fighting teams are called out. This will usually take several minutes. When there really is a fire, the fire-fighting will therefore be delayed with the same amount of time. If a failsafe detection of fire is used, or at least a system where the false alarms are fewer than the real alarms, the fire-fighting teams would immediately be alerted and the fire-fighting would start several minutes earlier than it does today. This would improve the possibility of putting out the fire or reducing, delaying its spreading, as the first minutes of the development of a fire is crucial. This failsafe detection of fire would have a high degree of effect at a reasonable cost.
This might be solved with cameras, as stated in section 7.2 "Decision Support".

Evacuation.
To design for emergency escapes with straightforward routing is essential, especially regarding evacuation during a fire, where the visibility can be low or non-existent. This is to some part regulated by SOLAS, Chapter 2.2 for ships built after 98, where an analysis of evacuation is required.
It is important to keep cabins, staircases and escape routes free of smoke in order to facilitate evacuation. The ventilation system could be used for this in areas not directly affected by the fire.

Equipment and Material.
The rules regulating equipment for fire-fighting, design of a sprinkler system and interior material are adequate as they are. However, lose interior equipment, i.e., lining material, furniture and such items, do not seem to be regulated by the rules in an adequate way. This needs to be looked into in order to minimize toxic gases and the growth and spreading of fire.

Safe Areas.
There should not be a special safe area protected against fire where people can gather, as this is found as being too vulnerable. The space would have to be very large and it would be difficult to evacuate all people to the area. The redundancy for this concept would be too small.

Instead, the whole ship, except where the fire is, should be regarded a safe area. A ship is divided into several vertical fire zones. The main issue is to contain a fire within a vertical fire zone. This is done by the closing of the fire zone by means of fire-doors, as regulated in the rules. The fire gases are, however, still a problem. Containing the fire-gases and smoke in the zone on fire, the ventilation system could be used to create an overpressure in adjacent zones. To be able to create a pressure high enough, the fans supplying the ventilation system with air might to have a larger capacity than is normal.
The pressure from the fire gases has to be let out in some way, otherwise the pressure in the fire zone will be higher than the ventilation system can create in the adjacent zones.
The ventilation system should be turned off in the fire zone to reduce the oxygen supply to suppress the fire.

RoRo-Decks.
The greatest hazard on roro-vessels is fire on a roro-deck. The problem is all petrol and flammable fluids in cars and trucks together with a large open area. A fire on a roro-deck is difficult to extinguish.
Fire should not be a reason for abandon the ship at sea. If there is a fire that cannot be put out, the ship must withstand the fire until it reaches land. As the concept ship then has to withstand a fire for at least 10 hours, the regulated A60 class division might not be sufficient, especially regarding the horizontal division between the roro-decks and the division between a roro-deck and other adjacent compartments. Suggestions are to have thicker thermal division in these areas.
Since it is prohibited to use CO_2 on roro-ferries, a deluge water-mist system might be the solution for the suppression of fire on a roro-deck. However, its capacity is not enough to extinguish a large fire on a large open area such as a roro-deck. To make it work, the roro-deck needs to be divided into smaller areas. A suggestion is to divide the roro-deck transverse with curtains. For the current layout of the concept ship (see Chapter 9 “Concepts”), two curtains on each roro-deck would be needed. If roro-deck 2 is divided into three sections by means of longitudinal bulkheads, as suggested in the working layout (Chapter 9), only one curtain would be needed for each section.

7.4 Progressive Flooding and Damage Stability.

7.4.1 General.

Many of the chain-breakers concern damage stability, or maintaining stability in a damaged condition in order to prevent capsizing. For water on a roro-deck, while the deck is still above the waterline, non-return scuppers or the possibilities of freeing the ports, i.e., open the bow-door or/and the aft ramp, to get rid of the water was suggested. Another suggestion is down-flooding, i.e., to get rid of water on a roro-deck by letting it flood down into the lower parts of the ship. Cross-flooding between ballast tanks, fuel tanks and compartments beneath the freeboard deck is also a method for helping to maintain stability during water intrusion due to grounding or collision.

Remote operation of the tank system (valves and pumps) from the bridge is a chain-breaker found during two accidents. The cases have here been pump-control rooms that have been flooded or in other ways made inaccessible at which it has not been possible to fill up ballast tanks or to shift fuel between tanks in order to maintain the ship's stability. The cost for this redundancy is considered as being fairly low in comparison to the high effect it can have.

Two chain-breakers are about not having or ending weak ventilation pipes through/on a freeboard deck. This is regulated in SOLAS. However, the rules for the dimensioning of the air vents going through a roro-deck down to the engine rooms is regulated only by SOLAS fire-protection rules. A design according to these rules will not withstand a car or similar crashing into it during a cargo shift. The throttle valve for the air vent is either positioned high up or down in the engine room. If the position of the throttle valve is high up and the vent is broken while there is water on the roro-deck, water will flood down into the engine room. Even if the throttle valve is located lower than the roro-deck, the valve might not stand the water pressure. To make these vents stronger is a rather inexpensive measure.

Another chain-breaker is to have the doors through the shell into the freeboard deck trunked to prevent water intrusion at a larger list. A trunked door implies a casing inside the door, which one needs to cross by stairs, before reaching the freeboard deck.

7.4.2 Progressive Flooding.

In rules and regulations, progressive flooding is dealt with by requiring that penetrations of watertight bulkheads should be minimised. Ventilation-ducts piping and watertight doors going through bulkheads create penetrations. Various types of locking-devices secure water tightness. Experience shows that in practice such locking-equipment is difficult to design in such away that it is failsafe. Further control-equipment for the locking-devices must be so robust that it works in an emergency. Associated with this type of equipment is also a safety management function to ensure that the equipment is in good condition and that the procedures for handling the equipment are adhered to by the crew. For example, watertight doors, which should be kept closed at sea, are left open. The technical solutions may be too complex and the necessary robustness is not there.

The concept of reducing possibilities for progressive flooding is in the first instance to regard the hull design as a two-barrier system where the outer hull is the primary barrier and the double bottom, outmost longitudinal bulkhead, freeboard deck collision bulkhead and aft-most transverse bulkhead as a secondary barrier. The space between primary and secondary barrier penetrations should be minimized to an absolute minimum, for example piping, cabling etc. is to be moved inside the secondary barrier and ventilation ducts to be arranged inside the secondary barrier.

Collision Structure.

In a collision, several compartments can be damaged and flooded. As ships according to the rules do not have to stand more than a two-compartment damage, a rip up of a ship's side beneath the water line can sink it. For many collision scenarios, double plates in the ship's sides with a collision structure in between (Figure 8), absorbing energy and distributing the force over a larger area on the inner plates would increase the collision resistance and reduce the penetration considerably.

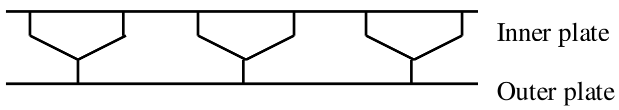

Figure 8. Collision structure.

Watertight Doors.

An ongoing problem that has often ruined the intention of the subdivision of vessels is open watertight doors between compartments. Watertight doors shall, according to the rules, be kept closed except when passing through them and there shall be an indication on the bridge for the position of each door. It should also be possible to close them from the bridge. In spite of these rules, ships are repeatedly lost due to open watertight doors.

Ideas from the chain-breakers are to have smart-card doors, i.e., each crew member has a card that opens the doors when approaching them and closes them afterwards in order to facilitate work and prevent people from leaving them open. Another idea is to have a permanent transition of pipes, cables, and hoses through watertight bulkheads at doors in order to facilitate work with the doors closed. The most controversial suggestion is to simply not have any doors through watertight compartments under the freeboard deck. In this case, the crew members would need to go up to the freeboard deck before entering a new compartment. To make this work, the ship would have to be designed, and the compartments equipped, in a way where passage to other compartments would not be necessary very often.

7.4.3 Damage Stability.

The damage stability of roro-vessels is a major problem. The main reason is the large open roro-decks. If a roro-deck is flooded, the free-water surface will make the ship very instable. If the ship is damaged in a way that will make it sink, the main issue is to maintain its stability as long as possible. When enough compartments are flooded beneath the roro-deck (freeboard deck) the roro-deck will be under the water surface and starts to be flooded. This will normally cause a roro-ship to capsize and is therefore a matter of vital importance to solve. Several concepts have been suggested for maintaining the stability of a roro-ferry in a damaged condition, as follows.

Cross-Flooding.

At collision and grounding, especially at a rip up, several compartments on the same side of the ship can be flooded. To maintain the ship's stability and to prevent too large a list, cross-flooding arrangements could be useful. The purpose of cross- flooding is to distribute water between ballast tanks, fuel tanks, void spaces and compartments below the freeboard deck by means of piping or openings, in which water can stream from a tank or compartment with a higher water level to a tank or compartment with a lower level.

The cross-flooding arrangement should not be a fully automatic system, but instead a passive one, in which the valves for flooding can be manoeuvred manually by the crew to be able to control the cross-flooding. The pipes need to be fitted with non-return valves to prevent water from flooding back if the ship lists. The non-return valves should be designed as to allow cross-flooding only when the water level in one compartment is higher than in the other compartment, compared to when the ship is on an even keel.

Cross-flooding should in general not be used if only one compartment is damaged, or maybe even two, if not needed. Even though cross-flooding increases the stability, compared to the absence of cross-flooding, the ship's draught will increase and the freeboard deck might sink under the water surface. It will also make compartments useless and equipment may be lost. Only a limited number of tanks and compartments should be used for cross-flooding at an early stage, however, it should be possible to flood all compartments, including the engine compartments, if this is necessary for maintaining stability. The emergency generator will need to have the capacity to operate all the ship's vital systems in this situation, as the main engines and the auxiliary engines with generators will be put out of service.

If, after a collision or grounding, the ship quickly lists considerably, cross-flooding may not work. Pipes may need to be connected to pumps in order to be able to pump the water between compartments.

At grounding, and possibly even at a collision, there is a risk that the cross-flooding pipes are damaged. This has to be considered when designing the piping for the cross-flooding system. To prevent unwanted flooding at ruptured cross-flooding pipes, valves operated from the bridge should be fitted to the pipes at each compartment.

For decision support, sensors for indicating the water level in tanks and compartments are needed, together with an indication of when, and in which direction, water is flowing in a cross-flooding pipe.

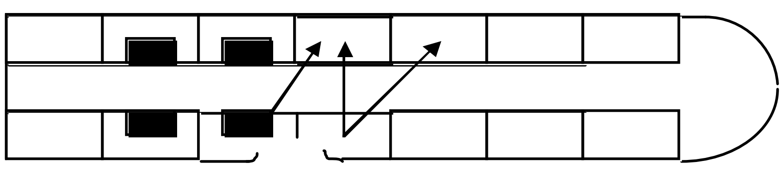

Figure 9. Cross-flooding.

Water on the Freeboard Deck.

While the freeboard is above the water surface, water can enter the freeboard deck either due to an open bow-door or aft ramp or through a hole caused by a collision or maybe an explosion from inside. In these cases, water could enter in the form of waves and by the ship's motion in the sea, i.e., rolling and pitching. The important thing in this situation is to get the water off the roro-deck, as a free water surface on roro-deck causes the ship to be very unstable. There are three suggestions for how to cope with this. These are 'Freeing the ports', 'Down-flooding' and 'Non-return scuppers'.

'Freeing the Ports'.

To free the ports means being able to open the bow-doors and the aft ramp enough to drain out the water. Aft ramps and especially bow-doors should never be opened at sea in bad weather, as waves and the ship's motions might make them fall off or deform them in a way where they cannot be closed afterwards. Especially bow-doors hinged to the hull via arms are very sensitive to this situation and they might fall off in a quite short period of time if opened in heavy sea.

'Down-Flooding'.

A second idea is to have a down-flooding arrangement where the water on a roro-deck is drained down into the ship. This would actually increase the ship's stability at first and if the water flooding into the roro-deck could be stopped before too much has been down-flooded, it would work. As stated before, the ship's draught will increase and equipment in the flooded compartments will be lost.

If, however, the water coming into the roro-deck cannot be stopped, the ship will sink deeper and deeper until the roro-deck is under the waterline. Water will then stream freely into the deck filling up the compartments used for down-flooding. Eventually, the roro-deck will start to fill, during which the free water surface on the roro-deck will become a problem in any case, and this will no longer be solvable by using this method only. The down-flooding would in this case work as a temporary measure.

'Non-Return Scuppers'.

A third idea is to have large non-return scuppers on a roro-deck to be able to drain the water out. This would work as long as the roro-deck is above the water surface and it would not increase the ship's draught or fill up the ship if the water intrusion cannot be stopped.

A combination of non-return scuppers and down-flooding arrangements for being able to increase the ship's stability, controlled by the crew, might be the best solution.

Division of a RoRo-deck with Bulkheads.

A subdivision of a roro-deck with bulkheads could limit the water to parts of the roro-deck. A cross-flooding arrangement with non-return valves, as described above, between these sub-divided compartments would increase effectiveness.

However, in this case, the subdivision needs to be made not only with longitudinal bulkheads but also with transverse bulkheads. A transverse subdivision is difficult to implement. A stationary subdivision would affect cargo space, or lane metres will be lost.

7.5 Other.

A helicopter platform would be of great help, except during heavy weather, for facilitating the pick-up of sick and injured people and for getting fire-fighters and medical teams onboard during a distress situation. It would also assist evacuation of some, but not all, passengers and crew onboard.

One chain-breaker is about equipment onboard when acting as a supporting vessel. This concerns standardisations of hoist equipment for lifeboats etc. There are today no rules regarding this, but it is being discussed by maritime authorities.

A point often neglected at the design stage is to design for maintenance and inspection.
If maintenance and inspection is difficult to carry out it may not be performed adequately and might thus affect the safety of the ship.

8. Collision and Grounding Criteria.

Present rules and regulations for the arrangement of bulkheads and decks in passenger ships are set in the SOLAS and Loadline conventions. The damage condition stipulates a 2-compartment standard.
Freeboard-regulations have, until the Stockholm agreement came into force, resulted in a very small freeboard, which meant that damage to the shell easily resulted in water on the freeboard deck. The effect of the Stockholm agreement is a significant increase in the freeboard. However, the damage-stability rules as formulated today with a 2-compartment standard, are in a sense too prescriptive and do not give possibilities for effective design-development to an improved damage-stability standard. The approach used in this project, aiming for an increase from a 2- to a 3-compartment standard, is an increase in the damage-stability standard.
Since the existing standard was developed, much analysis capability has been developed, for example Finite Element methods, and it is considered that this should be taken into account in the analysis process of ship safety. In particular, structural breakdown during collision and grounding can be modelled, which shows the penetration of shell, bulkhead and decks. Consequently, a more realistic approach can be made to the true inflow of water. Further, a better assessment of collision-resistant structural design can be taken into account. Thus, a development of a direct calculation procedure may be regarded as a concept for the improvement of the structural arrangement in order to make it more effective in case of collision/grounding. In the longer term, this would give the designer a better tool for sound product development.

There are obviously many aspects and details to be considered when developing such a procedure but in the main, the model should contain the following:

Loading conditions.

A) Collision in right angle to ship's side (Amidships).
B) B) Front collision.
C) Rip-up of ship's side.
D) Rip-up of bottom (grounding).

Damage.

Loading case A: Two compartments damaged. Penetration through B/5 bulkhead.
Loading case B: Damage should at least penetrate 6-8 metres aft of FP.
Loading case C: Rip-up. Length minimum 0.65 L. Penetration less than B/5.
Loading case D: Rip-up. Length 40 % of the ship's length.

Colliding ships.

The colliding ships should have the same displacement, be fitted with forecastle and bulbous bow.

Ship's speed

Ship's speed should be 60% of the design speed (Due to the normal weather conditions during these kinds of accidents).

Weather conditions.

Significant wave height, 3.5m (is used for damage analysis according to the Stockholm agreement).

Survival criteria.
The ship should have a new equilibrium not giving rise to more than 10 degrees list.

9. Concepts

The Concept Ship

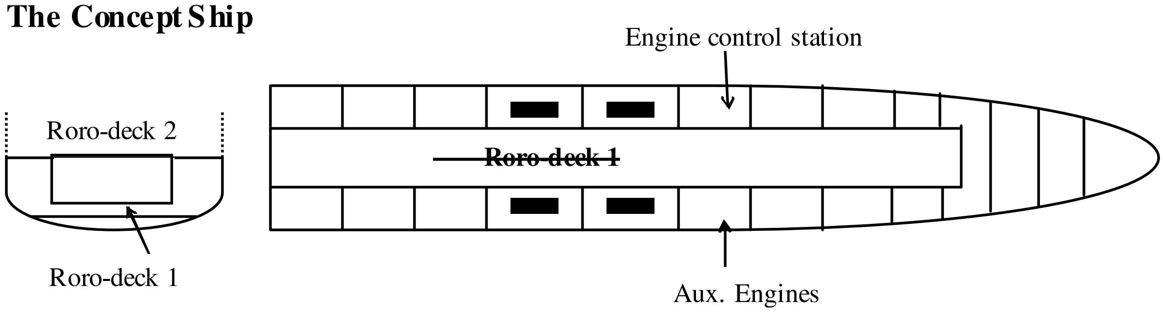

Figure 10. Schematic sketch of the concept ship's division beneath the freeboard deck.

The original plan of the concept ship NAOS is divided into 14 compartments reaching from the freeboard deck (roro-deck 2) to the bottom plates of the ship. In the middle is the lower roro-deck reaching almost throughout the ship's length in the centre, see Figure 10. This roro-deck is its own compartment and is not divided transverse the ship. The port and starboard side of the compartments are not separated from each other, but connected beneath the roro-deck. The reason is to have a cross-flooding between them in order to maintain stability during flooding.

There is an inner bottom in the ship of about one metre in height.

The four main engines are located in two compartments, two engines in each compartment and one on each side. The auxiliary engines are located in the compartment fore of the main engines on the starboard side and the engine control room is on the port side.

Power Redundancy.

This concept is vulnerable in several ways. First, if during a collision or grounding a hole is struck in one section, both sides of that section will be flooded. This could be good as the stability is maintained. However, if the hole is struck in an engine compartment, two engines will be lost. If the aft engine compartment is struck and flooded, all four engines will be lost since the gear boxes, positioned in the aft engine compartment, will not work if flooded, at least not for a longer period of time. The ship will in this situation lose all its propulsion power. A ship without power will drift alongside the waves and will, in large waves, be subjected to heavy rolling motions. If, due to damage, the stability of the ship is low (small GM) it could make the ship capsize.

The four main engines are positioned in compartments next to each other. A collision or grounding damage in between these two compartments would also put all four engines out of service.

The port and starboard engine compartments should be divided to prevent both engines from being knocked out at the same time due to grounding or collision. The propulsion line should be designed to function even under water for a certain period of time to be able to reach land.

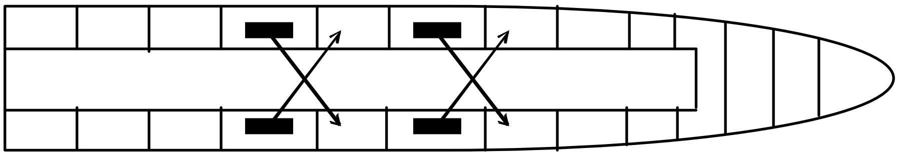

Figure 12. Configuration with a compartment in-between the machine compartments.

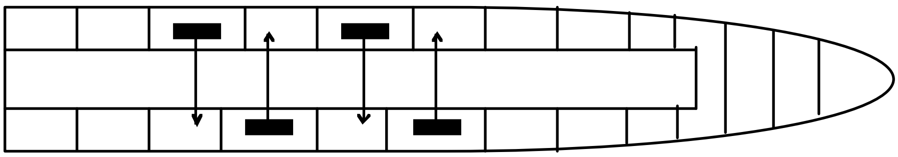

Figure 13. Chessboard configuration of the machineries.

To increase the power redundancy, the engine compartments could be positioned further apart. This can be done by having a compartment between the two engine compartments (Figure 12) or positioning the engines in a chessboard configuration (Figure 13). A two-compartment damage would in this case only affect one engine compartment. The auxiliary engines could also be divided into two compartments, one on each side, and it should be possible to operate the machinery from the bridge.

Damage Stability.
The compartments on opposite side of roro-deck 1, or at least the engine compartments, should be divided to prevent both compartments to be flooded if one is flooded.
To maintain stability, cross-flooding between the divided compartments could be used. The cross-flooding should not be between two-engine compartments, but from an engine compartment to a non-engine compartment as mentioned above. It should be possible for the crew to control the cross-flooding, preferably with the help of a decision support system. Cross-flooding should be possible from any compartment to any other of the closest compartments.

To increase the ship's stability, the point of gravity could be lowered by using lightweight material for the top structure of the ship.

There are many small not used void spaces on a ship. To increase the ship's stability in a damaged condition, these could be filled with non-combustible cellular plastic to prevent them from being flooded. This is, however, a rather expensive solution today.

Division of RoRo-deck 2.
On the concept ship, roro-deck 2 constitutes the freeboard deck. This deck is a large open area reaching from starboard to port almost along the whole length of the ship. Even if the ship is completely flooded beneath the freeboard deck, and is then obviously sinking, the ship will capsize when roro-deck 2 is flooded. Several solutions can be suggested. However, FE-calculations are needed to conclude which suggestion that will work and which that will be the best solution.

Figure 14. Schematic sketch of the current layout for roro-deck 2.

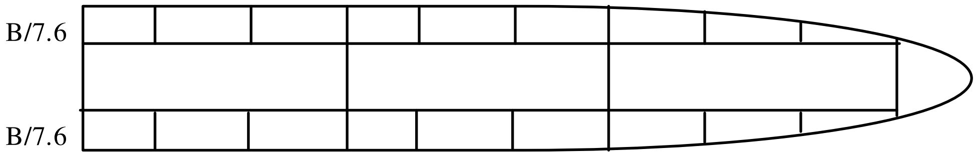

Figure 15. Schematic sketch of the current working layout for roro-deck 2.

The current working layout is divided in three sections longitudinally along the ship with two bulkheads. The two bulkheads are positioned at B/7.6 and divided transversely into several watertight compartments towards the outer shell plate. The roro-deck is divided transversely with two watertight doors into three compartments. This solution would maintain the ship's stability in all situations when the roro-deck is flooded, although a large portion of the cargo space will be lost.

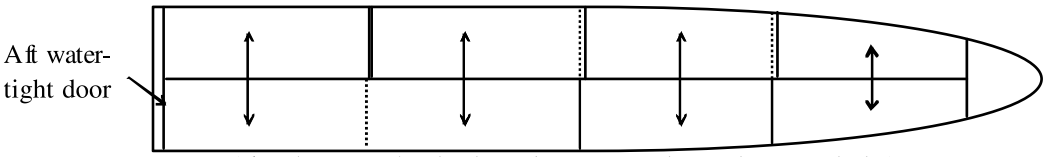

Figure 16. Schematic sketch of an alternative solution for roro-deck 1.

Another solution could be to divide the ship with a longitudinal bulkhead along the centre line and further divide it transversely with watertight doors into several smaller watertight compartments. In addition, if a watertight door is positioned inside the aft ramp and all the doors into the freeboard deck are removed or made watertight, the freeboard deck would be raised significantly. To maintain stability if one or several compartments on one side are flooded, the compartments could be connected via valves. The valves should be designed so as to allow cross-flooding only when the water level in one compartment is higher than in the opposite compartment compared to when the ship is on an even keel. This would help counteract listing and rolling motions. Possibility to pump water between the compartments is necessary if the ship does not rule, but lists to one side all the time.
The doors can be designed as sliding doors that can be pushed over to the opposite side of the roro-deck while loading on one side. This configuration would also allow loading and unloading via a bow-door, which would be difficult with the current working layout. The reason is that the doors in the current working layout would have to open to the sides of the roro-deck.
For this concept, lesser cargo space would be lost regarding the longitudinal division. However, some space will be lost due to the doors dividing the deck.

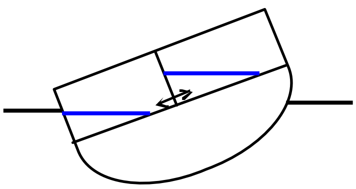

Figure 17. Counteraction of list and rolling motions. Cross section of roro-deck 2 divided with a longitudinal bulkhead with valves.

10. Summary.

As management usually is the starting cause of the events leading to accidents, education/training and stricter routines are the most effective methods for reducing accidents and are at the same time cheap measure to take. This, together with online stability calculations and decision support systems, would have prevented most of the accidents analysed in this work.

For fire protection, the main issue is to prevent a fire from spreading by keeping the fire within a vertical fire-zone, or a roro-deck, by means of thermal division, fire doors and the ventilation system. This will keep passengers and crew safe outside the zone on fire and, at the same time, fire-fighting can be concentrated to that zone alone.

To maintain damage stability, structural subdivision combined with cross-flooding arrangements, seems to be the most effective way.
For roro-deck 1 constituting the freeboard deck, non-return scuppers and down-flooding can be used.

The ideas and concepts presented in this report, based on the chain-breakers, are to be regarded as input for the different WP groups. Within your respective areas, you will be more competent to estimate the value of the ideas. If you choose to implement some of the ideas, the respective WP groups will have to develop them further in order to fit our concept ship, NAOS.

Evaluation of proposals can be difficult if there are several proposals to choose between and these need to be compared. In this situation, an evaluation matrix can be used.
An example is shown below.

Matrix suggested for evaluation of scenarios.
(The filled in matrix is just a dummy).

	Conceptual version of a general arrangement to meet survival requirements in collision			
Collision scenarios	Concept 1	Concept 2	Concept 3	Concept 4
Scenario 1 (SOLAS)	Fail	Ok	Ok	Ok
Scenario 2 (SOLAS)	Ok	Ok	Fail	ok
Scenario 3 (DESSO)	Ok	Ok	Fail	Ok
Scenario 4 (DESSO)	Ok	Ok	Ok	ok
Scenario 5	Fail	Fail	Fail	ok
Scenario 6	Ok fail	Fail	Fail	ok

The matrix is used to communicate judgement on a conceptual level on how different concepts meet collision scenarios. Some of these scenarios may be given by SOLAS as absolute requirements, marked (SOLAS) and others are needed from the DESSO consortium, marked (DESSO).
The scenarios should include descriptions of where the ship has been struck by another ship and how deeply. The concepts include different subdivision and cross-flooding solutions.
A "SOLAS" requirement can be to withstand a penetration depth of B/5.
A "DESSO" requirement is "to stay upright".

The columns represent the different proposals, or ideas, that are to be evaluated.
In the rows, there are different scenarios that should be met.
The result is a matrix with comments. The comments will be developed as the team is going through the matrix and utilises its professional judgement. Some of the scenarios cannot be evaluated without further calculation.

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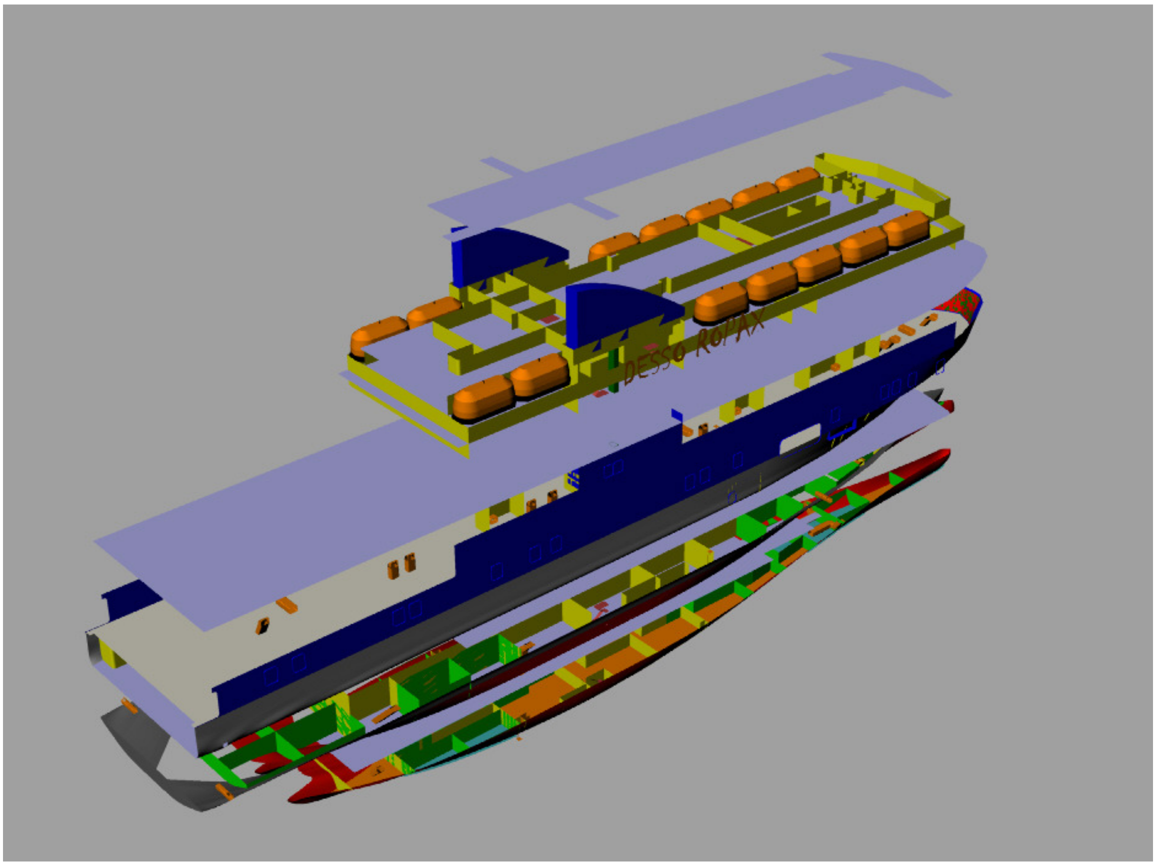
ISM (International Safety Management).
The Stockholm Agreement.
IACS (International Association of Classification Societies).
COLREG (Collision Regulations).

APPENDIX B

Work package 4

DESSO ROPAX Design

Final report



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Preface

The project, Design for Survival Onboard or DESSO, was initiated in the summer/autumn 2003, was formally launched 2004 and completed in March 2006.
The main funding came from Vinnova, Stiftelsen Sveriges Sjömanshus and the Swedish Maritime Administration. In terms of expert man hours, the project received support from its industrial participants.

The purpose: To find solutions to the problem how to care for the survival and possible mass evacuation of passengers and crew in case of a major structural damage or fire on a ro/pax or passenger ship.
The paradigm: To study the feasibility of designing a ro/pax ship to become her own lifeboat.
The result: To be a template for future improved safety for ro/pax and passenger ships.

The partners:

Chalmers Lindholmen	MarDeQ
Chalmers Marinteknik	NAOS
Globtech Marine AB	Silja Line
Kattegatt Design	SP
Kockum Sonic	SSPA
Lloyd's Register	Stena Line
	The Swedish Club

The nine Work Packages (WP) of the DESSO Project

WP 1: Project Management	SSPA
WP 2: Safety Assessment of ships.	Chalmers Marinteknik
WP 3: International Workshop.	SSPA
WP 4: RoPax Ship Design	Globtech Marine AB
WP 5: Upright and Afloat	Chalmers Lindholmen
WP 6: Decision Support	Kockum Sonic
WP 7: Fire Protection	SP
WP 8: Pax and Crew survival	Chalmers Lindholmen
WP 9: Concept Ship Display	SSPA

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Appendix

EuRoPax 3000, Main particulars and GA
DESSO ROPAX, Main particulars and GA

Table of figures/illustrations

1 Executive Summary

1.1 Terms of reference

According to the Terms of Reference, "WP 4 is intended to be the platform, expressed in a generic model of a ro/pax, the **EuRoPax 3000** - developed within the WP4 - in which the results of the other WP:s can be tested and evaluated." The result of the tests and evaluations are summarised in the **DESSO ROPAX** ship which fulfils the same commercial capacities as the original **EuRoPax 3000** but also the survival performance requirements identified in the **DESSO** Project.

1.2 For whom?

The final result is intended as a template out of which tentative owners may find ideas and solutions for improved safety.

1.3 State of the art

The generic **EuRoPax 3000** ship is fulfilling present rules for damaged stability (SOLAS and MCA).
The ship has a capacity of 1.500 passengers, 1.000 beds and about 3.400 lane meter trailer capacity. This capacity is typical for many European Short Sea Routes. The design is truly generic in the sense that a wide range of cargo access modes, capacities and passenger facilities can be adopted without changing the basic safety principles of the design. The same commercial capacities, flexibility and basic safety paradigms are adopted also for the **DESSO ROPAX.**

1.4 DESSO Targets

The DESSO targets are to develop the **generic EuRoPax 3000** into the **DESSO ROPAX** ship concept and to give the **DESSO ROPAX** ship qualities to become "her own life boat".

This means – in the **DESSO** interpretation - that the ship shall stay upright and afloat after the following damages:
1. SOLAS damage extended to three compartments.
2. MCA damage extended to three compartments.
3. Rip-up over a length of 65% of Lpp up to, but not penetrating, the deck 1 level.

Also:
- The ship shall, after the above damages, have a certain redundancy for manoeuvrability and for extended essential functions.
- In case of damages worse than the above, the ship may sink but this shall be without excessive heel or capsizing.
- The arrangements for abandoning the ship shall be multifunctional.
- Fire shall not be a reason to abandon the ship.

1.5 Results:

The **DESSO Targets** have been fulfilled in the **DESSO ROPAX** ship concept by adopting the following principle solutions:

1. Wide and closed side casings, transversally subdivided, are arranged from around DWL and up to deck 4, thus creating a "life belt" around the ship.
   The casings are arranged "outwards" which means that the casings do not restrict the cargo capacities and passenger arrangements compared with the generic **EuRoPax 3000**.
   This arrangement makes an upright survival, after the **DESSO** damages, possible, as well as an upright sinking - should the damages be more extensive than the **DESSO** ones.
2. The engine arrangements and systems are adapted to the various damage cases which means that minimum one engine compartment is dry and functional after any **DESSO** damage.
3. The spatial arrangement is laid out for easy fire fighting with equipment of sustainable type (high pressure water plus redundant pump arrangement), and for easy and safe evacuation (smoke evacuation and overpressure ventilation).
4. The abandon ship arrangement can be used for "float off", for "helicopter lift", for davit launching or for conventional raft launching.
   The allocated area for rescue equipment can also be used for a conventional life boat arrangement.

The more significant detail solutions adopted for the **DESSO ROPAX** Ship, based on the above principles, are further outlined and developed in this report.

Important to note is, that for the **DESSO** Requirements "stay upright and afloat" after a **DESSO** damage, and "sinking upright" in case of a more extensive damage, the chosen solutions are of "forgiving" nature that will require no action from the crew.
For the events of less serious nature, as for survival of the ship point of view, the designs for "safety by action" are dominant.
On the "incident trigger levels", suitable routines and training on all levels and for all involved categories are suggested to address situations of less serious nature in order to prevent from develop into significant situations .

1.6 Upcoming Rules

1.6.1 Floatability

The upcoming rules, as described in the MSC 80/3/4 Chapter II-1, are principally of probabilistic nature with complementary deterministic detail regulations.
A study, where the Generic **EuRoPax 3000** and the **DESSO ROPAX** have been evaluated, considering the new rules, has been done within the WP 4 and WP5. The study is by definition superficial as several parts of the new rules are still under discussion regarding interpretation and application.

The study suggests that the **EuRoPax 3000,** with the original lifeboat/liferaft arrangement, will arrive at an **attained index (A)** that may not fully satisfy the **required index (R).**
With a 100% lifeboat capacity, the required index will be lower and the attained index will, for this reason, be sufficient to reach the required index.
The **EuRoPax 3000** will – as shown in the WP5 report – capsize at most of the 3-compartment damages.

For the **DESSO ROPAX**, the required index demand will, due to the "liferaft alone" arrangement, be somewhat higher than for the **EuRoPax 3000**.
The survivability enhancements, applied to the **DESSO ROPAX,** will most likely only marginally improve the attained index compared to the **EuRoPax 3000**.
The **DESSO ROPAX** will – as shown in the WP5 report – survive all 3-compartment and MCA damages and she will not capsize after damages more extensive than that.

The new rules contain deterministic requirements that, in some cases, might be contradictory to the recommendations of WP4 and WP7.

1.6.2 Fire fighting

The **DESSO ROPAX** Ship is designed according to the upcoming rules as described in the WP7 and which are considered in line with the principles suggested for **DESSO**.

1.6.3 Cost aspects

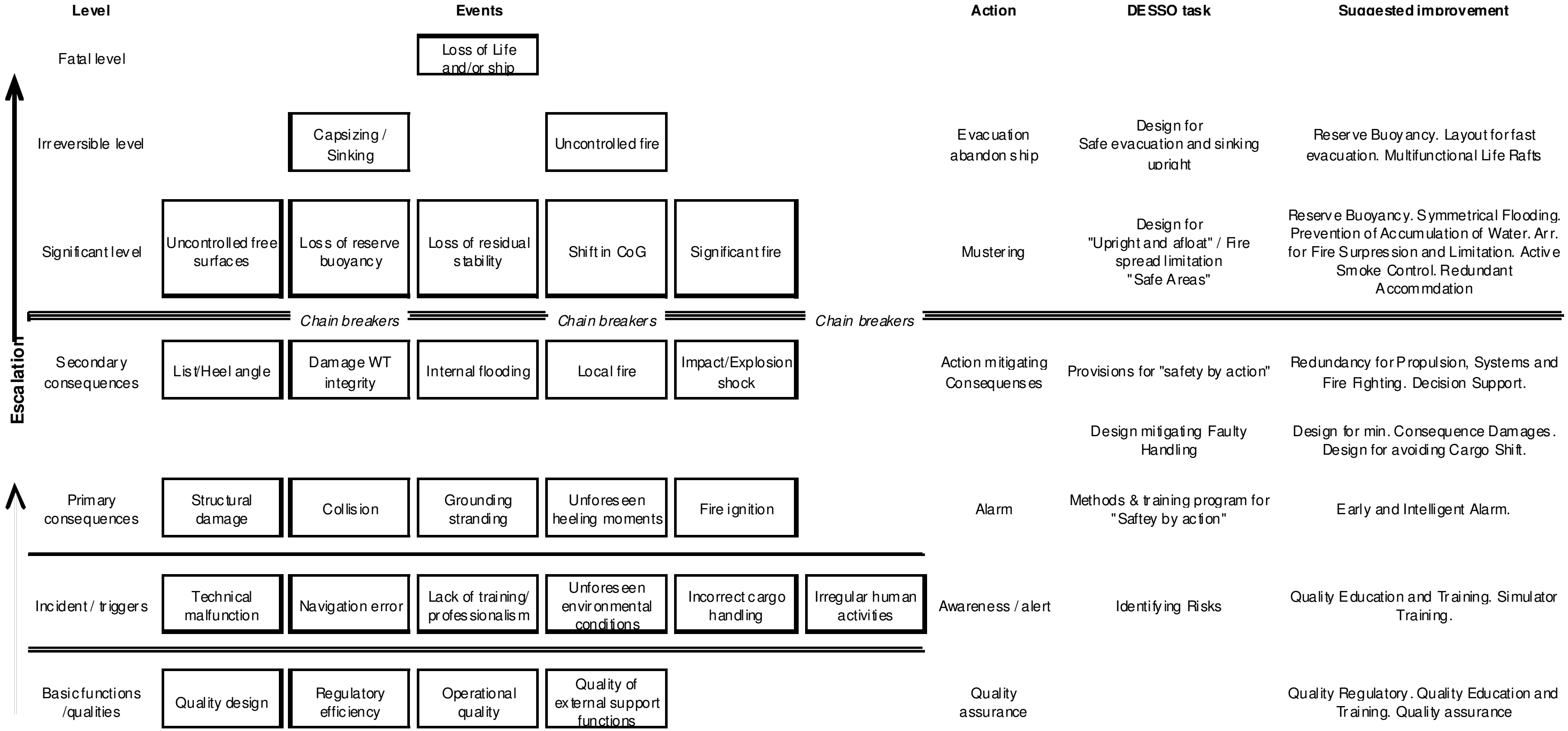
In general, safety features above the rules are not rewarded, neither by the authorities nor by the industry (insurance companies, clients etc.)
At the end of this report, an attempt is made to briefly analyse the suggested **DESSO** features from the cost point of view and at what conditions they might be attractive for a potential owner.
The analysis suggests that – apart from the redundancy – the **DESSO** features can be obtained at moderate or low extra costs.

1.6.4 Conclusions

The DESSO Project demonstrates that a ship that has a very high survival capacity after a damage and that if she sinks does it without capsizing is possible to design and build with a marginal extra costs.
The problem is that the upcoming rules, seems not to encourage this.
The lack of focus and transparency of the upcoming rules makes them very difficult to explain to the users, especially in terms of ship's behaviour after a damage. This must be considered a risk by itself.

2 Introduction

According to the terms of reference, "the WP 4 is intended to be the platform, expressed in a generic model of a ro/pax ship, the **EuRoPax 3000**, in which the results and findings of the other WP:s can be tested and evaluated".
The **EuRoPax 3000** is described in an earlier WP 4 Report and analysed from a floatability point of view in the WP 5 Report.
Initially the **DESSO** Damage Cases are described and illustrated as an understanding of their nature is essential for evaluation of the proposals for avoiding the consequences of these damages.
In order to test, complete and evaluate these various ideas and proposals in a systematic way, the WP 4 and WP 5 jointly developed a "Evolution" Flow Chart.
As the top events are of decisive influence on the major parameters (beam, freeboard height, sectioning etc.) of the **DESSO ROPAX** ship, it was found necessary to start with problems related to the top events and work the way downwards the event levels.
With the major parameters decided and introduced in the design, the boundaries for the other required solutions were set and identification and evaluation of the proposals and suggestions was considerably facilitated.



3 Survival criteria

3.1 Present IMO Rules for floatability.

The present IMO Rules for floatability of a passenger ship or ro/pax ship are deterministic and describe certain damage cases that the ship shall be designed to survive.

1. According to SOLAS, a 1, 2, or 3 compartment damage (depending on the "criterion of service"))is required. In the very majority of Ro Pax cases it is a two compartment damage defined as a damage to two adjacent compartments, unlimited in height and with a penetration of 20% of the ship's beam (B/5) shall apply.
In complement to this, "floodable length" shall also be fulfilled, granting the non submersion of the margine line, irrespective of the equilibrium heel.

2. According to MCA, a damage with a penetration up to 50% of the ship's beam (B/2), a longitudinal extension of the damage of one side compartment and an unlimited vertical extension shall also apply to withstand the floodable length requirement not usually reached by any vessel having a long compartment below the bulkheads deck.

3. According to the Stockholm Agreement, a certain amount of water on the freeboard deck shall be considered in conjunction with the SOLAS damage.

Redundancy.
- No redundancy for manoeuvrability including propulsive power is required.
- The electrical power redundancy is taken care of by an emergency generator with supply demand according to SOLAS.

3.2 Requirements according to DESSO

3.2.1 DESSO Damages

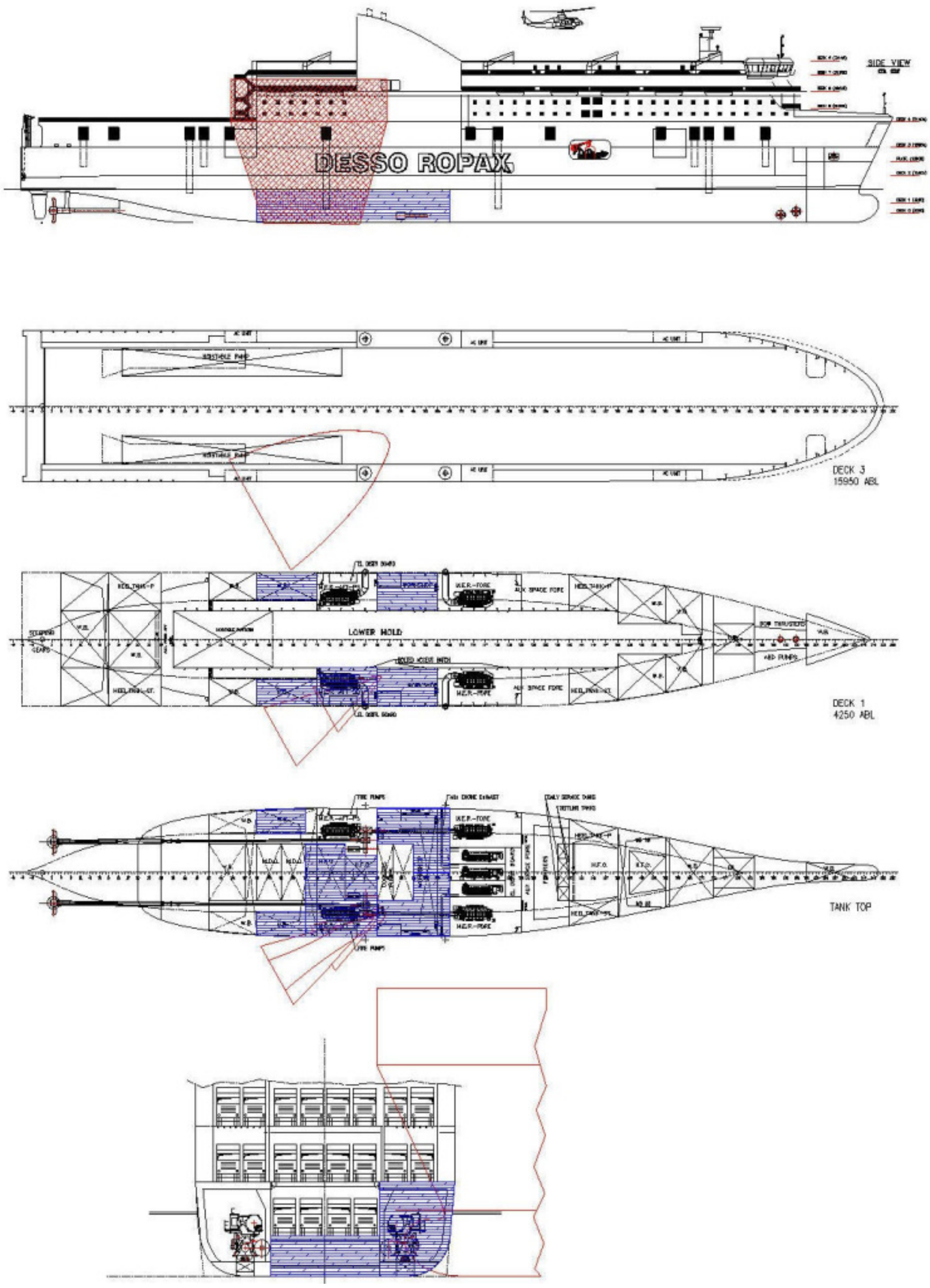
The DESSO damages, the DESSO ROPAX should survive, are more severe than those above described existing rules but considered relevant for the DESSO Project.

For upcoming rules: see chapter 8.

Damage 1

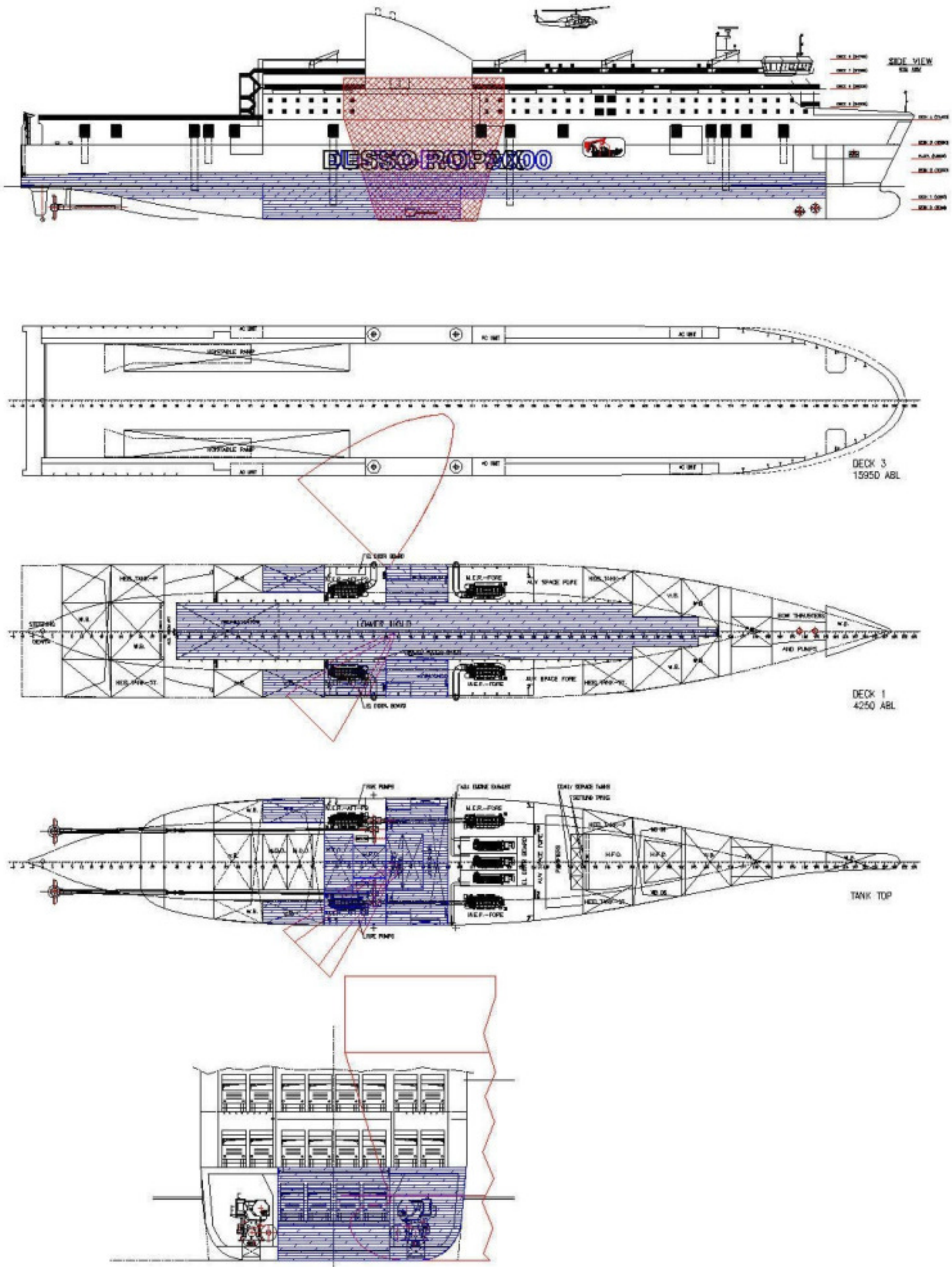
SOLAS extended to three compartments.

This means that three adjacent compartments are damaged up to B/5. No vertical limit of the damage.



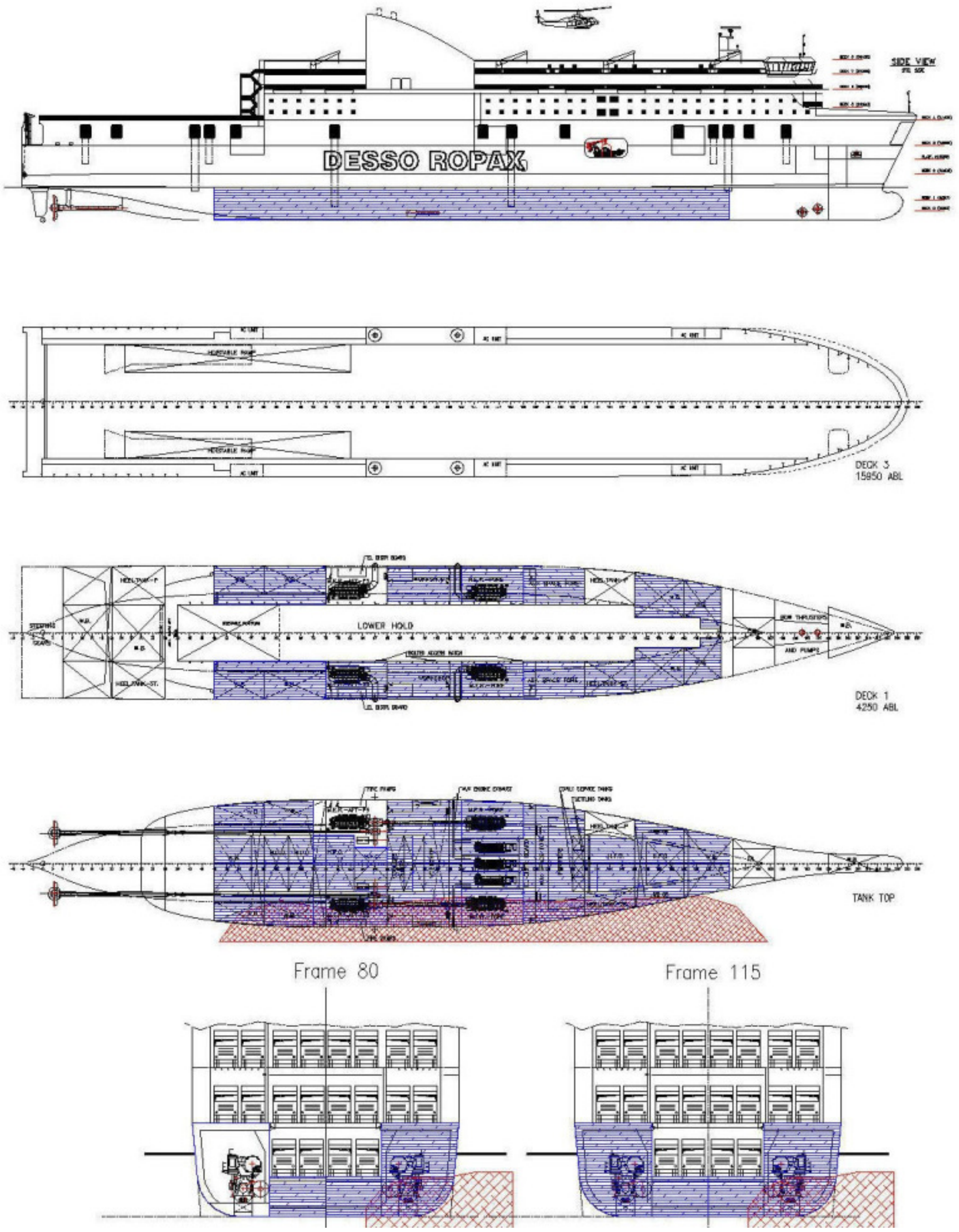
Damage 2

MCA extended to three compartments.
This means that three adjacent compartments are damaged up to B/2. No vertical limit of the damage.



Damage 3

Rip up to 65% of the Lpp with penetration up to but not penetrating the dk 1 level.
Transversally the damage is limited to 20% of B.



3.2.2 Actual damages

Figure 1 A Panamax container ship in collision with a handymax/general cargo ship.

The penetration is almost 100% e.i. the bulk ship is almost cut in two.
The horizontal extension is moderate. The vertical extension is "unlimited. The medium and large size container ships (panamax and post-panamax) with high speed and great mass possess an enormous inertia.

Damage 2
MCA extended to two, respectively three compartments.
Damage depth: up to B/2. No vertical limit.

Figure 2 A VLCC in ballast after a collision with a fully loaded cape size bulkship. The collision angle was about 45 degrees

The penetration is up to B/2 (see also picture 1).

Generally ro/ro ships offer more resistance against penetration due to the horizontal cargo decks. An engine arrangement outside a B/5 bulkhead adds to this resistance.

Figure 3 A VLCC after a collision with an OBO in ballast. The collision angle was about 90 degrees. The penetration is about to B/5.

Figure 4 A product tanker after a collision with a container feeder ship.

The collision angle was about 25 degrees. The collision started at about L/2 and ended in the superstructure aft. The bulb of the feeder ripped open on one side all the tanks from L/2 to aft.

Damage 3

Rip-up to 65% of the Lpp with a penetration up to - but not penetrating - the deck 1 level. Transversally the damage is limited to about 20% of B.

Figure 5 A rip-up ship in a dry dock

Relatively little dynamic energy can cause damages of considerable length.
In a recent example did a cape size bulk carrier slip over a sharp rock which ripped up all the tanks on one side to the full length of the ship to a depth of about 0.5 meter.

3.2.3 DESSO Fire survival criteria

Fire shall not be a reason to abandon the ship.
This means that fire – wherever it occurs – shall be possible to isolate and fight.
Remaining areas, outside the fire zone, shall be possible to regard as "safe areas".
The access arrangements, within the accommodation as well as the rest of the ship, shall be easy to use, logical to follow and without bottlenecks.

Figure 6 Large scale fire on Scandinavian Star

The pictures above demonstrates the problem with high located air intakes for pressurising areas around a fire zone.

Figure 7 Fire extinguished but the ship heeled over due to free water surface from fire fighting

3.2.4 DESSO Redundancy requirements

For the **DESSO ROPAX** ship, a propulsive redundancy shall remain after the DESSO damages.
This means that at least one engine room shall be accessible and dry after a DESSO damage. The functions of the engine and required supply systems shall remain.
Such functions are:

- Propulsion
- Electrical production and distribution
- System control

4 Irreversible Level

4.1 General

Should the **DESSO ROPAX** ship suffer a damage on the watertight integrity, which is more severe than the DESSO damages, the buoyancy might be lost to that extent that the freeboard deck (deck 2) will be submerged and water will enter on the freeboard deck, with a considerable loss of stability as a result.
The generic **EuRoPax 3000** ship will, in this scenario, lay down on its side or capsize and most likely sink.

4.2 The DESSO Requirements

The **DESSO ROPAX** ship is, in case of such a fatal damage, required not to heel extensively and if she sinks, sink in a reasonably upright position to facilitate an orderly evacuation.

4.3 Sinking upright

The following alternatives to achieve the **DESSO** requirements for "sinking upright" are investigated:

1. To down flood the water from the freeboard deck into the undamaged compartments below, thus improving the stability during the sinking.
The development of the capsizing scenario may however be very rapid (within minutes), and the time required for positive and well considered actions as well as prompt access to the systems required for the down flooding might be unpredictable and most likely completely insufficient. (see the Vossnack Report).
Also present interpretation of the freeboard regulations will make a down flooding arrangement difficult.

2. To improve the stability with a combination of closed side casings and transverse bulkhead (doors) on the freeboard deck.
A widening of the side casings corresponding to an increased ship's beam to 30,12m above the freeboard deck (originally on the **EuRoPax 3000** equal to 28,5m) and adding two transverse bulkhead doors, will increase the stability and limit the free water surface on deck 2 sufficiently to ensure an upright sinking. (see WP 5)
The bulkhead doors will however create obstacles for the cargo handling and the side casings will not be big enough to offer alternative space for technical installations and accesses.

3. To improve the stability with closed side casings wide enough (min 3.75m) to handle the sinking upright problem without any additional transverse bulkhead doors.

For the **DESSO ROPAX** ship, this alternative is chosen.

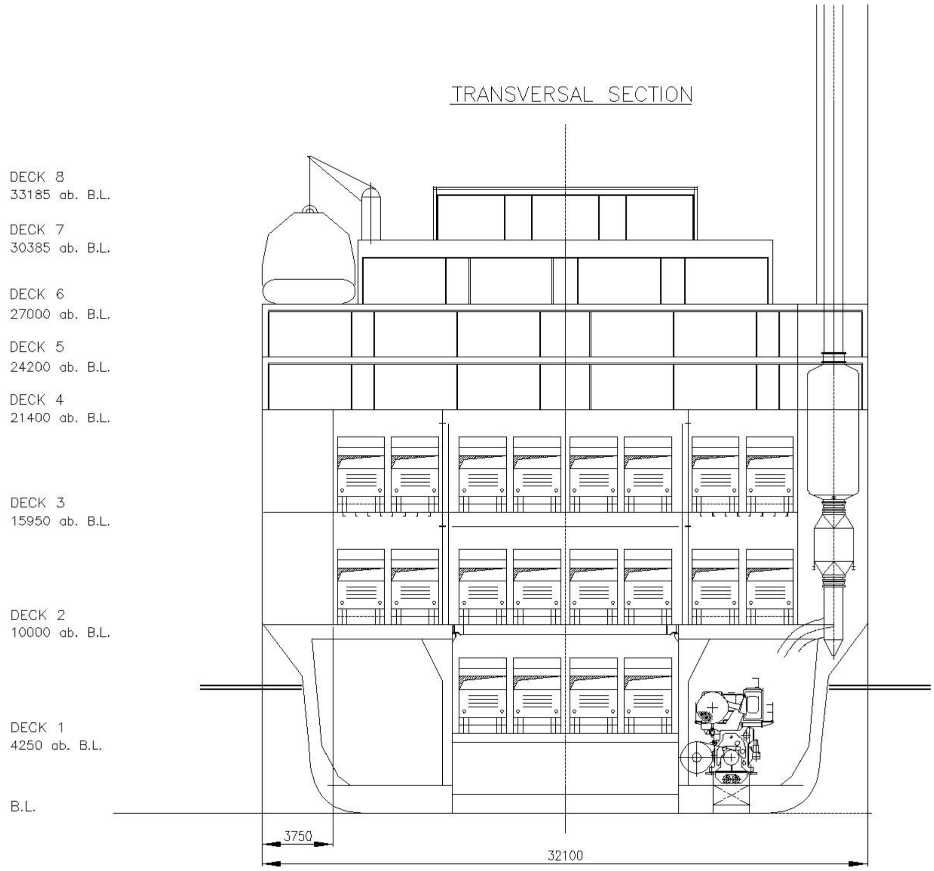


Figure 8 DESSO ROPAX design with wide closed side casings

4.3.1 Arrangements for the DESSO ROPAX ship for sinking upright

The basic philosophy to arrange for fulfilment of the DESSO requirements is as follows:

- In case of loss of reserve buoyancy, the waterline inertia shall increase with the increased draft to that extent that sufficient stability remains. This is achieved by an increased beam above the waterline.

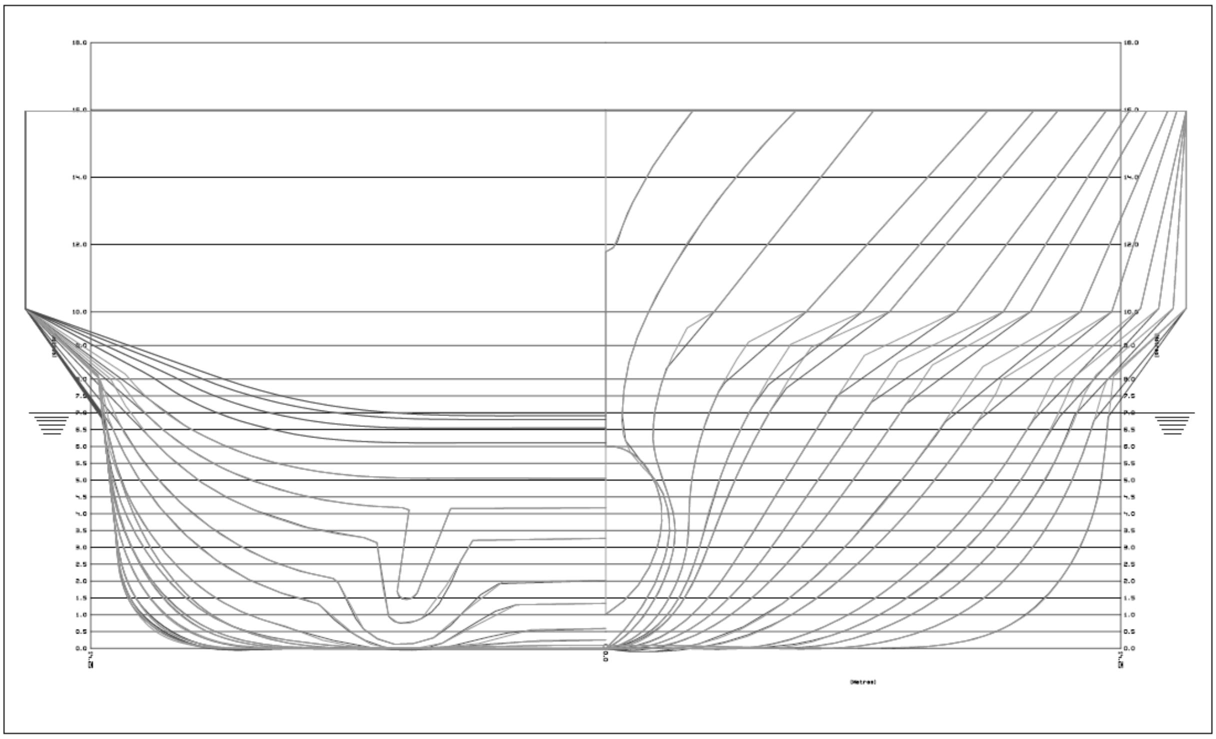


Figure 9 Increased beam above the waterline

- Should a damage be that extensive that the freeboard deck is flooded, reserve buoyancy is obtained by connecting the web flanges so a complete inner hull is created from the freeboard deck and up to below the lowest passenger deck.

The ship is thus supported by the double hull side walls as for a floating dock.

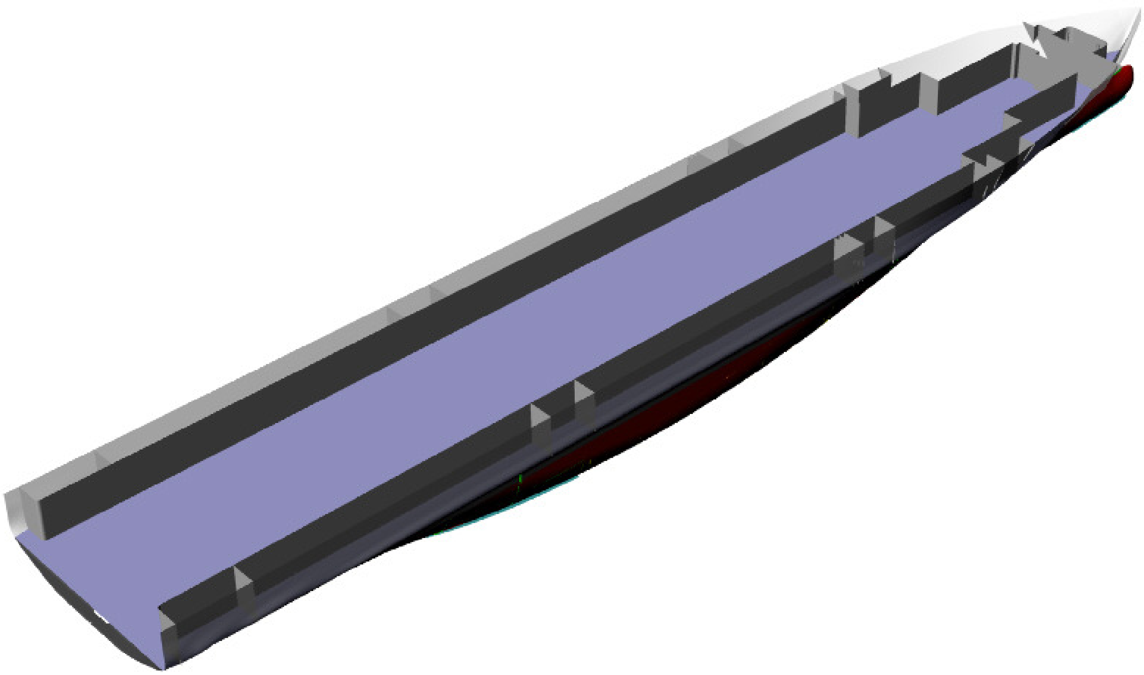


Figure 10 The ship is supported by the double hull side walls as for a floating dock

In case of a damage of such a magnitude that also the "dock walls" are severely damaged, the two lower passenger decks may offer a certain reserve buoyancy that prevents capsizing during the sinking. This is assuming that a reasonable watertight integrity of the superstructure is maintained.

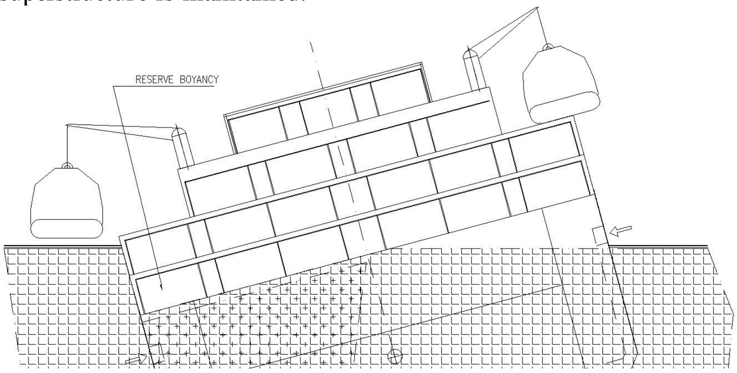


Figure 11 Reserve buoyancy in passenger decks

The side casings, widened to 3.8m each, giving a ship's beam of 32.12m above the freeboard deck and maintaining approximately the original beam of 28.5m in the waterline are found sufficient to fulfil the DESSO requirements.
These wide side casings offer alternative spaces for various technical installations (boiler, silencer, air condition units, ventilation arrangement, access etc) that otherwise would have occupied commercial space.
The wide side casings do also provide wider areas on the passenger decks for commercial use and facilitate the creation of an ultimate reserve buoyancy in the passenger accommodation.

In order to limit the heeling during the sinking it is assumed that the compartments of the side casing are fully interconnected all the way up to the deck 4 (lowest accommodation deck) so minimum asymmetry is created.

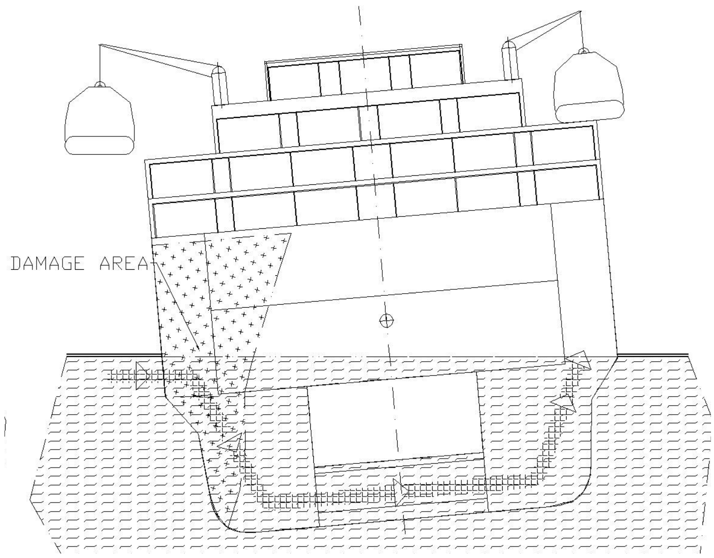


Figure 12 Cross flooding to minimize asymmetry

Longitudinally fore and aft of the damage, undamaged compartments offer spare buoyancy that will assist to keep the ship upright and slow down the sinking.

When the sinking has progressed to that level where water reach the air intakes, located in undamaged sections, that leads to the engine room or lower holds, water may enter and fill the undamaged sections.
As the ship at this stage may have a list of about 20 degrees, this water may initially worsen the heeling considerably over a certain period of time.

To avoid this and thus maintain the buoyancy in the undamaged parts, the ventilation ducts are designed in such a way that they create a watertight passage from the outside of the hull to the area they are ventilating, thus leaving the space they are passing, dry.

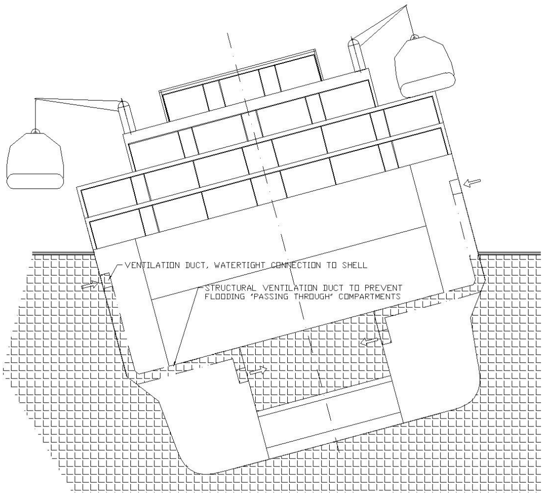


Figure 13 Ventilation duct arrangement to minimize flooding

The section shows an undamaged transverse zone.

4.4 Uncontrolled fire

4.4.1 Accommodation

Upcoming SOLAS requirements call for "safe areas" within the accommodation in order to minimise the need for abandon the ship in case of fire.
A "safe area" – according to the SOLAS definition – is an "area in the context of a fire casualty, from the perspective of habitability, any area outside the main vertical zone(s) in which a fire has occurred, such that it can safely accommodate all the persons onboard to protect them from hazards to life or health and provide them with basic services".
The above means that the "safe area" can be any space outside the main vertical zone(s) affected by fire.

Should abandoning of the ship be needed, shall, according to the SOLAS rules, "adequate means of egress/escape to life saving appliances be provided from each area identified or used as a safe area, taking into account that a main vertical zone may not be available for internal transit".
(for a full definition and detail description of "Safe Areas" see the WP7 Report)

Arrangements for the DESSO ROPAX ship facilitating evacuation

For the DESSO ROPAX ship, this is provided for by arranging the accommodation decks to simplify orientation and provide easy access to the stair cases to the assembly stations. These are arranged, with one for each fire zone, as **"safe areas"** with direct access along the ship's side to the outdoor gangway on which the life rafts are located. The arrangement does also provide for an outdoor passage from one area to another "bypassing zones lost by fire".

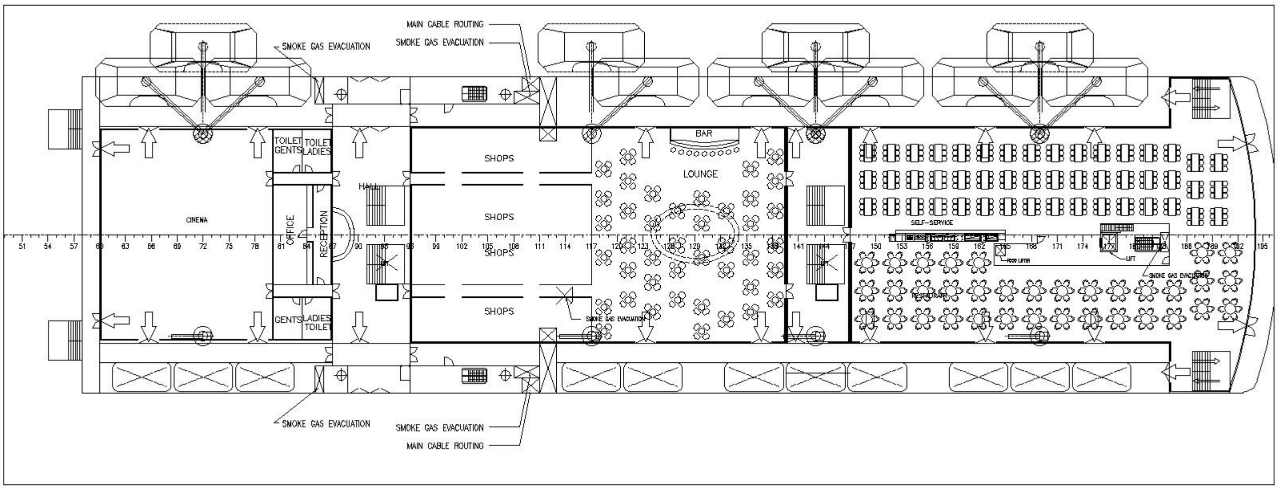


Figure 14 Evacuation deck

Within the blocks of passenger cabins, the corridors are arranged in the longship direction. The arrangement makes it possible to "seal off" a corridor with a cabin on fire (and not necessarily the whole block of cabins), thereby facilitating both evacuation and fire fighting.
Longship corridors are also easier to walk, in case of excess heel, than transverse ones.

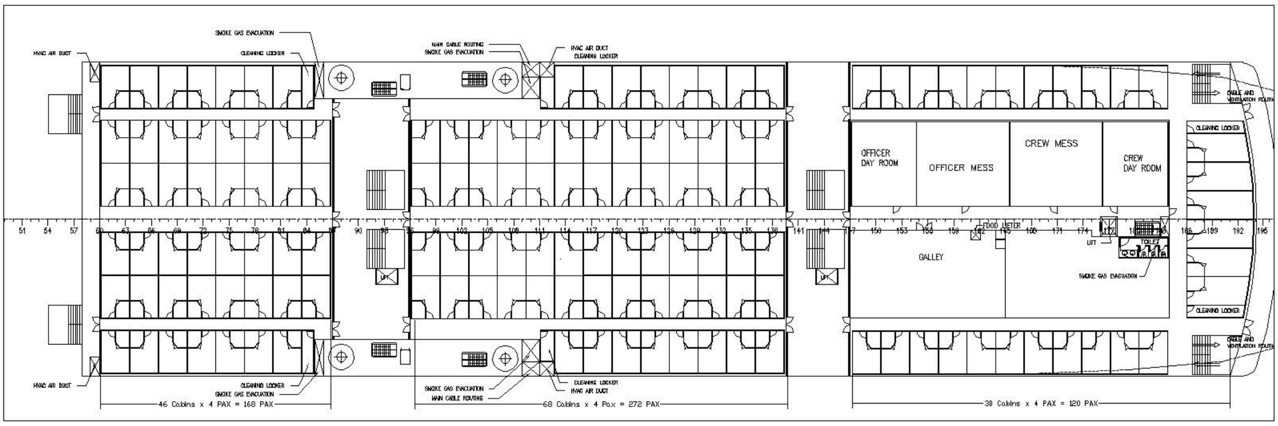


Figure 15 Within the blocks of passenger cabins, the corridors are arranged in the longship direction

Provisions for supply of fresh air and evacuation of smoke and toxic gases is necessary for a safe evacuation and for the habitability.
The DESSO solutions are described in detail in the WP7 Report.
Normally, (like on the generic EuRoPax 3000 ship) the arrangements for ventilation and air condition, including the intakes for air, are located on the upper decks. This may create problems for finding air intakes that not run the risk of sucking gases and smoke instead of fresh air into the areas in question.

For the DESSO ROPAX ship, the wide side casings (necessitated by the floatability requirements), are used to accommodate the units for air condition and ventilation and related intakes for air on a low deck level (dk 3), starboard and port in pairs for each fire zone.
This arrangement, together with the DESSO redundancy for manoeuvrability and extended supply of electricity will facilitate substantially to care for the supply of fresh air and extraction of smoke also in the "irreversible" scenarios.

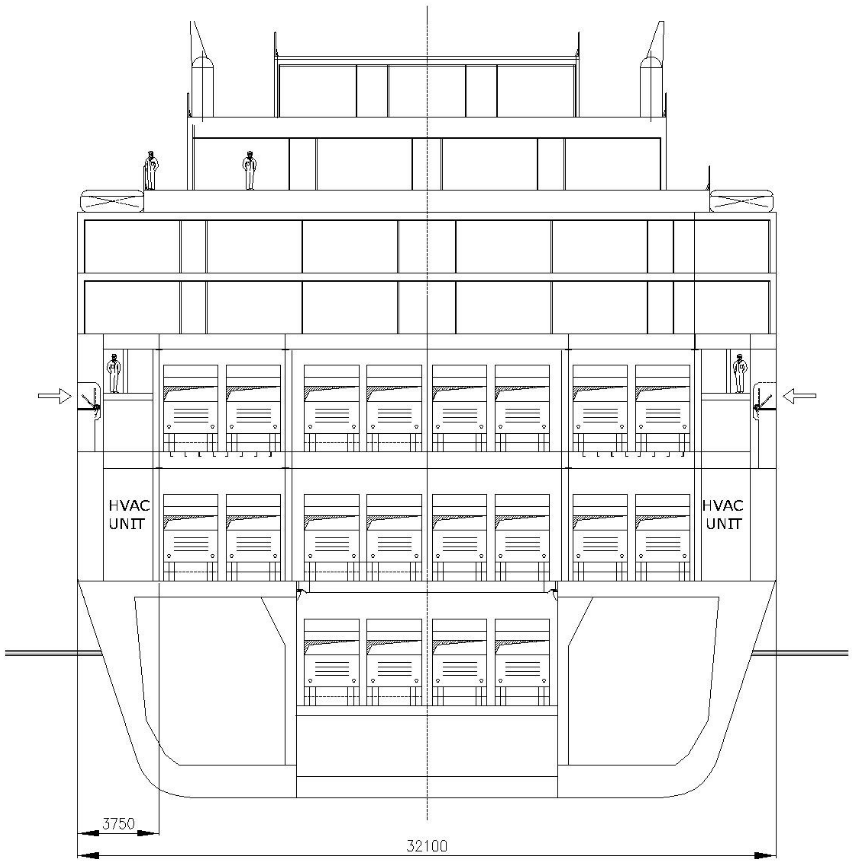


Figure 16 HVAC units in side casings gives low located air intakes.

4.4.2 Engine areas and cargo areas

For the purpose of facilitating abandoning of the ship, necessary adoption of the arrangements, according to the recommendations in the WP 7 Report, can be done within the existing principle layout of the cargo decks and observing the redundancy requirements for the machinery functions that are dealt with later in this report.
The major access/escape way from the engine rooms and cargo holds is via an A-60 trunk with inclined stairs that goes directly to the safe areas/assembly stations. In addition to that are the normal emergency escapes that are connected, via air locks, to the passenger escape ways.
In addition to this access way, the cargo holds and engine areas have emergency escapes according to the rules.

4.5 Abandoning of the ship

Above a certain level of damage (see WP5 and WP7 Reports), the ship is most likely impossible to keep afloat or habitable. Consequently the ship has to be abandoned. An imperative requirement to do this in an orderly fashion is that the ship is in a reasonably upright condition at any time during the sinking and abandoning operation.

In case of fire, redundancy for electrical supply and partly manoeuvring capability is required by DESSO.
The former to keep the systems needed for the prime movers (main engine) running, assist to operate the abandon ship equipment and keeping the evacuation areas free from smoke and toxic gases. The latter is to assist, by suitable manoeuvring, to keep the evacuation areas free from smoke and engulfing flames.

4.5.1 Arrangements for abandoning of the DESSO ROPAX ship

Regarding the choice of abandon ship equipment, several proposals have been investigated. (see WP8 Report).
The most radical one is to let part or parts of the superstructure become a "safe haven" that can be disconnected from the ship and float away in the case the ship sinks. Various types of free falling types of lifeboats have also been contemplated as possible solutions. None of the above proposals are however presently on a sufficient stage of development or have the desired capacity. They will therefore be dealt with on principle basis only. (see WP8 Report).

For the purpose of the DESSO ROPAX ship, it is decided to base the system for abandoning of the ship on inflatable rafts - possible to launch loaded - with a capacity of 100 persons each and fast rescue boats only. No conventional lifeboats will be used.
Presently a raft, possible to launch loaded has a maximum capacity of 48 persons. The major suppliers see no difficulties to enlarge the concept to the desired capacity.

The rafts will be located on the gangways outside the public areas on deck 6.
The areas in the gangway are sufficient to arrange for 100% raft redundancy - should this be deemed necessary.

Should so be desired, the raft arrangement can be replaced by conventional lifeboats without further alterations of the accommodation.

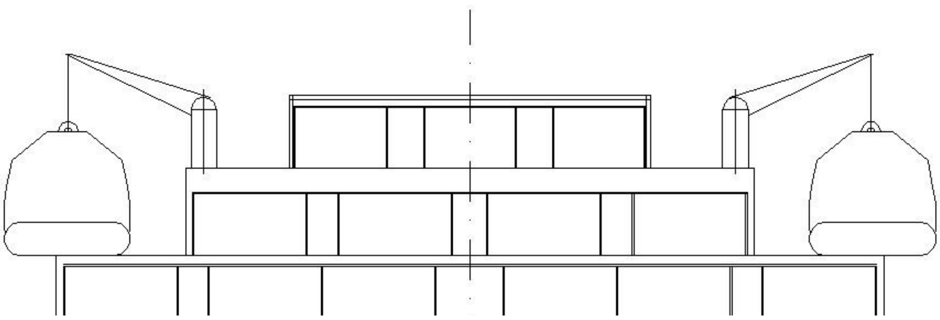


Figure 17 The life rafts will be located on the gangways outside the public areas on deck 6

The public areas are designed to serve as assembly stations (safe areas) and direct access to the rafts is arranged.

The rafts are possible to inflate in situ and can either be launched:

- by crane, loaded
- by helicopter, loaded
- by "float away" loaded
- conventionally with inflation in the water and embarkation by slide

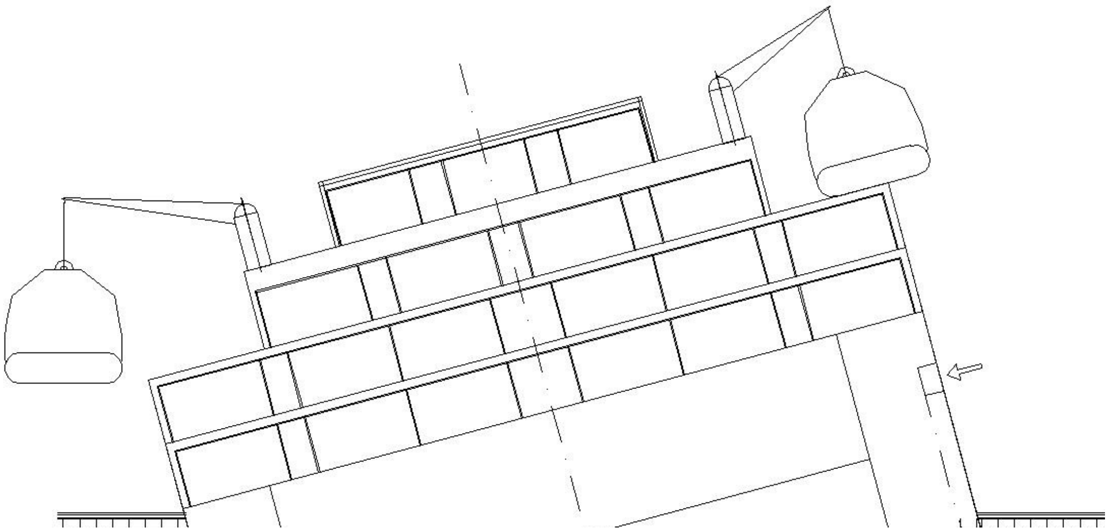


Figure 18 The rafts can be launched by crane

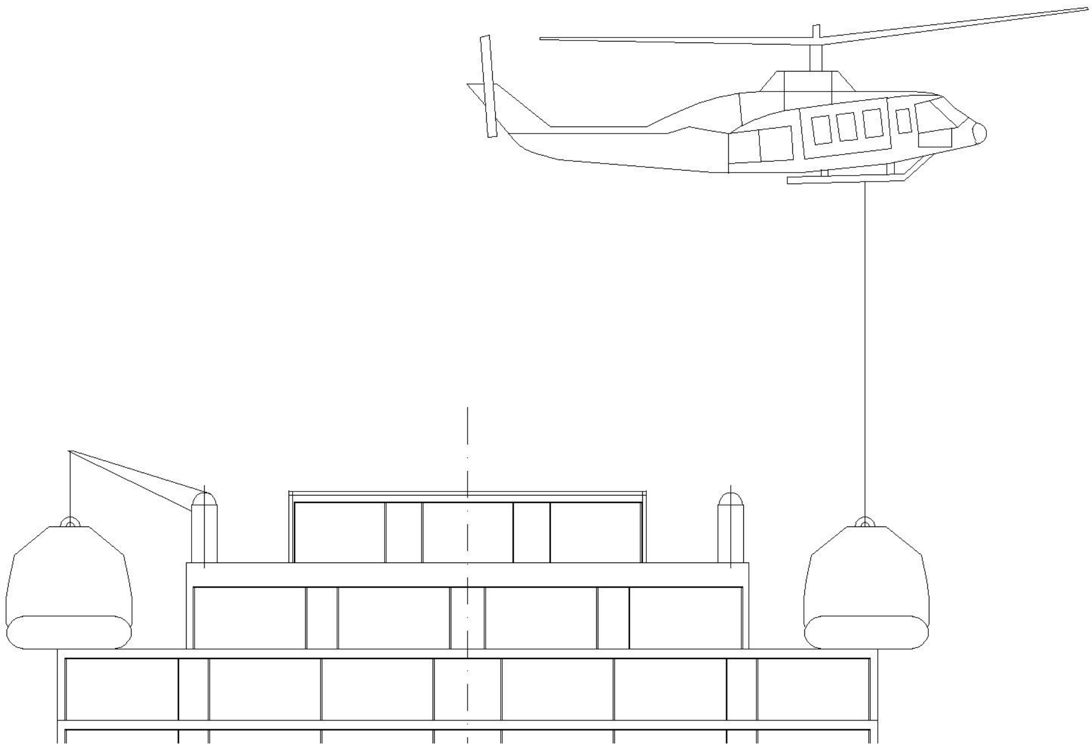


Figure 19 Lifted away by helicopter.

The Russian MI 26 is reported to have a take off weight of 56 tons, a light weight of 28 tons which leaves a dead weight of 28 tons including fuel. The rafts are estimated to have a weight of approx. 14 tons with 120 persons onboard.

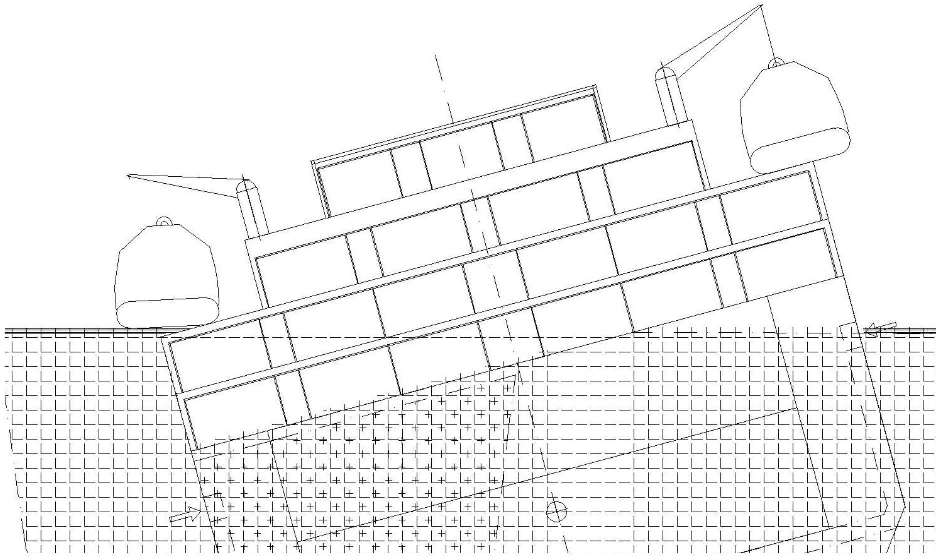


Figure 20 Float off

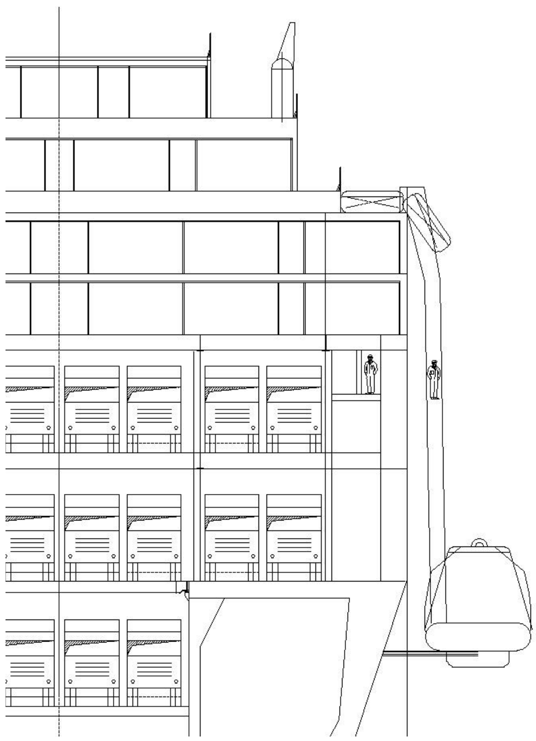


Figure 21 Life raft inflated in water and embarked

Note:
In the upcoming probabilistic rules, the required index is increasing with decreasing number of life boats in relation to the passenger number. This means that a life boat capacity for the full number of passengers and crew gives a lesser required index than rafts alone. (see the WP 5 Report)

Fast Rescue Boats

The fast rescue boats will be located in the side casings, in a recess, on the level between deck 2 and deck 3.
This location ensures a short pendulum arm.

5 Significant Level

5.1 General

The further occurred incidents are allowed to develop uninterrupted, forming chains of evens leading to a significant level, the more difficult it is to prevent the chains to develop a final disaster.
Consequently**, safety in situations that have reached a significant level must – to a great extent - be conceptual and forgiving.**
This means that the design of the DESSO ROPAX ship must contain such qualities in it's basic design that the ship is capable – up to a defined level - to forgive and absorb the human mistakes or whatever that has taken the ship into the significant situation.
On the other hand **- prompt and qualified actions with access to relevant means - can always, and at any stage, improve a given situation and even reverse a potential disastrous chain of events to a less harmful level.**

5.2 The DESSO damages on the watertight integrity.

For the DESSO ROPAX ship, the damage cases which are identified as significant and capital are:

1. A SOLAS damage extended to three compartments.
2. MCA extended to three compartments.
3. Rip-up over a length of 65% Lpp up to but not penetrating the deck 1 level.

These damage cases are previously detailed described in this report and also in WP 5.

The above DESSO damage cases contains elements of uncontrolled free surfaces, loss of residual stability, loss of spare buoyancy, significant fire and shift of centre of gravity and may be the top of a wide range of chains of event of various origins.
The more typical of these origins are headlined on the levels below the "significant level" in the initially described "Accident Assessment Flow Chart".

5.3 The DESSO survival standards

The DESSO ROPAX ship has been given an inherent capability to survive these damages upright and afloat and with maintained redundancy for propulsion and electrical power.
The DESSO ROPAX ship shall also have an inherent standard so fire shall not be a reason to abandon the ship.

5.4 Upright and afloat after a DESSO damage on the watertight integrity

The generic EuRoPax 3000 has, according to the rules, a capacity to survive a structural damage corresponding to MCA + 2 comp. according to SOLAS and this without any propulsive redundancy.

For the DESSO ROPAX, the decisive DESSO damage requirements for "upright and afloat" are the cases 2 and 3 as described earlier under chapter 3.2.1DESSO Damages.

5.5 Arrangements for "upright and afloat" for the DESSO ROPAX ship

To fulfil the requirements for "upright and afloat", widened and closed side casings corresponding to a B=32.12m are adopted (as for the "sinking upright" requirement). The subdivision for this casing is up to deck 4 the same as for that below deck 2 (the freeboard deck).
(see WP5 Report)

To facilitate the "propulsive redundancy" requirement, the aft engine rooms are separated with a longitudinal WT arrangement. The longitudinal separation of the aft engine rooms will, in case of a damage, create a certain undesired asymmetry of the flooding and consequently a heeling of the ship. This is considered acceptable as the redundancy adds so much to the "safety by action" capacity including the correction of the heel it causes.
However, certain restrictions in the geometry must be observed in order not to create an unacceptable large heeling moment. (see also "Redundancy" next chapter)

The longitudinal separation of the forward and aft engine rooms is done to facilitate access arrangements both for personal and for redundant cable routing.

In order to limit the risk for excessive heel in case of flooding both an aft engine room and a fully utilised heeling tank pair, the heeling tanks are split up in a forward pair and an aft pair on minimum two compartments distance from the aft engine rooms.

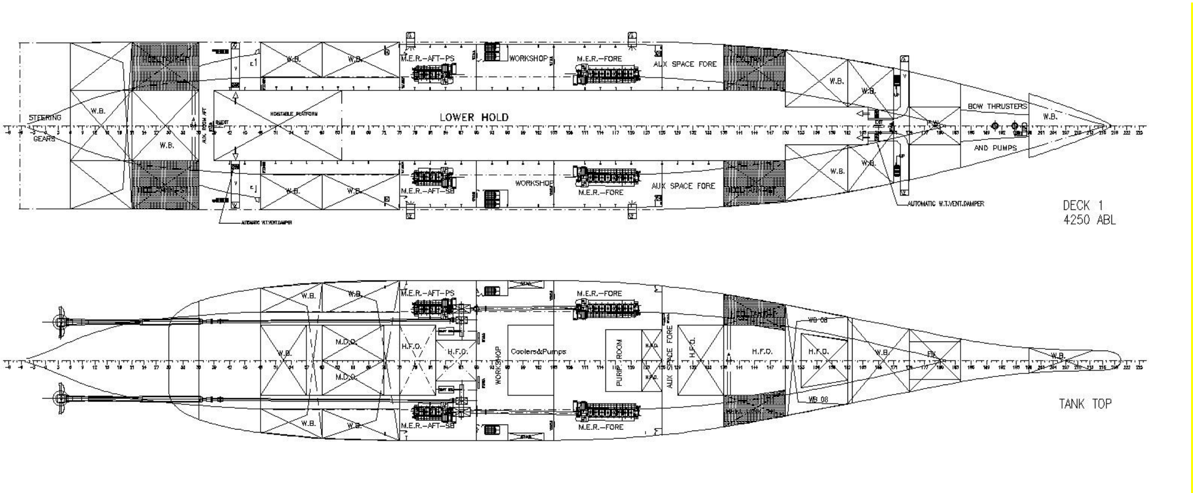


Figure 22 Aft pair of heeling tanks situated more than 2 compartments away from aft engine room in order to minimize asymmetry in case of a 3 compartment damage

5.6 Upright and afloat at an uncontrolled free water surface scenario

Uncontrolled free water on the freeboard deck or the decks above, may rapidly develop into scenarios with significant and capital loss of stability, with consequent risk of capsizing of the ship. (see descriptions of the Herald of Free Enterprise and the Estonia in the WP2 Report). The capsize of the Normandie, due to trapped water from a fire fighting operation, is classic.

Arrangements for control of free water on the DESSO ROPAX ship

For the DESSO ROPAX ship, the freeboard is 3.0m on the design draught and 2.8m on the scantling draught.
The chosen solution to free the freeboard deck and above from harmful water - may it be from structural damage or from fire fighting - is to arrange remote operable freeing valves along the ship's side; two forward and one aft per side. The area of each valve has an area of about 0.5m2 which is deemed sufficient to prevent clogging from debris. Above valves lead directly overboard and are intended for emergency use only.

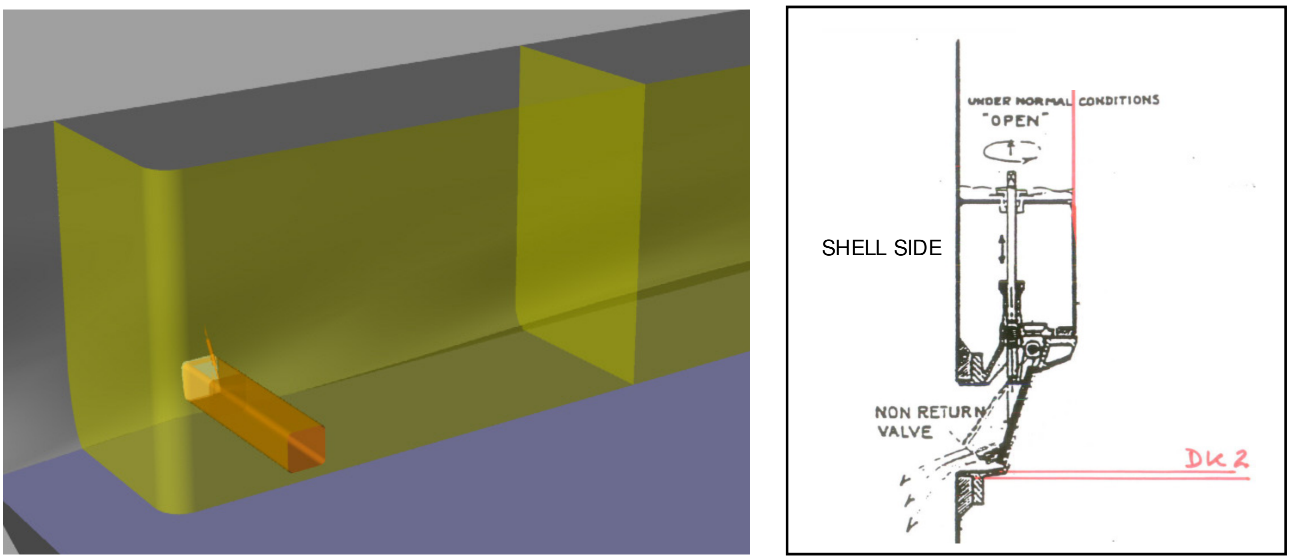


Figure 23 Freeing valves from main deck

Harmful amount of water on the freeboard (dk 2) level can also in emergency and under certain conditions be discharged overboard via the stern ramp/door. For this purpose – and also for the purpose of closing the deck in case of fire – the ramp/door is made remote and wirelessly operated.

The previously mentioned increased side casings give a powerful righting leaver curve that will lessen excessive heel.

5.7 Upright in case of shift of Centre of Gravity

Unexpected shift of CoG can occur due to events like shift of cargo in heavy weather or due to human error (see "Zenobia", "Vinca Gorthon" and "Jan Heweliuz" in the WP2 Report).

Arrangements for limiting a shift of cargo on the DESSO ROPAX ship.

Due to the "straight lane concept" in the cargo area of the DESSO ROPAX design, pillars in between the cargo lanes are not an obstacle for the cargo handling and can therefore be accepted. The pillars are used to form an efficient limitation of excessive heeling moment after a cargo shift and to limit the weight of the deck structure.

The DESSO ROPAX ship has, because of the side casings, a forgiving righting leaver curve limiting the initial heel and facilitating corrective ballast pumping.

Asymmetric loading will only be able to compensate for by the heeling tanks and not by the ordinary ballast tanks which are symmetrically located. The reason for this is that otherwise lack of careful loading might be balanced by excessive use of ballast, which in turn means a risk of excess heel if ripped open in an accident.
The two pairs of heeling tanks are located fore and aft respectively in order not to be damaged both or together with the aft engine room in case of a 3-compartment damage.

The straight lane concept for the cargo areas makes symmetrical loading easy and uncomplicated.

5.8 Fire fighting arrangement for the DESSO ROPAX

The basic philosophy is that all spaces of the ship shall be protected by the same type of system.
The choice of system for the DESSO ROPAX is high pressure water mist. For the detail description references are made to the WP 7 Report.

A fire fighting system with water of high pressure deluge type or high fog type do also limit the transfer of heat from a zone on fire compared with CO2. The systems are also perpetual as long as the pipes and pumps are operable.

In order to assure requested DESSO redundancy the fire pumps and systems are located symmetrically one in each of the aft engine rooms.

For the manual fire fighting equipment, the WP 7 gives detailed recommendations.
Regarding the spatial location of the fire main line and the fire stations in the cargo holds, this is arranged with the fire main as a ring line outside the B/5 and with branches up to the upper decks in the emergency escapes and regular access ways.
The fire stations are located at the respectively deck levels inside the access and escape ways and in the corridors (see also WP7 report).

5.9 Evacuation from accommodation fire zones in case of a "significant fire"

An overriding DESSO requirement is that "fire shall not be a reason to abandon the ship". The detail requirements for fulfilling this are formulated in the WP7 Report.

The arrangement of the passenger areas and crew quarters are arranged for simple orientation and easy and safe access to the evacuation zones (safe areas), with stairways, at the end of each corridor.

Each group of passenger cabins contains three parallel and separate corridors. The separation of the corridors facilitates the limitation of cabins directly affected by smoke and toxic gases in case of fire.
The stairways in the evacuation zones lead directly to the internal safe areas/assembly stations at the deck above the accommodation areas.

The ventilation arrangement is capable of **active smoke control** which means that the smoke is extracted from the escape routes in a possible fire area while the surrounding areas and stairways are kept under overpressure to prevent smoke from spreading into these areas. This arrangement improves safe evacuation and facilitates manual fire fighting.

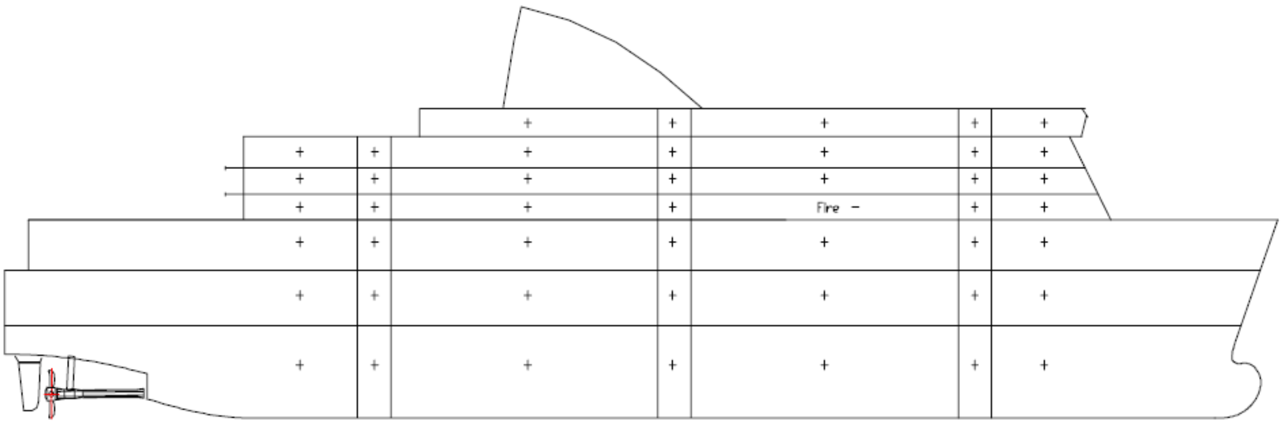


Figure 24 Smoke gas evacuation

5.10 Fire limitation arrangements

The cargo hold on deck 2 and 3 are provided with two fire curtains each to limit the areas for a possible fire.
(see also the WP7 Report)

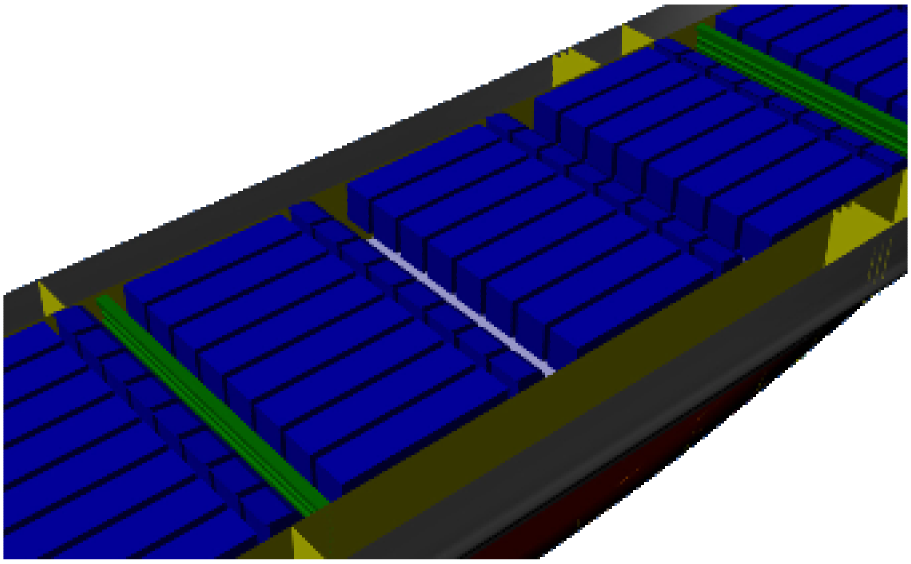


Figure 25 Fire curtains on deck 2 and 3

The WP 7 recommends extended fire insulation above the rules under the accommodation and between the cargo decks. The arrangement suggested in the DESSO ROPAX, offers no obstacles to this.
For the fire insulation between the cargo decks (A60) this can alternatively be achieved by water from the sprinkler system.

5.11 Dangerous cargo

The arrangement of the EuRoPax3000, with the open sides on deck 4, was not considered due to the fire fighting and dangerous cargo point of view. From the residual stability and residual buoyancy point of view the arrangement, with a non watertight deck 4 volume, provides no contributions and is deleted in the DESSO ROPAX. An open deck space is arranged on the DESSO ROPAX on deck 4 aft of the superstructure. The arrangements on this deck concerning fire fighting, armatures etc are in accordance with the IMDG rules for what is allowed to be carried on an open deck (see also WP8 report).

6 Secondary and Primary Consequences Levels

6.1 General

On these levels, incidents from the level below (Incident Triggers) have resulted in the development of potentially dangerous chain of events. One of the major targets for the **DESSO ROPAX** ship design is to create natural breakers in the potentially dangerous chain of events, thus preventing them from developing their potential into "significant" or "irreversible" levels.

The chain breakers can be of conceptual design nature like

- compartmentation with regards to water tightness or fire,
- spatial arrangements
- improved fire insulation
- etc

They can also be of "safety by action" nature where means are built into the conceptual design that allow the crew to detect and to act to stop or even reverse the development of the chain of undesired events.
Examples of this category of chain breakers are:

- Well designed early alarm systems
- Decision support systems
- Well designed and logically arranged manual fire fighting equipment
- etc

6.2 Collision, grounding or stranding

Collision, grounding or stranding may all result in structural damages. Structural damages may also be caused by other reasons like wave impact, loose cargo, technical malfunctions etc. Unless the above events result in damages beyond the **"irreversible" level** (a damage more extensive than a **DESSO** damage), the **DESSO ROPAX** ship is conceptually designed to forgive and stay afloat.
It is however imperative that the watertight integrity is maintained as designed and not put out of action by open access ways that should be kept closed or by non-compliance modifications etc. Failures in the above respects may cause undesired/unexpected cross flooding with fatal consequences as a result.
Due diligence in the design of access-ways, in the broad sense of the word, will contribute considerably in increased safety in this respect. Protection against consequences that may not seriously jeopardise the safety of the ship are also considered, simply for that reason that damages after an accident can be kept limited.

6.3 Arrangements of access ways

In the following sections, the arrangement principles of the access ways for normal and for emergence operation, as adopted on the **DESSO ROPAX** ship, are described. The descriptions are made out of the viewpoint **"avoiding accidental progressive flooding of water"** and **"avoiding transmission of fire, smoke and toxic gases"**. Where applicable, the access ways are located within the same vertical WT zone and the same fire zone respectively.

Cargo Access Arrangement (CAE)

The existing rules and regulations determining the design, functions and scantlings are considered relevant and covering in most of the **DESSO** damage cases.
The additional **DESSO** demand is for the ramp covers on the free board deck (dk 2) which on the EuoPax DESSO are designed to withstand a water pressure from below. The pressure head is taken from the rip-up damage case when the ship is assumed to float in an equilibrium with deck 2 as the new "tank top".

The ramp cover and the stern ramp/door can be remotely operated in order to enable closing of the cargo areas in case of fire. (see "Silver Ray" in the WP2 Report). It is noted that remote operation of CAE is prohibited in the upcoming rules MSC 80/3/4 regulation 13-1/4.

Access Arrangements for Passengers

In the EuRoPax DESSO, the access to the passenger and the crew accommodation is arranged amidships and athwartships SB and P on deck 6 which is the Public Area deck.
A possible – but not shown – alternative for a Mediterranean style –mooring situation, is to arrange for access from aft via the wide side casings up to deck six where a reception area is arranged.

The ordinary access ways between the passenger accommodation decks are arranged as double stairs in the centreline and double stairs and lifts athwartships SB and P.
The centre line stairs are located one in each of the fire zone cofferdams plus one out door aft.
The athwartship stair/lift arrangement is amidships in the embarkation area. This arrangement is extended downwards to deck 2 and deck 3 to provide access for drivers from these decks. This access is arranged in an A-60 isolated WT trunk with WT doors to deck 2 and 3 and with arrangement for overpressure in case of fire.
The trunked WT and A-60 emergency escapes goes vertically from the cargo areas via airlocks to the accommodation accesses and further to the assembly stations (=public areas) on deck 6.

Access Arrangements for crew

The normal entrance to the accommodation quarters for the crew on deck number 7 is via the same main entrance as for the passengers.

The access from the crew quarters to the navigation bridge is straight forward through the central corridor.
The access to the mess rooms on deck number 5, galley and stores on deck number 4, is via a dedicated crew stair and lift arrangement.

The emergency exits are the same as from the passenger accommodation.

The access to the engine rooms and cargo areas is arranged SP and P in the engine casing, where dedicated lift and stairs are arranged from the deck 7 (crew quarters) and down to the engine workshop areas. Exits are arranged at the deck number 2, number 3 and number 4 levels.
This access is arranged in an A-60 isolated WT trunk with WT doors to deck 2, 3, 4, 5 and 6 and with arrangement for overpressure in case of fire.

Emergency escapes from the cargo holds are arranged according to the same principles.

General, emergency
In all access ways, where WT doors are arranged, these are swinging inwards to avoid progressive flooding in case of submerging.

Access for provision and stores

The access openings for handling of the provision and stores are, on the **DESSO ROPAX** ship, arranged within the same fire zone as they areas (galley and serving counters etc.) that they serve.

The handling principle for the stores, provision, laundry, garbage etc. is that it is unitised in 20' ISO units that are transported to deck 3 under the store-rooms on a trailer and then lifted, through a WT hatch in deck 4, into the store-room.

From the provision store and preparation area, the food goes via a lift to the galley and from there – also by lift – to the serving stations.
To the shops the goods is transported by lift and trolley.

Access for engine spare parts and for engine maintenance

General

Experiences show (see WP 2 and "Stena Nautica") that unauthorised open access ways between WT compartments may severely worsen the consequences of damages on the WT integrity.
The reason for the unauthorised open access ways may vary but a very common reason is "necessary for access for maintenance and transport of spares".
Thus it is of highest importance that strict routines for permissible access through WT bulkheads are laid down but equally important that the ship has a spatial lay-out that unauthorised opening of WT passages simply is not needed. Necessary maintenance must be able to perform efficiently without shortcuts in the safety routines.

As the DESSO ROPAX is capable to survive an MCA damage extended to three WT compartments, and in some cases even extended to four compartments, the following policy for the WT doors between the engine/workshop compartments is suggested:
" Either the forward door or the aft door of the workshop is allowed to be open for passage and for work at sea – but never both simultaneously".

Access for spare parts

The majority of the components that require access for heavy spare parts and their handling auxiliaries, are located in the four main engine compartments.

For damage survival reasons, the two forward engine compartments are cross connected.

For the same reasons, the engine rooms are in longship direction separated with a WT compartment which is cross connected.

The two aft engine compartments are, for redundancy reasons, separated SB and P.

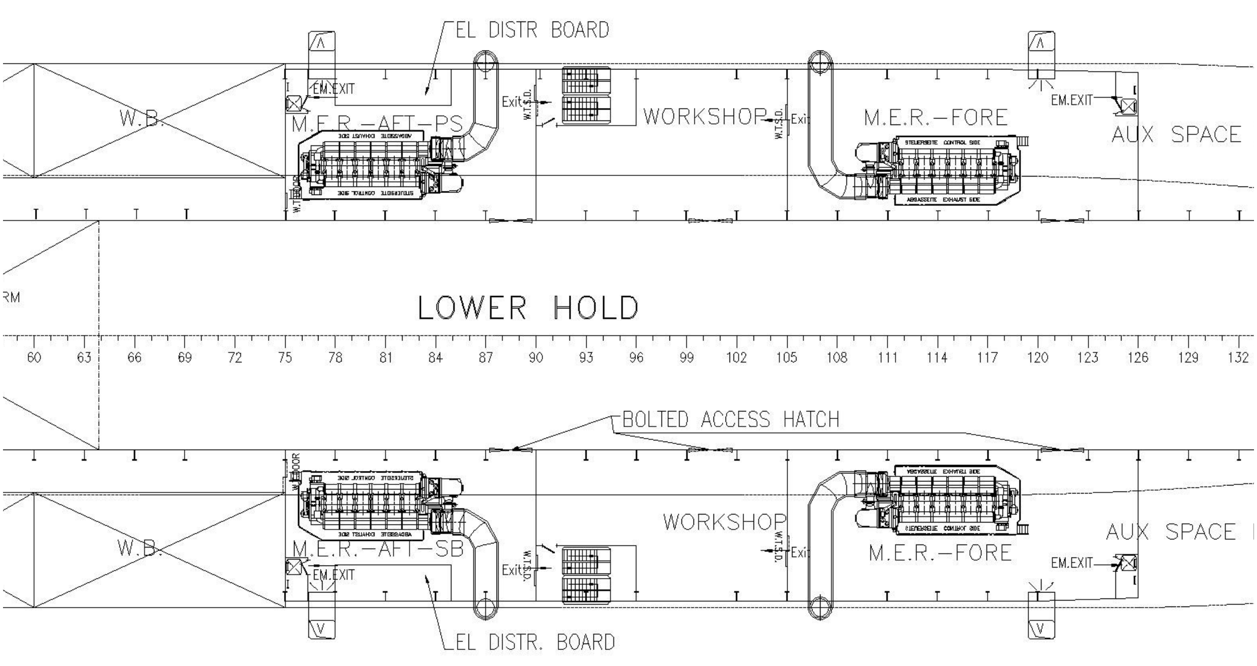


Figure 26 Access for spare parts

The WT compartment, in between the two engine room pairs, is allocated for workshops, spare part stores, engine office (which is not the same as engine control room – see "redundancy") and change room.

The access arrangement for access for personnel to the workshop etc area and to the engine rooms is shown on the General Arrangement.
The principle for the arrangement is that should a flooding occur in the engine room or workshop, the door to the other compartment will be more firmly closed by the water pressure even if all the cleats are not properly locked.

In the lift, which has a lifting capacity of 1 ton, minor spares can be transported from the deck 2 level.

For the access of heavier spare parts to/from the engine rooms/workshop, bolted doors are arranged in the bulkheads between the compartments.
For access from shore to workshop and to the engine rooms, bolted doors are arranged in the longitudinal bulkhead to deck 1.
The above openings are for shore operation only and need not and must not be opened at sea.

Other mayor components for outside the engine rooms (like steering gear, ventilation, boiler rooms etc, are arranged with access doors/hatches – WT or not, as case may be.

Access for bunkers and other fluids, (pilot access)

The access stations for bunker and fluids (like fresh water, lub-oil, hydraulic oil, urea, sludge, black/grey water etc.) are located SB and P between frames # 95-99.

The stations are located in WT recesses in the double hull, each with a WT door in the ship's side and with WT access to the crew access-way (stairs and lift) between the engine room and superstructure.

This makes the bunker door also suitable as pilot access.

The piping from the station goes vertically down to the engine workshop area from where it is branched out to the various tanks and treatment stations.

The bunker doors can be remotely closed in case of fire.

Outlet for exhaust gases

The wide side casings are used for arranging of boilers, exhaust boilers and silencers below the passenger accommodation levels. The arrangement means better possibilities for the passenger area access ways and layout.

Access for Air

Passenger and crew accommodations.
Active and passive smoke control is arranged for.
Passive smoke control is arranged according to present rules which means that in case of fire all ventilation shall be stopped and all fire dampers shall be closed.
The philosophy behind an arrangement for **active smoke** control is that stairways, escape routes or other areas shall – in case of fire - be kept under overpressure by the ship's ordinary HVAC system.
From fire zone shall the smoke and toxic gases evacuated by a separate and normally closed down system.

The HVAC system is arranged below the passenger accommodation in the wide side casings with low located inlets. The arrangement is symmetrically SB and P and air can - in case of fire - be taken low down and from the windward side.

The smoke extraction system is equally located in the wide side casings but with high located outlets. The arrangement is symmetrically SB and P and smoke can - in case of fire - be discharged on the leeward side.

The air intakes/outlets are provided with WT fan dampers of gas puff absorbing type. (This means that they are capable to retrieve their function after a having blown open by a gas puff).

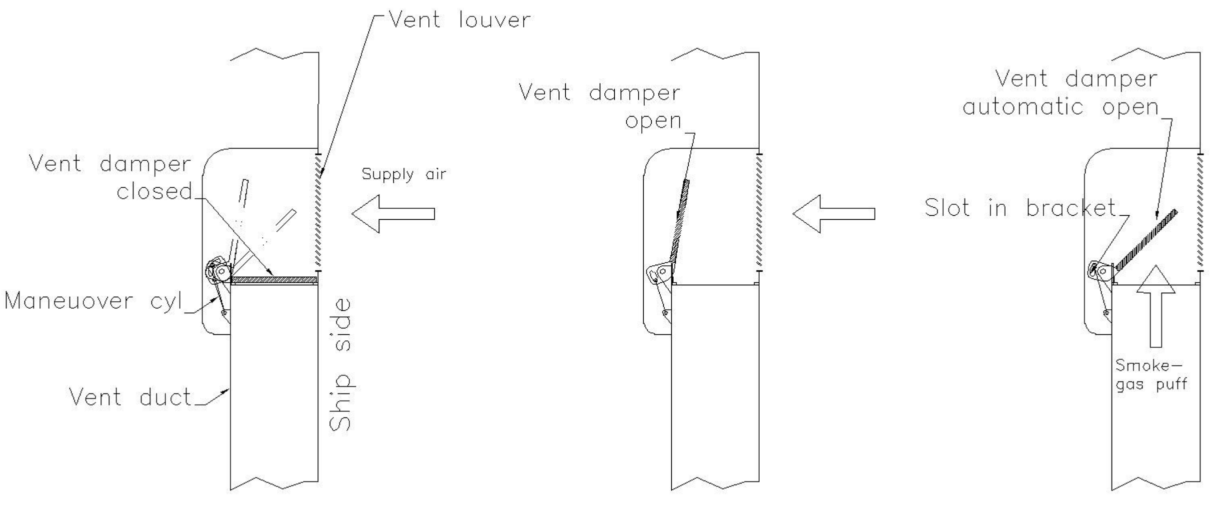


Figure 27 Gas puff proof ventilation dampers

Ro/Ro Cargo decks

The roro cargo decks are provided with a ventilation system for use in port, based on longitudinal exhaust forward, and with natural supply via the stern ramp/door and ramp covers.
At sea the ventilation is based on longitudinal exhaust/supply. In addition derivent fans will secure avoiding of badly ventilated pockets due to various cargo configuration.
Each deck is provided with its own separate ventilation ducts.
The fan dampers are of the gas puff absorbing type. The stern ramp/door and the ramp covers are possible to close remotely.

The deck 1 ventilation trunks have WT automatic gates at the passage of the longitudinal B/5 bulkhead in the lower hold.

Engine rooms

The air supply to the engine rooms are arranged in the wide side casings and with natural exhaust via the funnel.
Both the supply fans and the natural exhaust ways are provided with dampers of the same type and function as for the cargo holds.

6.4 Redundancy

Purpose of improved redundancy

At the DESSO Seminar in mid 2004, it was concluded that a maintained redundancy for electrical power and for manoeuvrability, is of high importance for "safety by action" in case of damage on the WT integrity, in case of fire and in case of abandoning the ship.

Manoeuvrability means possibilities to lessen the impact of waves, to avoid grounding in close to shore situations, to avoid collision in close to ship situations, to reach sheltered waters etc.
In case of fire, manoeuvrability means possibilities to lessen the impact of smoke and flames and in case of abandon ship it means possibilities to a more controlled operation.
Redundancy in case of fire does also mean possibility to have hydraulic power to remotely close CAE and fire dampers.

Present Regulations for Redundancy (2005)

According to the present rules and regulations (SOLAS Reg. 42), an emergency generator supplying energy to a number of well defined emergency functions of category illumination, communication, navigation, emergency bilge, emergency fire fighting, shall be installed.
No emergency system support to propulsive power or emergency propulsion is required.

The Reg. 42 says that "the location of the emergency source of electrical power …. shall be such as to ensure to the satisfaction of the Administration that a fire or other casualty in the spaces containing the main source of electrical power ….. will not interfere with the supply, control and distribution of emergency electrical power.

It was considered questionable weather this is possible after a "significant" SOLAS damage.
An MCA damage will be capable – according to it's definition – to knock out the entire emergency source wherever located and/or isolate the rest of the ship from the main el-suppliers weather workable or not.

Arrangements for propulsive redundancy for the DESSO ROPAX ship

For the **DESSO ROPAX**, a propulsive redundancy shall remain also after a 3-compartment SOLAS + MCA damage and for a rip-up damage penetrating the double bottom but transversally limited. (Damage cases 2 and 3)

To achieve this, following spatial alternatives have been investigated:

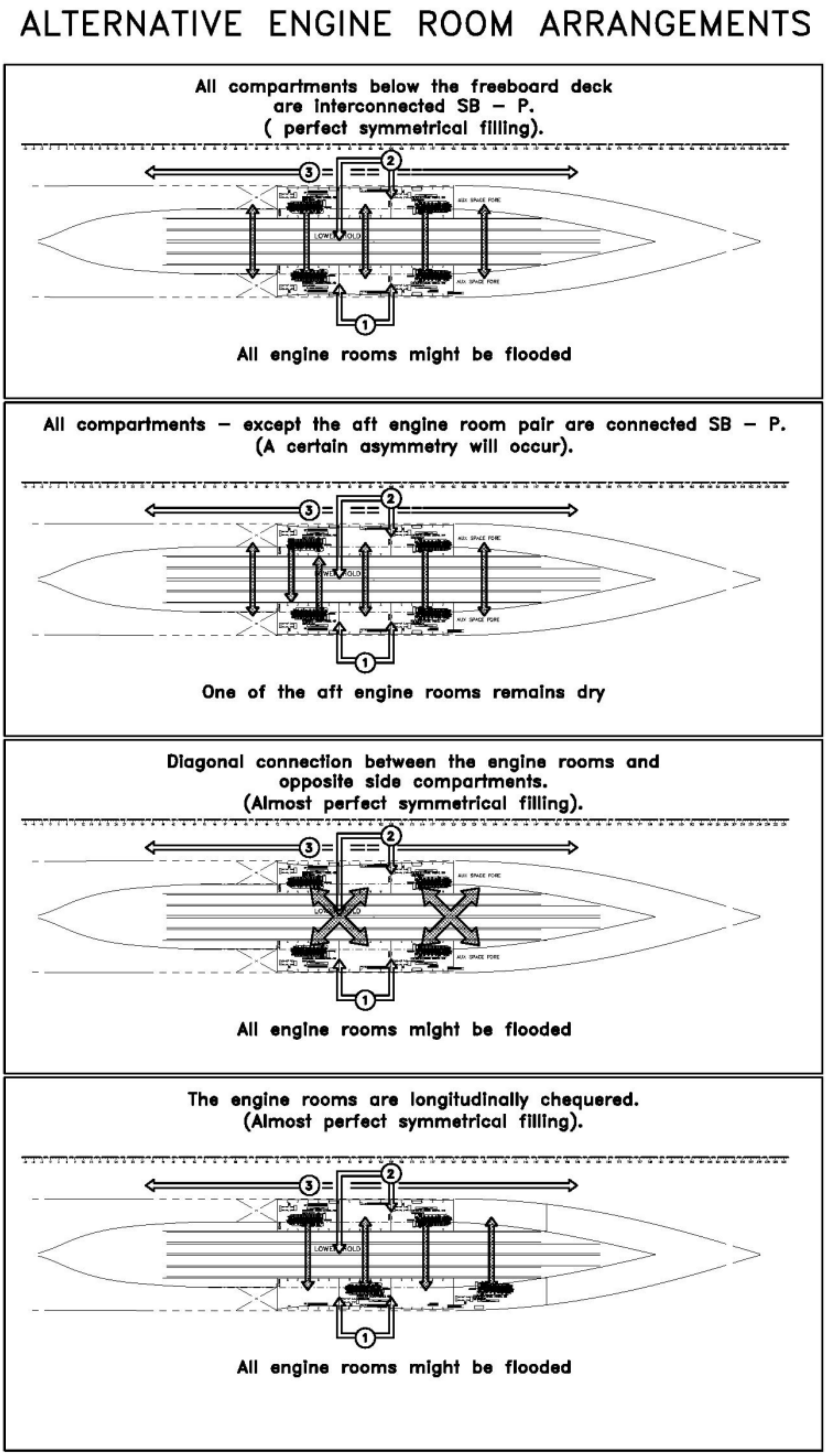


Figure 28 Possible engine room arrangements and redundancy

The table shows that in order to have one engine room dry and accessible for operation after the **DESSO** damages, alternative 2 is the one to be chosen.

Seen from a pure **DESSO** Redundancy requirement point of view, a longitudinal separation of the engine rooms is not required as the **DESSO** redundancy relay entirely on "opposite side aft" engine room.
However, any damage of regular SOLAS 2-compartment type would without this separation flood three engine rooms instead of two.

Engine room auxiliaries

For a proper function of the propulsive prime movers, gears and shafting, the auxiliary systems like fuel, lubrication, cooling water etc. and a free flow of exhaust gases must be arranged for.
The operation of the equipment must be possible "on the engines" as well as on a central computer system (CCS) with a multitude of possible operation stations.
Two capital operations centres are arranged; the bridge and the alternative operations centre aft on the deck 7.

A central engine control room is considered superfluous and even not desirable.

The main engine auxiliaries - like pumps for fuel, lub oil, water etc - do requires electrical power.
For this purpose the main engine rooms will have their own source of independent electrical supply.

The arrangement of the generators is as follows:
- In the aft engine rooms is located the gear box with a shaft generator each with their own distribution board.
- The two forward engine rooms will have a common set of generator rooms located in between the two engine rooms. There will be three generators each in a comfort and fire insulated compartment. The distribution board will be in common for the three generators.

A consequence of this arrangement is that a substantial redundancy also for the supply of electrical power is created which might make the traditional emergency generator superfluous.

Electrical distribution system

The layout for the power cables and signal cables is done considering a 50% redundancy as far as practical, after a DESSO damage.
The basic principle for the arrangement is that the cabellage is done SB and P in fire insulated and watertight trunks in the engine casings, leading straight upwards to the deck 7 level where it is branched forward an aft to the two operation centres.
From these main lines, power and signals are branched off as they pass the consumer areas/areas with equipment to be controlled.

Note 1.
The arrangement of the aft engine room is – due to the requirement of limited asymmetric flooding – very cramped if the "margin line" shall not be submerged.
The margin line requirement, which comes from SOLAS, has with the DESSO side casing arrangement no practical meaning. The Swedish Maritime Administration allows a transversally stepped freeboard deck as defined in the present rules to cope with this problem.

Note 2.
Should a twin engine arrangement be preferred – instead of the present four engine arrangement – a certain degree of redundancy can be achieved with the following arrangement:
- The forward main engine room is kept as is in principle but the engine size and power and consequently the length is adopted as required.
In case of damage both engines are flooded.
- The aft engine room including separating tanks are kept as is but without any engines. Only the gearbox with shaft generator (now also arranged for propulsion drive), distribution board etc are kept. The longitudinal extension is made shorter accordingly.
- The generators are arranged as previously but in WT cages and with separate distribution boards in WT rooms.

In case of flooded forward engine rooms it is possible to have one of the generators driving a shaft generator/motor for propulsive redundancy.

7 Incident triggers

7.1 General

In the analysis of disasters in the WP 2, as well as in the in the other WP reports, the presence of the human factor as initiator of disastrous chains of events and incidents is clearly visible.
Human shortcomings are found to be the origin of the events as well as the reason for inability to identify or to execute suitable remedies to break the disastrous chain of events.

Very seldom, completely unexpected events (a freak wave, meteorite hit etc.) are to be blamed.

To cure the "human factor" problem it is often asked for
- more rules
- more training

in that order.

7.2 Non compliance

A study of the events, referred to in the WP 2 and other WPs, suggests that not a small number of the disasters is emanating from lack of compliance with, or cheating of existing rules.

Examples of disasters, where lack of compliance with existing rules, has played a decisive role are:
- Estonia
- Sundancer
- Scandinavian Star

Examples of rule cheaters are:
- Zenobia
- Rocknes

Example of cargo non compliance:
- Silver Ray

In the above examples, the shortcomings are suggested not to be on the seafarers side but ashore.

The examples from the first group suggest that lack of appreciation, from those issuing the relevant certificates or permissions to sail, is at hand.

The examples from the second group suggest that lack of appreciation, from those who designed the actual ships, and from those who did the approval, is at hand.

The example from the third group suggests that those who allowed the actual car (with fire works onboard) to be loaded on the Silver Ray did not understand the importance of checking what is allowed to carry and why.

Lack of appreciation and training is suggested to explain the frequent inability to cope with the problem to break a disastrous chain of event that is under progress.
This goes both for those who are designing the tools and those who are using them.

7.3 Interaction between the actors on the sea transport scene

With the assistance of Class Rules and International and National Regulations and modern design tools, there are excellent possibilities for the industry to create ships that are both efficient and safe.

However, fulfilment of the rules and regulations is no guarantee that the ship is suitable for its purpose or "safe" according to the state of the art.

Also,
Contradiction between enhanced safety and existing rules as well as upcoming rules exists.

The rules for survival capability at decisive damage does sometimes draw the attention from solutions that may prevent a minor damage to develop into a decisive one.

The ISM Code sets forth important rules for the seafaring and gives the safety at sea a considerable lift.
But - the Code is not entirely free from principle objections regarding the placing of the ultimate burden for safety onboard on the master of the ship.

- A ship is a product composed with little or no influence from those who carries this ultimate responsibility for its safe operation.
- A master is obliged to see to that his ship complies with the status assumed in the certificates. But that the original certificate certify technicalities, that are in compliance with relevant and required rules, has appeared being not allowed to be trusted. (Sundancer, Estonia).

7.4 Training for "Safety by Action", Simulator Training

Severe accidents are fortunately rare.
Experiences gained from one ship or types of ship in emergency situations are neither frequent nor directly applicable to other ships or to other types of ships without a rather extensive analysis in between. Training for nautical situations and manoeuvring is frequently done at our nautical colleges in very advanced simulators.

Analysing of accidents or incidents is by far less done – if at all - at our nautical colleges or at our technical universities and this is also the case when it comes to training for possible actions to break a disastrous chain of events.

Worthwhile to notice is that major ferry and liner operators are using, for the in house training, suitable and advanced programs to an increasing extent.
How to handle damage on the WT integrity is an important part of that.

Within the **DESSO** Project, analysis of a few significant disasters is done. (see WP2 Report)
The findings suggest that all of them have started with something rather trivial. This might be within the field of design, maintenance, status control or operation.
An initial trivial event has been allowed to develop in an undisturbed chain of events into the final disaster.

The WP2 findings also point at the incapability of the operators to handle the situations as they develop

7.4.1 DESSO Proposal

A continuous collection and analysis of event chains that have ended up in disasters or potentially disasters is organised at the Maritime universities.

The purpose of the **DESSO Proposal** is to create a living Data Base within the field of Adopted Maritime Safety (human behaviour, technical solutions, decision support etc.) with the aim to create a better understanding of the anatomy of disasters.
The Data Base shall be made up in such a way that it can be used for :
- Education and training of ships officers, operative personnel, naval architects and administrators for a better understanding in the anatomy of disasters.
- Development of simulator technologies for training of sea going and other relevant personnel.
- Continuous and ongoing identification of areas for research and development.

7.4.2 Decision support

Any successful safety by action activity must be based on an appreciation of the situation – the more complete the better.
The WP8 has described a system based on collection of information regarding the situation in various parts of the ship after a damage.
It is however important that any onboard decision support system is workable when needed – namely after a damage of that extent that DESSO has defined.

8 Upcoming rules

8.1 Floatability

The upcoming rules, as described in the MSC 80/3/4 Chapter II-1, are principally of probabilistic nature with complementary deterministic detail regulations.
A study, where the Generic **EuRoPax 3000** and the **DESSO ROPAX** have been evaluated, considering the new rules, has been done within the WP 4 and WP5. These studies are by definition superficial as several parts of the new rules are still under discussion regarding interpretation and application.

The studies suggest that the **EuRoPax 3000,** with the original lifeboat/liferaft arrangement, will arrive at an **attained index (A)** that may not fully satisfy the **required index (R).**
With a 100% lifeboat capacity, the required index will be lower and the attained index will, for this reason, be sufficient to reach the required index.
The **EuRoPax 3000** will – as shown in the WP5 report – capsize at most of the 3-compartment damages.

For the **DESSO ROPAX**, the required index demand will, due to the "liferaft alone" arrangement, be somewhat higher than for the **EuRoPax 3000**.
The survivability enhancements, applied to the **DESSO ROPAX,** will most likely marginally improve the attained index compared to the **EuRoPax 3000**.
The **DESSO ROPAX** will – as shown in the WP5 report – survive all 3-compartment and MCA damages and she will not capsize after damages more extensive than that.

The new rules contain deterministic requirements that, in some cases, might be contradictory to the recommendations of WP4 and WP7.

8.2 Fire

The **DESSO ROPAX** Ship is designed according to the upcoming rules as described in the WP7 and which are considered in line with the principles suggested for **DESSO**.

9 Cost / Benefit Aspects

9.1 Costs

The Generic **EuRoPax 3000**, fulfils the SOLAS as well as the MCA rules for damaged stability and also, with some modifications, the upcoming SOLAS probabilistic damaged stability rules.
The **EuRoPax 3000** and the **DESSO ROPAX** has identical cargo capacity and cargo area layout and the same passenger capacity although with a slightly different layout.

The costs for adopting the "above the rules" safety features of the **DESSO ROPAX** ship, compared with those of the Generic **EuRoPax 3000** can be described under four major headlines:
- Enhanced floatability and "sinking upright".
- Enhanced redundancy.
- Enhanced fire safety and fire fighting
- Life saving appliances

Enhanced floatability and "sinking upright"

These features are achieved by adopting wide and fully enclosed side casings.
The additional steel needed for this is estimated to about 600 tons.
The light weight of the **EuRoPax 3000** is estimated to about 10.200 tons out of which construction steel is about 7.500 tons.
In this context, the added 600 tons is about 8% increase of the construction steel and probably less than 2% of the ship's total cost.

Enhanced redundancy

A four engine arrangement is assumed already in the Generic ship and the added cost to separate the engine compartments longitudinally is considered marginal.
Considerable costs is however caused by the required doubling of the needed auxiliary systems like fuel, lub oil, cooling water etc as well as doublings of the systems for operation and electrical power including structural protection thereof.
Without doing detail studies of different ambition levels any estimate will be very approximate.
Low ambitions in this respect give low costs - high ambitions give high costs.
For the highest ambition levels a cost increase of 15 to 20% of the engine and system costs might be expected.
As the total engine and system costs for a ship of this type might be some 25% of the total costs for the ship, an increase of 4 to 5% of the ship's total cost might be expected to achieve a full **DESSO** Redundancy.

Enhanced fire safety and fire fighting

For the **DESSO ROPAX** ship this means a totally water based fire fighting system with increased capacity, increased fire insulation/separation, increased number of sensors and additional ventilation arrangement (smoke evacuation).
Redundancy for power and water supply in a part of the enhanced fire safety concept.
Cost wise these added qualities may amount to less than 1% of the ships costs considering savings for the CO2 system and belonging arrangements.

Life saving appliances.

The **DESSO** concept calls for a multifunctional life saving arrangement based on inflatable rafts.
The arrangement is chosen and developed according to the advises from the expert panel (WP 3) who clearly favoured rafts compared with conventional lifeboats.
The upcoming rules goes the opposite way and penalise substantially any system not based on a 100% lifeboat capacity application.
Cost wise the **DESSO** arrangement is equal or less expensive than a full lifeboat arrangement.

9.2 Benefits

General

Safety features above the valid rules or those in the near future upcoming ones, gives in general little - if any - benefit or reward in the eyes of the authorities and the insurance companies.

Possible benefits may be gained within areas like "Image for the Company", for making compulsory safety rules more rational to perform or to limit identified high risks in the actual commercial service.

Redundancy

Enhanced propulsive redundancy may lead to a possible saving in case of a future avoidance of a salvage bill or avoidance of a total loss.
In the first case a cost/benefit analysis will most likely be discouraging.
In the last case the insurance companies may give a marginal premium reduction but most likely not.

If combined with the feature "different power needed for summer/winter schedules" an enhanced redundancy can be achieved at marginal costs.

Fire safety

Enhanced fire fighting (and cooling for better insulation) created by means of an all purpose high pressure water system may appear beneficial due to simplicity in maintenance compared with various combined systems.

Damage survival

To widen and close the side casings offers possibilities for attractive arrangements.
Examples of such possibilities are:
- More flexibility to arrange the passenger accommodations including assembly stations and abandon ship arrangement.
- Wide side casings can be utilised for allocation of
. Boilers and silencers which otherwise would either been high located or disturbed the accommodation layout.
. Mob and FRB boats get positions for a better and safer launching arrangements
. Lower arrangement of ventilation and air treatment units for facilitating of smoke evacuation systems.
. Easy arrangements for access and emergency routes.

10 Conclusions

The DESSO Project demonstrates that it is possible to design a ship that has a very high survival capacity after a damage and that if she sinks, does it without capsizing.

The Project demonstrates that this is possible to achieve without limiting any carrying capacity or commercial quality.

The additional costs for satisfying the DESSO requirements are possible to keep modest.

The upcoming rules, as described in the MSC 80/3/4 Chapter II-1, are principally of probabilistic nature with complementary deterministic detail regulations.
The deterministic requirements might, in some cases, be contradictory to the recommendations of WP4 and WP7.
Examples: Penalties for life rafts only. Remote closing of cargo access equipment not allowed.

The **EuRoPax 3000** and the **DESSO ROPAX,** may both satisfy the required probabilistic index but will, as demonstrated, behave completely differently in case of a damage.
This must be considered a risk by itself.

APPENDIX C

DESSO WP5 Report No. 4:

Staying upright and afloat

Static stability assessment

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SUMMARY

Within the DESSO-project a State of the Art Generic RoPax design constitutes the basis for all analysis work. The design "As-Provided" is compliant to applicable intact and damaged stability rules and regulations. The aim of the project is to create a conceptual design of a ropax ship that is safer than "state of the art"

The task of work package 5 is to conduct intact and damage stability analysis and to propose and implement proposals for enhanced safety that will have effect on the stability analysis.

This report describes the major part of the work of WP 5 in the DESSO project. The most important design alterations directly improving safety made and evaluated by WP 5 is:

1. wide transversally divided side casings on the freeboard deck and the deck above for improved damage stability

2. subdivision arrangement of the main engine rooms for improved propulsion redundancy

The wide side casings will dramatically improve the stability properties and increase safety in severe damage scenarios. The subdivision arrangement of the main engine rooms will significantly improve the propulsion redundancy of the concept ship.

INTRODUCTION

Staying upright and afloat is the most fundamental property of most floating structures. If this demand is not fulfilled all other good properties are in vain. The WP 5 task is to meet this demand for the DESSO ship. The ability to stay upright is of paramount importance if the ship is designed to function as "its own lifeboat". Therefore the DESSO ship should stay upright in damage conditions worse than those stipulated in the regulations and even be able to sink without excessive heel or capsize.

This is done by variation of the water tight compartments in the ship and analyzing the stability properties. This is also an iterative process where findings have to be evaluated together with the other WP's in the "design spiral"

In order to, in a systematic way, search for and determine the significance of various design alternatives, WP4 and WP5 have together established a "Chain of Events Flow Chart", Figure 1

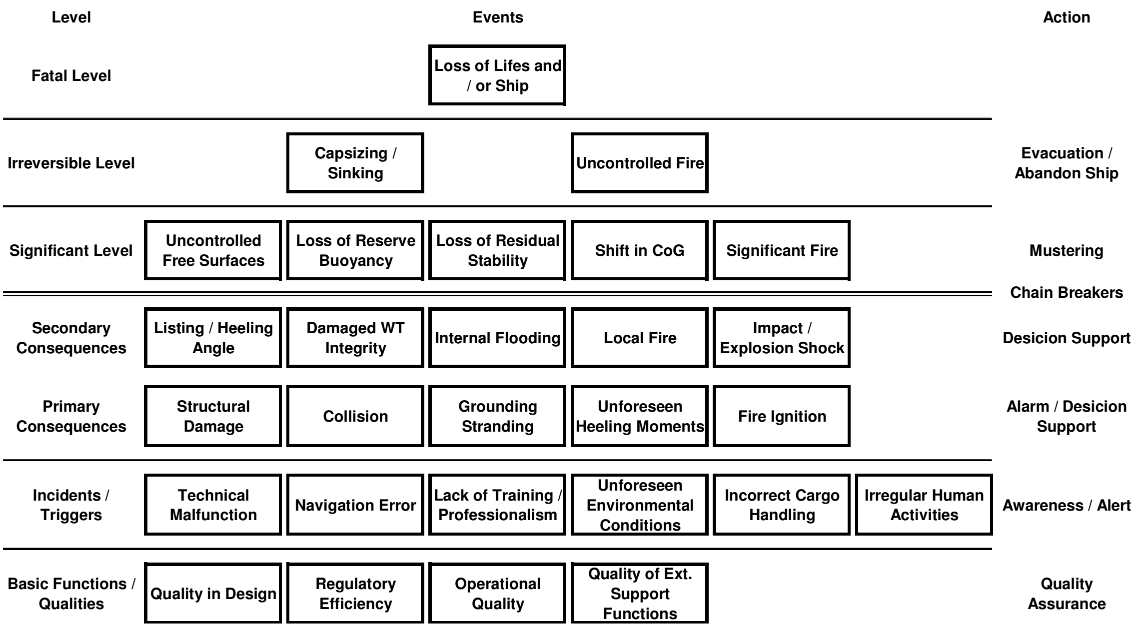

Figure 1 WP4 and WP5 Chain of Events Flow Chart

From a WP5 aspect the importance of the following ship properties is quite obvious.

1. Means to preserve Reserve Buoyancy,
2. Means to preserve Residual Stability,
3. Means to control / limit Free Surfaces,
4. Means to avoid Shifting of CoG.

In order not to be influenced nor restricted by the constraints of applicable rules and regulations in the concept generation and development work, a deterministic approach to the static stability assessment work is applied. Meaning that watertight compartments and groups of 2, 3, 4, …, adjacent compartments will be penetrated in a systematic order and evaluated with regard to floatability / stability after damage.

It should be noted that the design of course must remain compliant to relevant rules and regulations, making sure that the DESSO concept ship will not end up as a sub-standard vessel.

RoPax ferries and stability

The ropax ferry, with big external doors close to the waterline and a large open vehicle deck, has a reputation for being a high risk design. If any water enters the vehicle deck the ship will become unstable and the water quickly accumulates on one side of the deck causing ship heel. Below follows a simplified but illustrative explanation.

Consider a ropax ferry with a car deck covering the whole width of the ship. The stability contribution from some casings for access purposes and the space in front of the collision bulkhead can be neglected. Further suppose the ship has a large symmetric damage with an equilibrium water line somewhere above the main deck, Figure 2. If the main deck is damaged, the ship will not have any form stability. The ship stability properties will be governed in the same way as for a submarine i.e. the centre of gravity have to be below the centre of buoyancy for the equilibrium to be stable. For a normal ropax this is not the case.

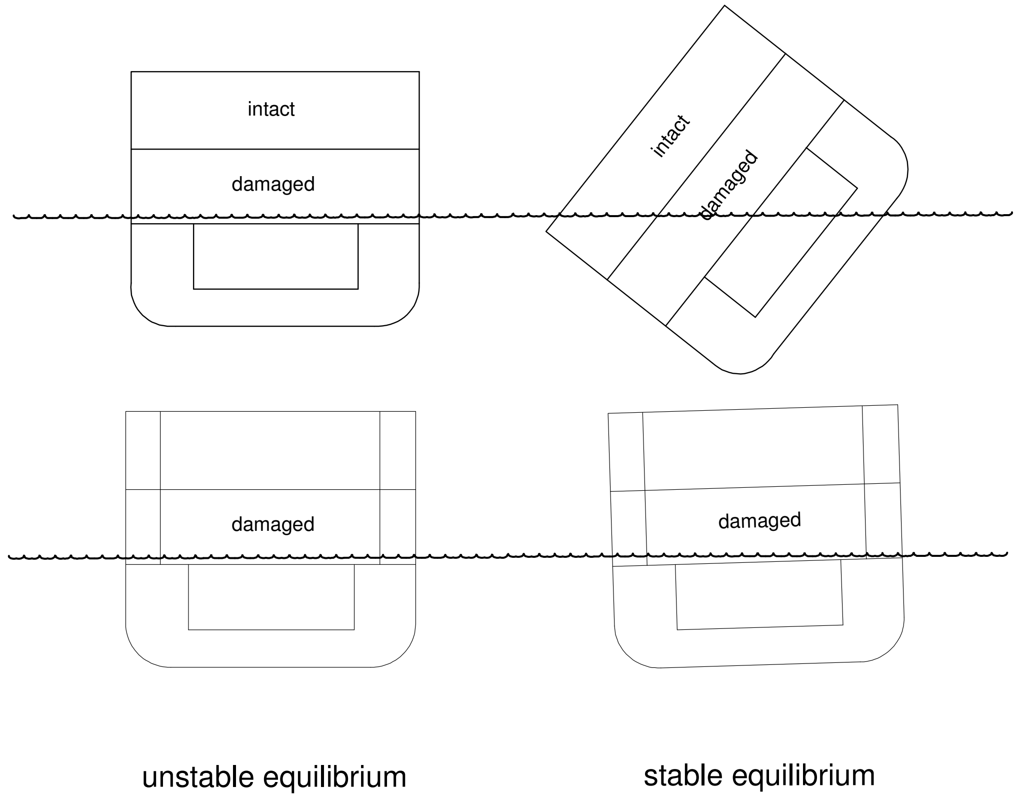

Figure 2 Equilibrium with and without side casings for a large damage.

The equilibrium will be unstable and if the superstructure above the main deck is not considered watertight the ship will turn upside down. If it is considered watertight, the ship will still have a substantial heel, basically depending on the height to the watertight deck above (but likely more than 20°) .

This example is not as far fetched as it might seem at first. Of course the damage has to be very substantial for the ship to be at above equilibrium. But once there, either the ships centre of gravity has to be unrealistically low or quite substantial side casings have to be fitted. Else, most real ropax ferries will show above behaviour. Cargo shifting will also make the situation worse.

The list in the lower right side in Figure 2 is not due to the free surface effect. It arises from the side casing being damaged on one side only, i.e. a small asymmetry in the damage case.

If the damage is smaller, e.g. SOLAS two compartment, but water is still shipped by e.g. waves onto the main deck the situation is actually worse when initial stability is considered. There will be a larger distance between the centres of buoyancy and gravity because there is no flood water below main deck that would lower the centre of gravity. The water plane area of the intact ship is also smaller than the damaged water plane area. Fortunately the amount of water on deck is unlikely to become very large and will only cause a smaller heel (unless the flood water is continuously "pumped" by the waves so that the gross amount of water on the main deck is increased over time).

A modern roro ship, such as the template ship, will loose its stability and eventually capsize if subjected to progressive flooding. This will not be the case though when the ship is damaged according to present SOLAS regulation. The damage itself or other circumstances, such as progressive flooding or weather conditions, has to be more severe.

Capsize will forego any sinking scenario on a typical ropax ship. It can also be a much faster event than the relatively slow loss of buoyancy that will cause sinking. Since the free surface effect of a roro deck is large enough to make the ship instable, water entering the roro deck will automatically be located at the worst position, at the side creating heel. The roro deck has a very large volume hence progressing flooding will eventually lead to capsize of the ship.

METHODS

The template ship

The template ship is a modern ropax with symmetric subdivision and a relatively large freeboard. It has two full beam and length roro decks (one is freeboard deck) and one narrow roro deck, inside of B/5, below the freeboard deck.

A validation of the hull form and subdivision in a WP5 software environment was established by comparing hydrostatic properties and volumetric capacities to values as initially provided by WP4. A very good representation of the bare hull, without deduction for Bow Thruster Tunnels, including a 12mm Shell Plating was confirmed.

Further analysis shows that the template ship is compliant with SOLAS intact and damage stability rules. Due to the large freeboard after any SOLAS damage the ship is also compliant with the “Stockholm agreement” regulation.

Figure 3 shows the hull lines of the template ship. A more comprehensive description of the template ship can be found in (WP 4 report).

Floating Status Loading Condition 11

Draft FP	6.679 m	Heel	zero	GM(Solid)	1.665 m
Draft MS	6.827 m	Equil	Yes	F/S Corr.	0.197 m
Draft AP	6.974 m	Wind	0.0 kn	GM(Fluid)	1.468 m
Trim	aft 0.29/179.50	Wave	No	KMT	14.111 m
LCG	83.614f m	VCG	12.446 m	TPcm	40.80

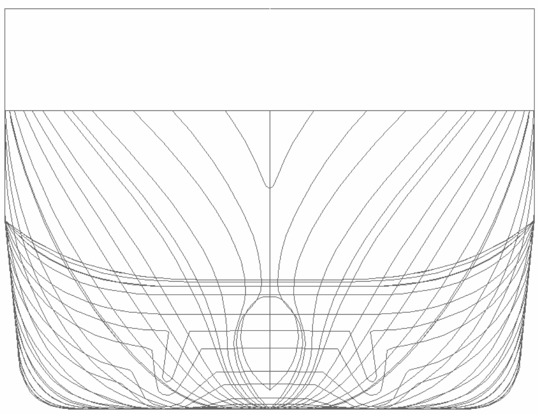

Figure 3 Hull lines of the template ship

International workshop

In order to establish within the project a European network an international workshop was organized in Gothenburg 15-16 June 2004, to which external experts were invited.

The discussions in the workshop topic related to stability and floatability, named "Topic 5 - Arrangements for Avoiding Capsizing and Sinking" can be concluded as follows:

1. In order to control the ship's heading, the ability to maintain some propulsive power was considered as imperative for the survivability of the ship.

2. The ability to sink upright was considered valuable. However, in accordance with studies on human behaviour during evacuation at various angles of list carried out at University of Greenwich under Prof. Ed Galea, an angle of list up to 5-7° could be acceptable.

   Should a so called "Float –Off" be applied, the sinking upright will of course of vital importance.

3. It was concluded that "Rip-up" or "Raking" damages, which are not accounted for in the prevailing rules, are interesting especially for navigation in the narrow and shallow straits, and rather confined waters surrounding the Scandinavian coast line. These damages should, however, include more than three adjacent compartments.

4. It was mentioned that statistics proved that more than 50% of collision damages resulted in a transverse penetration beyond B/5. Also the longitudinal and vertical extension of a hypothetical damage were discussed to some extent. Statistics of damage cases will be made available to the DESSO-project.

5. The Workshop Topic 5 attendants were informed about the ongoing work within especially the MCA and the HARDER project. Presently, two proposals regarding the floatability and stability of RoPax vessels, are being prepared, eventually to be submitted to the IMO. A link to some information related hereto was provided after the workshop.

Quantitative pre study of sinking scenario

At an early stage of the project a simplified study of the ship sinking process was made. This was made in order to obtain a first quantitative measurement of the instability (negative GM) present when the main deck is flooded.

In this study the only assumption made of the damage was the added weight and vertical centre of gravity of the flooded water. Hence the study is not directly dependent of the arrangement of the compartments below the main deck.

The hull lines of the intact template ship was used to obtain the displacement, centre of buoyancy, KB, and the metacentric height, BM, for the different stages in a sinking process. The ship had zero trim in the study.

The loading condition LC11 (Fully Homogenous Load Departure) is used as an input to the study.

Draught 6.8 m (LC11)		
Draught	6.8	m
displ	20640	ton
displ	20136	m^3
KG	12.4	m
GM	1.67	m

Draught 10 m		
Draught	10	m
displ	34643	ton
displ	33798	m^3
displ diff	14003	ton
assumed cog	5	m
new KG	9.4	m
new GM	4.32	m
WOD		
Deck 2		
assumed L	155	m
assumed B	28.5	m
FS corr	8.8	m
GM (WOD)	-4.5	m
Side casing	3	m
GM (WOD)	-0.03	m

Draught 13 m		
Draught	13	m
displ	48855	ton
displ	47664	m^3
displ diff	14212	ton
assumed cog	11.5	m
new KG	10.0	m
new GM	3.48	m
WOD		
Deck 2		
assumed L	155	m
assumed B	28.5	m
FS corr	6.3	m
GM (WOD)	-2.8	m
Side casing	3	m
GM (WOD)	0.39	m

Draught 16 m		
Draught	16	m
displ	63722	ton
displ	62167	m^3
displ diff	14867	ton
assumed cog	13.5	m
new KG	10.8	m
new GM	3.24	m
WOD		
Deck 2		
assumed L	155	m
assumed B	28.5	m
FS corr	4.8	m
GM (WOD)	-1.6	m
Side casing	3	m
GM (WOD)	0.87	m

Draught 19 m		
Draught	19	m
displ	76187	ton
displ	74329	m^3
displ diff	12465	ton
assumed cog	17.5	m
new KG	11.9	m
new GM	1.88	m
WOD		
Deck 2		
assumed L	128	m
assumed B	28.5	m
FS corr	3.3	m
GM (WOD)	-1.4	m
Side casing	3	m
GM (WOD)	0.25	m

Figure 4 Quantitative study of sinking scenario

The starting point of the study is a loading condition with draft 6.8 m (even keel) and KG 12.4, very close to Fully Homogenous Load Departure. The next step is to stipulate a new damaged draft of 10m, this coincide with the height of the freeboard deck (deck 2) and calculate a new displacement. The difference in displacement corresponds to the weight of the flooded water. An estimate of the centre of gravity of this floodwater is made and a new KG is calculated. From the new KG and the KB for the stipulated draught "intact" GM is obtained. The roro deck can now be modelled by a rectangle and the reduction of GM due to the free surface effect can be calculated. This reduction (FS corr) will typically be several meters. The same procedure is repeated for increased draughts. By decreasing the width of the roro deck the influence of intact side casings can also be studied, Figure 4.

If the draught is increased further, deck 3 will eventually be submerged and an analogous stability problem will arise. In order to stay upright the side casings will have to continue on deck 3. The height of deck 3 is 15.95 m and the height of deck 4 is 21.40 m.

It was decided at an early stage of the project that watertight side casings, with the same sub divisions as the compartments below the freeboard deck, should be fitted. These should serve as reserve buoyancy with large heeling resistance that will keep the ship upright and afloat in a severe damage scenario.

Damage cases

It was concluded that the Stability Assessment work may well be divided into two stages of a damage scenario or degree of damage severity as follows:

1. Damages or early stages of an accident scenario not resulting in immersion of Freeboard Deck.

   Efforts should be made to minimize the resulting angle of list, to preserve reserve buoyancy and residual stability in order to prevent or delay the immersion of the main deck.

2. Late stages of an accident scenario or severe damages resulting in the immediate immersion of Freeboard Deck.

   In these cases the large open deck will result in free surface effects which dramatically will reduce the stability. In order to control the development of such an accident, a substantial part of the ship's buoyancy and water plane area must be shifted from the "intact case" underwater body athwartships to the side casings.

   Efforts should be made to limit the free surface, preserve reserve buoyancy and residual stability, $G'M > 0$.

An improvement of the subdivision below freeboard deck will, for the relatively small damage cases, result in a rather limited increase of an already high survivability. While a successful arrangement above freeboard deck can facilitate a degree of survivability as an alternative of a high probability of capsizing. Hence, efforts should be made to reduce the consequences of damages where the freeboard deck becomes immersed.

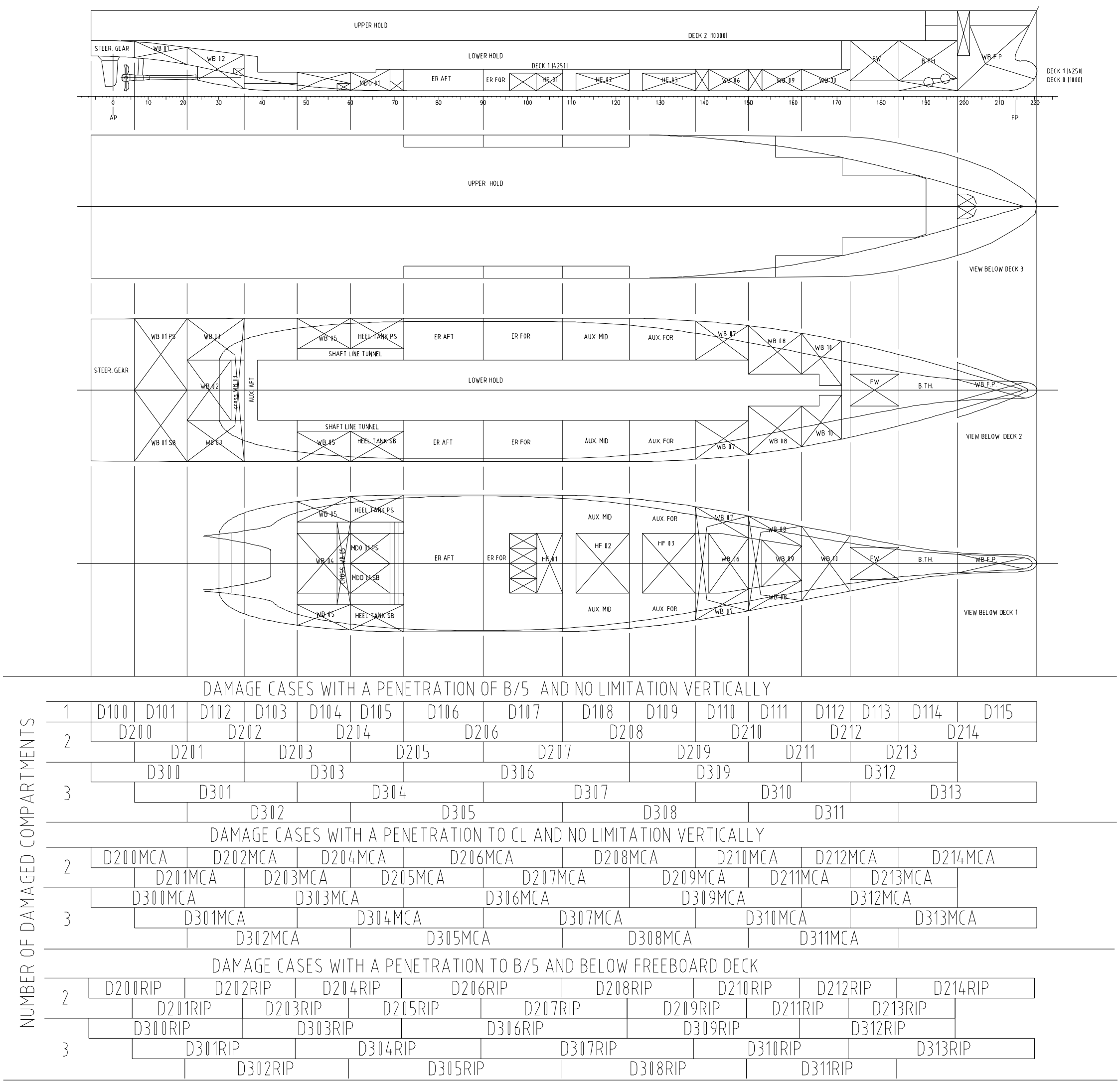

Figure 5 Damage cases

Figure 5 shows damage matrix consisting of all analyzed damages with a damage length up to and including three compartments. The damage cases are divided in three categories:

1. Damages with a transverse penetration up to B/5 with no limit vertically, 1-3 compartments. (1-2 compartments are the only damage cases regulated in SOLAS)

2. Damages with a transverse penetration up to B/2 with no limit vertically, 2-3 compartments. (The name of the damages ends with MCA)

3. Damages with a transverse penetration up to B/5 and below the freeboard deck, 2-3 compartments (The name of the damages ends with RIP)

All these damage cases have been analyzed for every change of the watertight integrity throughout the project. The ship depicted in Figure 5 is the template ship but the damage definitions will also be applicable for the concept ship since no compartment has been added or deducted longitudinally.

In addition to these damages, analyses have been made for a number of other damages in order to investigate sinking scenarios and larger rip up damages.

Possible buoyancy of the superstructure above deck 4 has not been accounted for in the analysis.

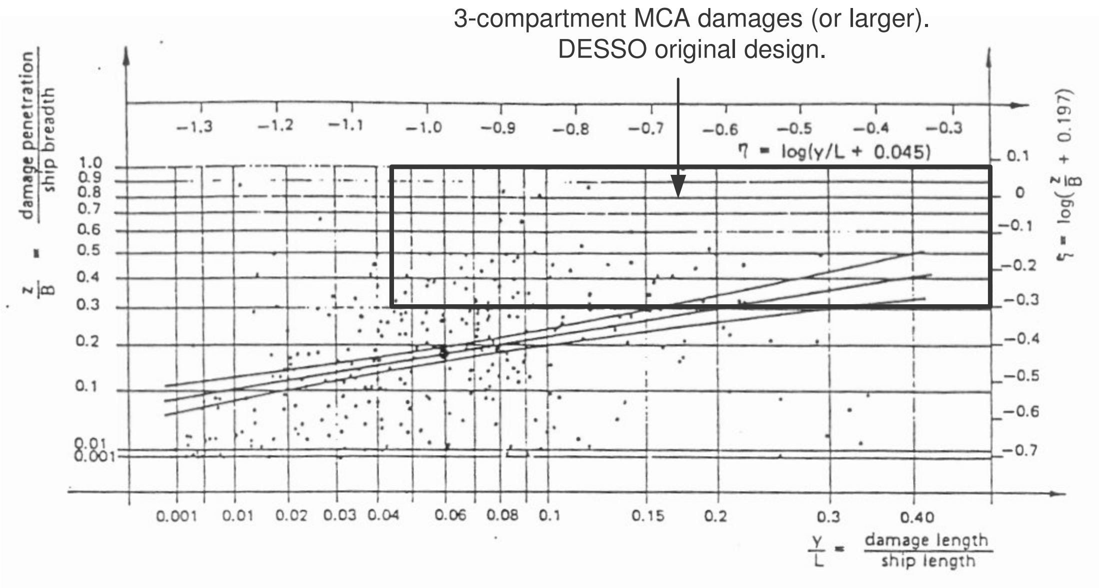

Figure 6 Black dots in this graph represents actual damages on cargo and ro-ro ships, L>100m. (Explanatory notes for probabilistic calculations. IMO SLF 35/20 ANNEX 3)

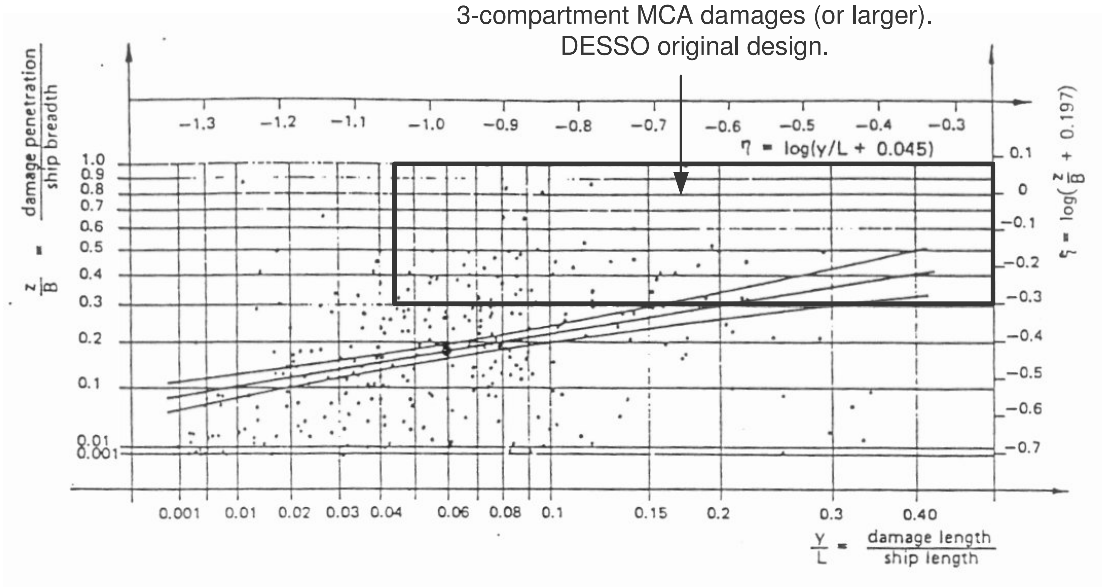

Figure 6 is a graph over damage statistics that shows damage length versus damage penetration for a large number of actual damages, represented by the dots in the graph, on cargo and ro-ro ships with lengths over 100 m. The damage extension inside the rectangle corresponds to the 3 compartment MCA damages on the template ship. Damage extension is of course dependent on the structural arrangement of the specific ship in but this graph can give some conception of the probability of a certain damage extension on the template ship.

Figure 7 shows an example of a possible extension of a three compartment MCA damage on the DESSO ship.

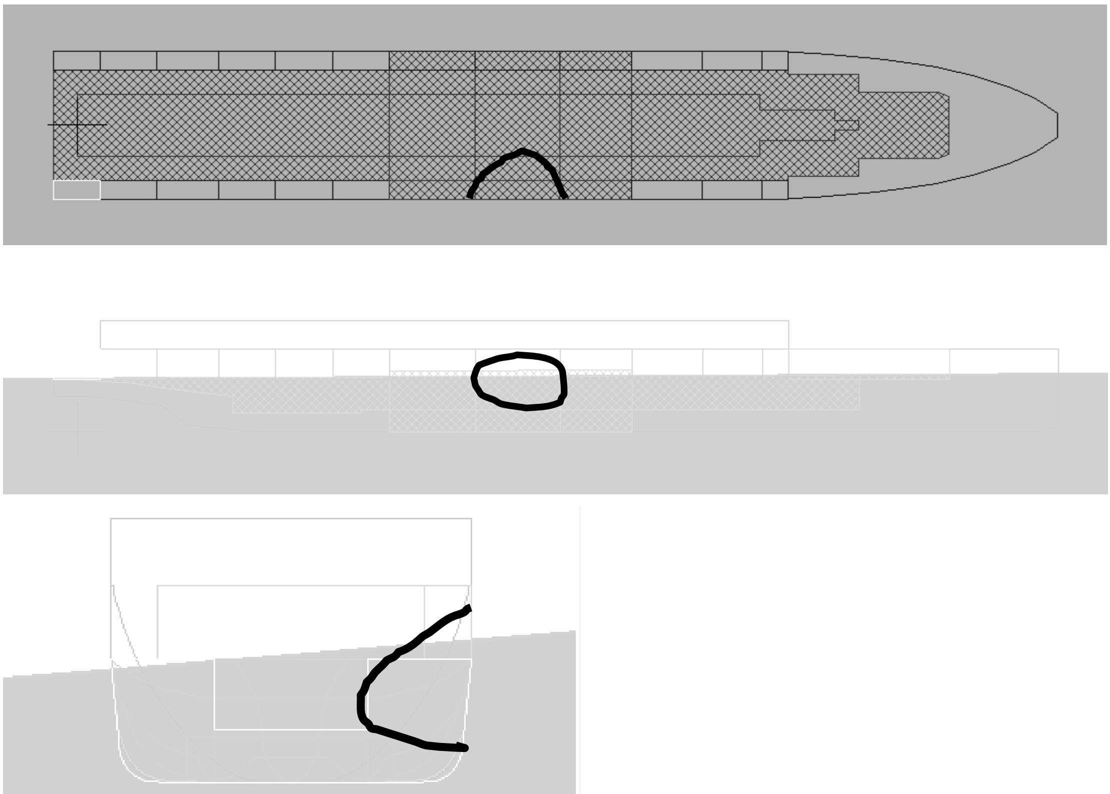

Figure 7 Extension of a three compartment MCA damage (D306MCA).

RESULTS

The concept ship

Below follows a description of the DESSO concept ship mainly expressed as differences from the template ship in terms of arrangement of compartments and hull geometry. A more general description of the concept ship will be found in (WP 4 report).

The DESSO ship has an increased beam, from 28.5 m to 32.1 m. The under water part of the hull is unchanged. The widening of the hull starts at about 8 m above the keel and full beam is reached at 10 m above the keel, at deck 2, Figure 8. The compartments below deck 2 are stretched to fit the new hull. By this widening, 3.75 m wide side casings can be fitted without loss of cargo capacity, i.e. lanes. The main purpose of these casings is to enhance the damage stability properties of the ship. Parts of the casings can also be used to accommodate exhaust system from the main engines. The casing reaches the full length of the ship and has a longitudinal subdivision corresponding to the compartments below deck 2. The casing reaches up to deck 4.

Floating Status

Draft FP	6.705 m	Heel	zero	GM(Solid)	1.645 m
Draft MS	6.836 m	Equil	Yes	F/S Corr.	0.188 m
Draft AP	6.967 m	Wind	0.0 kn	GM(Fluid)	1.456 m
Trim	aft 0.26/179.50	Wave	No	KMT	14.096 m
LCG	83.673f m	VCG	12.452 m	TPcm	40.80

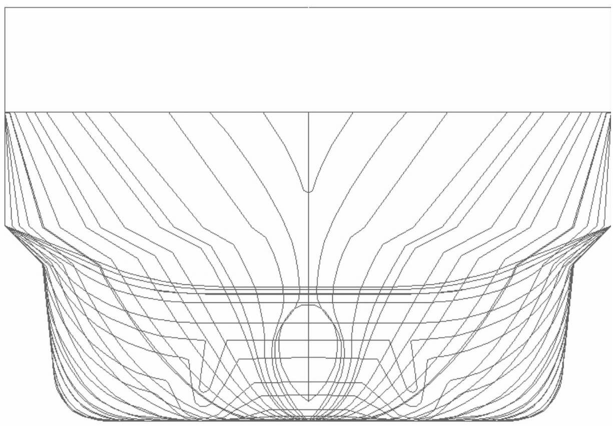

Figure 8 Hull lines of DESSO ship.

In order to achieve an enhanced propulsive redundancy the two engine room have been separated longitudinally by one compartment, the forward main engine room has been moved one compartment forward. In addition, the aft main engine room has been transversally separated with two longitudinal bulkheads under the sides of the lower hold (deck 1). This starboard port separation is necessary to maintain propulsion for any two compartment damage, but it will also cause undesirable asymmetries in a few damage cases. In order to reduce the asymmetry, the aft main engine room has been shortened by moving the aft bulkhead four stations (3.52 m) forward, Figure 9. Furthermore, the heeling tanks directly behind the aft main engine room also introduce asymmetry in case of damage. These are moved aft, changing location with a symmetric water ballast tank (WB05), to avoid excessive asymmetry. Since the new heeling tanks are smaller, another pair is introduced in place of a ballast tank (WB07) in the forward part of the ship. The loading of the heeling tanks is adjusted to obtain the same floating status as for the original template ship.

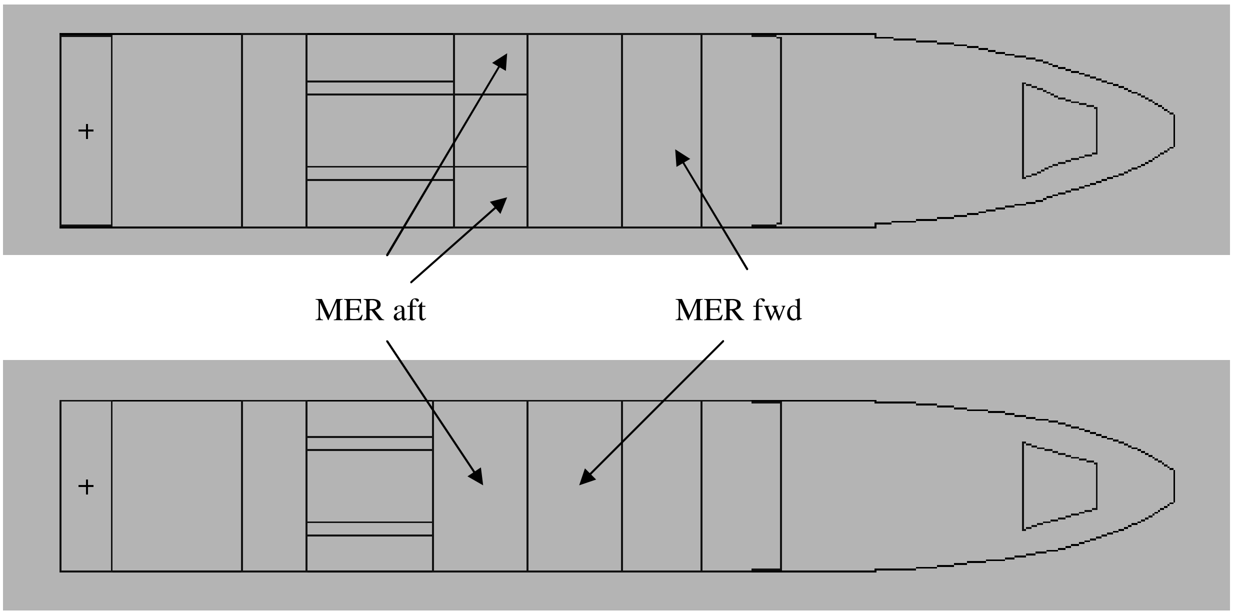

Figure 9 Arrangement for improved propulsive redundancy. Concept ship – above. Template ship – below.

Stability analysis

In this chapter results and conclusions from the stability analysis of the final concept ship is presented. In the following chapters the different design changes eventually leading to the final concept ship is presented. These design changes has resulted in damage stability analysis of a number of “intermediate concept ships”. The results from these analyses are mainly omitted in this report, only conclusions are included.

In **Error! Reference source not found.** the intact stability particulars of the template ship and the concept ship is presented. The only difference in the stipulated loading of the ships is in the loading of the heeling tanks. The loading have been adjusted on the template ship to obtain the same floating status as the template ship. In a later design stage of the concept ship this assumption has to be reviewed as would the quantitative results in this report. This would not effect any of the principle results however.

The righting arm curves will differ after a few degrees of heel when the widening of the concept ship comes into effect. The widening starts about one meter above the water line. The template ship is not assumed to have any buoyancy above deck 3. In **Error! Reference source not found.** the righting arm of the concept ship is presented with buoyancy up to deck 3 and deck 4 respectively.

Error! Reference source not found. contains GZ curves of different damage cases of the template ship and the concept ship, compared side by side. The buoyancy of the upper side casings (between deck 3 and deck 4) of the concept ship have been omitted for easier comparison. Note that the y-axis is not generally to scale. It can be clearly seen, however, in the righting arm curves for the SOLAS 2 compartment damages that the concept ship has an ample reserve stability compared to the template ship. The concept ship has a wider range, larger maximum and larger area for all 14 cases. In damage cases D205 and D206 the list due to the asymmetric subdivision of the aft main engine room is shown. The list is close to 10 degrees in both cases. D208 can be considered to be the most severe SOLAS 2 compartment damage on the template ship; it is the damage with lowest maximum righting arm. The same damage on the concept ship has better stability values than any of the damages on the template ship.

The next section in **Error! Reference source not found.** shows the 3 compartment MCA damages. The difference between the template ship and the concept ship is dramatic. In these damage cases the freeboard deck will be partly or fully submerged in the equilibrium position. For the template ship these equilibrium are unstable and the ship will capsize in all but the two foremost cases. The concept ship will survive all damages. The three damages including the asymmetric aft main engine room, D304MCA-D306MCA, will not have an increased list angle compared to the SOLAS damages. Note that all but the three foremost damages will have a list angle of a few degrees. This is due to the asymmetry imposed by the damaged casing compartments

The worst SOLAS damage on the concept ship in terms of heel angle is D205. This damage actually violates present SOLAS regulations since the margin line is submerged. There is a negative freeboard at the ship side by a few centimetres. The ample reserve stability from the side casings will still provide a very high safety and this violation can be regarded as a trade off for the high propulsion redundancy. D205 together with D206 and D106 will also require calculations to comply with Resolution 14 of Annex 4 in SOLAS, “Stockholm agreement”. The template ship was automatically compliant through the high damage freeboard due to symmetric subdivision. The calculations were performed with a constant weight of water on the freeboard deck and without any buoyancy above deck 3, the most conservative calculation. **Error! Reference source not found.** shows that the concept ship is compliant.

Analysis has also been made on several larger rip up damages. The worst possible rip-up damage in terms of list angle is a 7 compartment damage stretching from the aft heeling tank to the forward heeling tank. This damage will include one side of the aft main engine room and thus all asymmetric compartments. The equilibrium heel angle will be about 15 degrees. If the heeling tanks are counter filled the heel angle will be reduced to 7.5 degrees. The floating status of this damage can be found in **Error! Reference source not found.**. A further extension, forward and/or aft, of this damage will result in a smaller equilibrium heel angle. The same damage on the original design will result in an equilibrium heel angle of 12 degrees.

Full length side casings

To add full length side casings is the most natural way of solving the problem with water on the freeboard deck and to enable upright sinking without capsizing. The casings will serve as symmetric buoyant spaces where they are of best use to maintain stability, as far from the CL as possible.

The ship was first altered to have two meter full length side casings. With two meter casing all eight lanes on decks 2 and 3 can be kept, Figure 10.

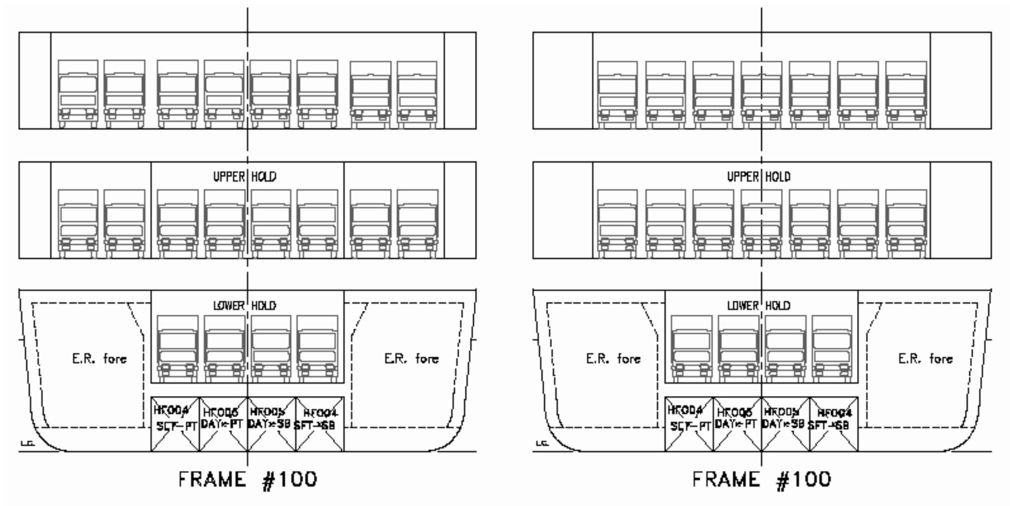

Figure 10 2 m side casings (left), 3.75 m side casing (right).

The result of the damage calculations was that although the two compartment SOLAS damages naturally showed better damage stability properties, the three compartment MCA damages made the ship capsize in most of the 14 cases. A combination of two meter casings and transverse bulkheads on deck 2 was also implemented and evaluated, see below.

As the alternative with two meters full length casings did not give enough stability, casings of 3.75 meters width was implemented in the model. The 3.75 m casings are only possible if one lane is omitted from deck 2. This configuration gives ample reserve stability when the three compartment MCA damages was analysed. The results of this analysis is qualitatively similar to corresponding analysis of the final concept ship, see Appendix 4. The GM and maximum GZ was generally slightly lower however.

The loss of cargo capacity can be considered to be a large disadvantage with the wide casing alternative. The omitted lane will also shift the remaining lanes by one half of a lane width (1.75m). This in turn will be a problem for the supporting pillars between deck 2 and deck 3. Two lanes would be lost if the pillars can not be shifted accordingly.

Transverse bulkheads on freeboard deck

A combination of two full beam transverse bulkheads combined with more narrow side casings was also tested. These bulkheads will reduce the flood volume and free surface area on the freeboard deck with about 1/3 or 2/3, depending on if one of the bulkheads is damaged or not. This made it possible to fit side casings narrow enough to accommodate all cargo lanes on the freeboard deck. The transverse bulkheads will however cause problems with the cargo handling. The bulkheads were located at station #72 and #123 respectively, Figure 11.

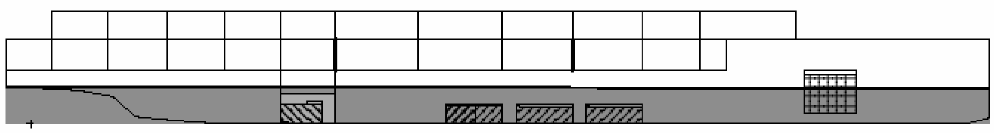

Figure 11 The transverse bulkheads is located at the thick lines through the lower casing.

Ship widening

With the disadvantages of either transverse bulkheads or wide side casings one additional alteration was investigated. Widening of the ship in order to maintain the number of lanes and still not have to fit transverse bulkheads on the freeboard deck.

When the outer hull of the ship is modified, all compartments with the hull as a boundary is stretched to fit the new hull i.e. there will not be any new void spaces, the number of compartments is kept, some changed in shape and volume. Some additional fairing of the new lines is desirable, but this will not significantly effect the stability calculations.

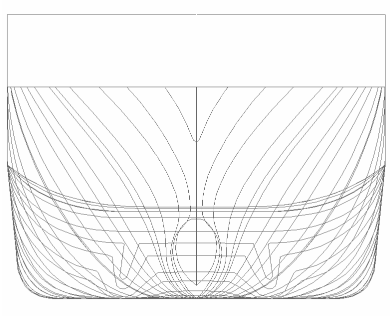

Figure 12 Lines of template ship: beam 28.5 m

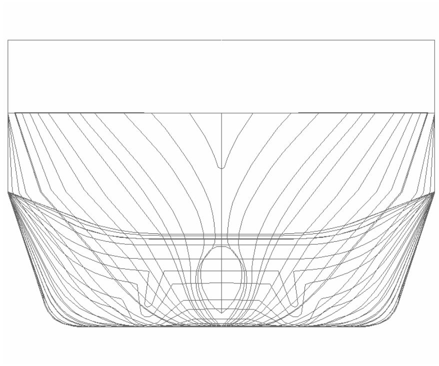

Figure 13 Lines of widening #1: beam 32.1 m. Straight lines from freeboard deck (full beam) to the tangent of bilge.

Figure 13 shows widening #1. This widening will change the under water part of the hull (the benefit of comparison with the initial ship will be lost). The draught and trim are not significantly changed. The displacement will only increase slightly. This is due to an increased volume of the heeling tanks, which are defined to be 50% filled. However the widened beam will result in a doubling of the GM, from 1.55 m to 3.05 m due to a widening of the ships waterline of about 1.6 m. The increase of GM will increase the roll acceleration and might increase motion sickness among the passengers.

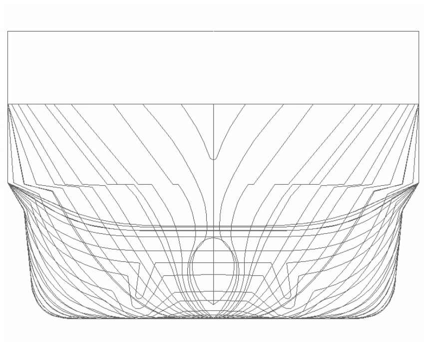

Figure 14 Lines of widening #2: beam 30.5 m. Straight line from freeboard deck (full beam) joining original hull about 2m below freeboard deck.

Figure 14 shows widening #2, where the geometry of the outer hull is only changed above the water line and GM is not effected. The beam is only increased by two meters. The damage stability was insufficient without loss of lanes or fitting of transverse bulkheads.

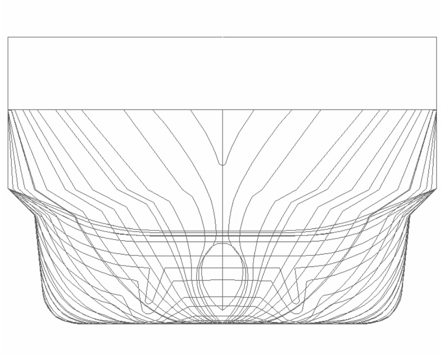

Figure 15 widening #4, concept ship: beam 32.1 m. Straight line from main deck (full beam) joining original hull about 2m below freeboard deck. (The hard shines in the final lines have been softened slightly to reduce sloshing.)

The final hull widening, the hull shape of the concept ship, is shown in Figure 13. The under water part of the hull has the same shape as the template ship and the GM will be moderate, not causing excessive roll accelerations. The beam is large enough to keep all cargo lanes and the wide side casings that will provide sufficient reserve stability without the aid of transverse bulkheads.

Propulsion redundancy arrangement

A large degree of propulsion redundancy is of great importance. With propulsion power the damaged ship can sail to the nearest port or at least be able to manoeuvre to maintain the most favourable heading with respect to the situation e.g. wave direction and damage location.

The goal was to maintain propulsion power in any two compartment SOLAS damage (this is not a requirement from the authorities). There are several possible arrangements to obtain this but also several practical requirements to meet.

The final proposal is to separate the engine rooms longitudinally, with one compartment between, and to separate the aft engine room with two longitudinal bulkheads. SB/Port separation is necessary to obtain propulsive redundancy. The separation of the aft engine room will not only be beneficial. It will create a built in asymmetry in the arrangement and thus larger heeling angles in case of damage.

With this configuration, shown in Figure 9, propulsion redundancy will be possible for any SOLAS and MCA damage as well as large rip up damages and 3-compartment MCA damages.

Subdivision below freeboard deck

General

An improvement of the subdivision below freeboard deck will, for the relatively small damage cases, result in a rather limited increase of an already high survivability. While a successful arrangement above freeboard deck can facilitate a degree of survivability as an alternative of a high probability of capsizing.

Hence, efforts should primarily be made to reduce the consequences of a damage when the freeboard deck becomes immersed. However, the postponing of a negative freeboard should be strived for by arranging a WT subdivision below freeboard deck that:

I. As far as practicable resulting in symmetrical damage cases,

II. As far as practicable minimizing loss of buoyant volumes,

III. As far as practicable minimizing free surface of compartments in case of flooding.

The subdivision below freeboard deck can, for practicable reasons such as functionality, allow uncomplicated construction, facilitate access and maintenance etc, not be totally optimized from a damage stability point of view. These below deck compartments are arranged to encompass machineries and utility systems and tanks for consumables. In addition a lower hold is arranged for the carrying of payload.

Based on the above, a number of alternative watertight integrity concept arrangements below freeboard deck have been worked out and analyzed, see Figure 16 First Concept Generation - Alternative Watertight Integrity Arrangements.

These concept arrangements are derived, believed to primarily add some stability enhancing qualities to the generic RoPax. No considerations for the arrangement feasibility or “cost-benefit” respectively have been made in the concept generation process, except for some “common sense” concerns which have been taken into account.

Below Freeboard Deck Conceptual Arrangements

Since the below deck transverse subdivision initially has been confirmed as efficient from a stability aspect, the original position of the transverse bulkheads has been preserved. The following below-deck arrangements have been generated from a floatability and stability point of view and analysed accordingly:

NAOS-00 Represents the Generic RoPax Original Design as provided by WP4.

A1B0C0 This configuration represents below-deck compartments arranged to accommodate machinery and utility systems only. The original longitudinal bulkheads have been preserved well within the B/5 limit. The lower hold, however, has been omitted and replaced with various miscellaneous spaces for utility systems, longitudinally separated by extensions of the transverse bulkheads from the ship’s side to side.

A2B0C0 The arrangement is similar to the A1B0C0 case but an asymmetry has been introduced by segregating the SB and PS by applying a "true" double bottom.

A3B0C0 This arrangement comprises a more traditional machinery arrangement, having two separate main engine rooms, one SB and one PS, each of which accommodating a pair of main engines mounted in parallel to a common gear per shaft. In order to achieve this arrangement the breadth of the ramp down to Lower Deck has been reduced from four lanes to two lanes in parallel.

A4B0C0 The arrangement is similar to the NAOS-00 Original Design configuration. However, the free height of the lower deck compartments have been reduced from 5.75 m to 4.50 m which corresponds to the free height as stipulated for trailer traffic on the European roads. The excess in deck height has been re-arranged to enclosed buoyant void spaces. Recesses in this "life-belt" must be done in the way of machinery venting and uptakes.

Figure 16 First Concept Generation - Alternative Watertight Integrity Arrangements

Evaluation of First Concept Generation

D208MCA In order to assess, from a stability / floatability point of view, the various concept arrangements as presented above, all arrangements have been exposed to the same damage case, D208MCA, which was determined to be the most severe 2-compartment damage, see Figure 17.

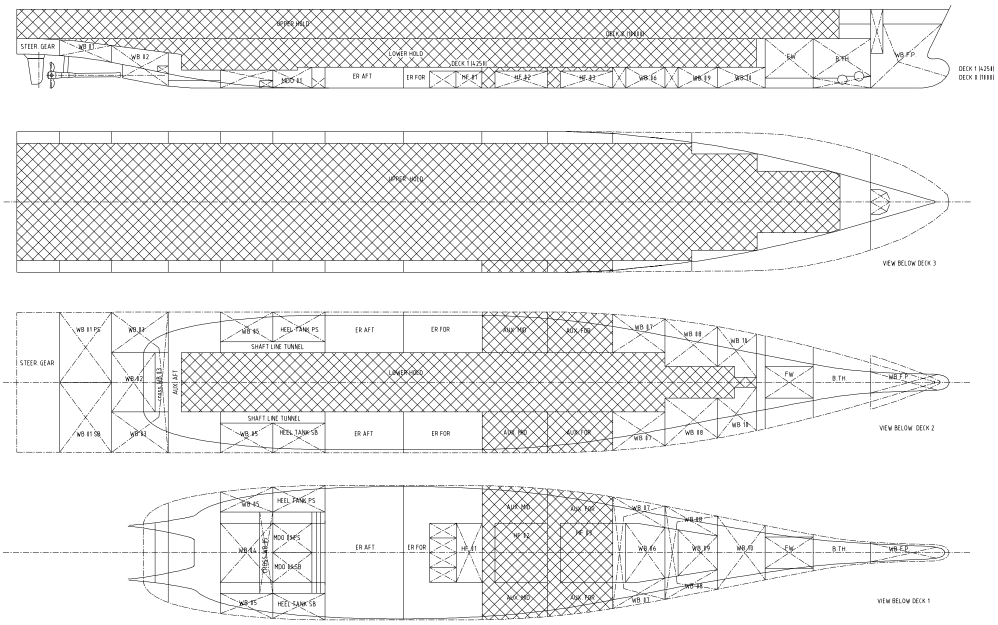

Figure 17 Damage Case D208MCA

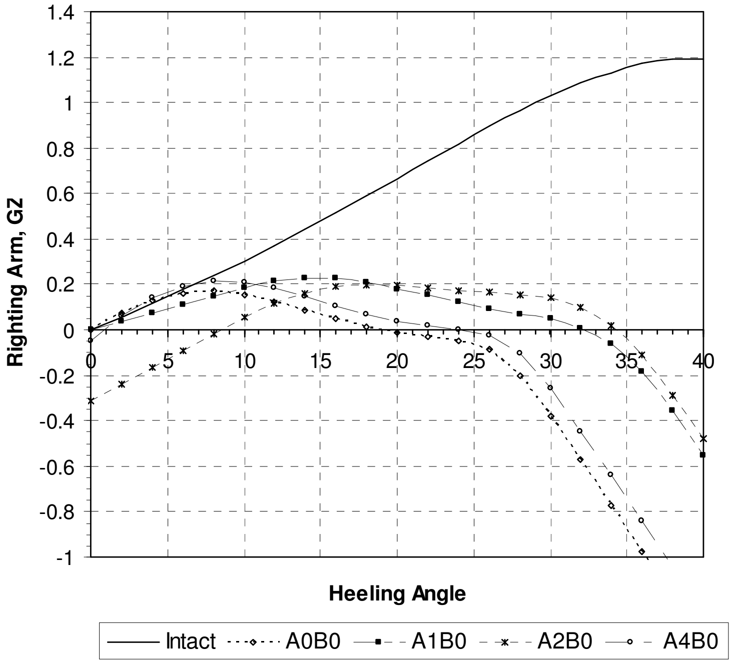

Figure 18 First Concept Generations – Assessment Curves

Conclusions

The results as presented in Figure 18 show that the arrangement A1B0 results in the most favourable righting arm curve providing some information on the stability-cost relation for the 412 Lane Meters.

The asymmetrical case A2B0 results in a list at equilibrium corresponding to 8 degrees. The righting arm curve however, provides the highest range of positive stability.

The "Life Belt" as depicted in the arrangement A4B0 could maybe constitute some energy absorbing buffer zone. However, from a stability point of view the "Life Belt" will suffer the same extent of damage as will the adjacent hull, meaning that any significant contribution to enhanced stability will not occur prior to immersion of the Freeboard Deck. It will of course provide a significant reserve buoyancy when large damages are suffered.

Non of the above arrangements have been fully adopted in the final DESSO Concept Ship. However, the assessment of the various arrangements has provided information valuable for the completion of the Concept Ship.

CONCLUSIONS

To stay upright and afloat requires buoyancy. To stay afloat is to have enough buoyancy to counteract the weight of the ship. To stay upright is to have enough buoyancy at the right position compared to the position of the weight of the ship. The physics of ship damage stability is simple enough, but when it comes to actual design, where many other aspects besides stability have to be considered, things get more complex.

Ship design is normally very much based on previous experience and constrained by rules and regulations also built on previous experience. In the DESSO project the aim is to go beyond the regulations, to set a higher standard and design a ship significantly safer than existing ships. With no specific constraints by regulations it was necessary to go back to the basic physics.

The idea of wide side casings was put forward quite early in the project. This it not new as a concept, but does not exist on actual ships in the form proposed in the DESSO concept design.

The wide side casings constitute large reserve buoyancy and are, by its athwardship location, optimized to create large reserve stability.

During the project it was realized that different aspects of the subdivision for watertight integrity could be quite clearly separated depending on the severity of the damage scenario studied. It is obvious that the side casings, located above the freeboard deck, does not influence the floating position and GM of any SOLAS damage, but they can improve the stability if dynamic conditions, wave and wind environment, is considered as well. On the other hand if larger damages are studied changes of the subdivision below the freeboard deck generally has a minor influence on the stability properties. An important exception is the introduction of asymmetries below the freeboard deck. The casings were designed to counteract the free surface effect of the roro decks but not with a large margin. Therefore a larger asymmetry below the freeboard deck will be maintained as a shift of the centre of gravity of the flood water on the roro deck. In the end of course a stability assessment of the final design as a whole has to be made.

It is assumed that all buoyant spaces on the concept ship can be damaged; the ship is not “unsinkable”. For the same reason the ship is not “uncapsizeable”. But the side casings make it possible for the concept ship to stay upright through a sinking scenario while this is impossible for the template ship.

A final conclusion is that the DESSO concept ship will be able to survive, without excessive heel angles, a large number of damage scenarios where the template ship together with most of the existing roro/ropax fleet would capsize.

APPENDIX D

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Fire safety approach on the DESSO ROPAX

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Fire Technology
Borås 2006

Abstract

Fire safety approach on the DESSO ROPAX

This report summarises the fire safety approach on the DESSO ROPAX.

The basics starting point of the work was that the DESSO ROPAX should fulfil all the prescriptive requirements given in SOLAS Chapter II-2, the FTP Code, the FSS Code and other relevant documents.

In addition to these measures, the intention has been to minimise the growth and spread of fire from its point of initiation, and/or maximise the time one can survive on the burning ship. Such improvements has been made by an astute design and lay-out of the ship, judicious selection of material in order to minimise the growth and spread of fire, rapid fire detection and response, coupled to fire mitigation or a combination of these activities. It is imperative that the reliability of active fire protection measures, such as fire detection systems or sprinkler systems, is high. Redundancy and reliability beyond the present regulatory requirements has therefore been sought.

Key words: Ships safety, fire protection, ro-ro ships.

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Contents

Preface

Fires represent a serious hazard for ships; several studies have shown that fire is the second largest hazard for crew and passengers on ships. Foundering due to collision, grounding or hull structural failure is generally considered as being the largest hazard.

The main objective under WP 7 of the DESSO project is to improve fire safety on ro-pax ships by minimising the growth and spread of fire from its point of initiation, and maximise the time one can survive on the burning ship.

One important outcome of the project is the conceptual design of a ro-pax ship having better fire safety than "state of the art".

The authors of this report would like to acknowledge the following persons for their valuable input:

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Jan Sanderoth, Consilium Fire & Gas AB

Johan Wikman, the Swedish Maritime Administration

Sammanfattning

Målsättningen med DESSO-projektet (Design for Survival Onboard eller populärt ”fartyget som sin egen livbåt”) har varit att utveckla ett fartygskoncept med en säkerhetsnivå avseende bland annat flytbarhet, evakueringsmöjligheter och brandsäkerhet som är bättre än ”state of the art”. Vid en kollision eller en brand är det meningen att passagerarna skall kunna stanna kvar ombord på fartyget. Fartyget skall därefter kunna ta sig till hamn för egen maskin eller evakuera passagerarna under säkra former.

Denna rapport redovisar hur brandskyddet ombord på konceptfartyget är utformat. Konceptfartyget har fått namnet ”DESSO ROPAX”.

En naturlig utgångspunkt är självfallet att samtliga av dagens brandsäkerhetskrav skall vara uppfyllda. Utöver detta har säkerhetsnivån höjts genom att bland annat välja inredningsmaterial och elkablar med bättre brandegenskaper än dagens krav, använda redundanta säkerhetssystem med hög tillförlitlighet, dela av ro-ro däcken i mindre rumsvolymer, förbättra brandisoleringen mellan vissa delar av fartyget, använda aktiva brandgaskontrollsystem, etc. Inte minst viktigt har varit att utforma fartygets layout så att risken för brandspridning och konsekvenserna av en brand minskar. Dessutom har stor möda lagts vid en utformning som medger att passagerare enkelt skall kunna orientera sig ombord och snabbt skall kunna utrymma.

Utöver detta har det s.k. ”safe area” konceptet tillämpats på fartyget. Det innebär att alla delar av fartyget, utanför den vertikala brandzon där en brand startar, skall vara säkra för passagerare och att basala funktioner för att erbjuda passagerarna sanitet, värme, vatten, mat, sjukvård, etc skall finnas.

Sökord: Fartyg, brandskydd, brand, säkerhet.

1 Introduction

1.1 Scope

The main objective under WP 7 of the DESSO project has been to improve fire safety on ro-pax ships by minimising the growth and spread of fire from its point of initiation, and maximise the time one can survive on the burning ship.

One ultimate goal of the project is that the conceptual design of the DESSO ROPAX should have fire safety level better than "state of the art".

Such improvements can be achieved through an astute design and lay-out of the ship, judicious selection of material in order to minimising the growth and spread of fire, rapid fire detection and response, coupled to fire mitigation or a combination of these activities. It is imperative that the reliability of active fire protection measures, such as fire detection systems or sprinkler systems, is high. This will require additional redundancy beyond the present regulatory requirements.

The starting point for the work is that all prescriptive requirements given in SOLAS Chapter II-2, the FTP Code, the FSS Code and other relevant documents should be fulfilled. Measures for improving fire safety beyond this level shall, preferably, be:

- realistic,
- simple and achievable, and,
- cost effective.

The work has focused on three main areas on board a ro-pax ship, namely the:

- accommodation and service spaces,
- machinery spaces, and,
- ro-ro cargo decks (defined as "special category spaces").

In WP 2, an analysis [1] of the damage due to fires, the risk for fire spread and consequences of such spread for two disastrous ship fires, the fire on board Scandinavian Star in 1990 and the fire on board Silver Ray in 2002, have been carried out. This analysis was made in order to identify key event chain breakers, which provide the greatest potential benefit for improvements.

1.2 Fire safety measures on board ro-pax ships – the principles

1.2.1 Present regulatory requirements

The fire safety on board modern ro-pax ships relies on a series of measures, which may be summarised as follows:

- **Preventing fire from occurring.** This is achieved, for example, by using spray shields around flanges on pipes for fuel and lubrication oil, thermal insulation of hot surfaces, the use of combustible material with restricted ignitability, minimization of the possibility of ignition of flammable cargo vapour, etc.

- **Early fire detection.** A fixed fire detection system as well as manually operated call points is required throughout the ship.

- **Fire patrols.** Crew regularly patrol the ship which facilitates both the possibility of detecting a fire as well as manual fire fighting.

- **Manual fire fighting.** Fire mains, with hydrants and hoses as well as portable fire extinguishers aid the possibilities for fighting a fire manually.

- **Limiting the growth of fire and the generation of toxic gas.** The use of non-combustible material and surface lining material with low flame-spread characteristics and limited production of smoke and toxic gases limits the growth of a fire and the generation of toxic products.

- **Fixed fire fighting systems.** Almost all spaces on board a ro-pax ship require fixed fire fighting systems with either automatic or manual activation.

- **Preventing the spread of smoke.** Closure of fire doors and the ventilation system will prevent or limit the spread of smoke.

- **Preventing fire from spreading.** The ship shall be subdivided by thermal and structural boundaries using “A” class and “B” class divisions.

- **Means of egress.** Safe escape routes for passengers and crewmembers shall be provided.

Obviously, the management of the ship as well as the skill and training of the crewmembers are important, however, such considerations are outside the scope of this project.

1.2.2 Guidelines for alternative design and arrangements

The revised SOLAS chapter II-2, *Construction - Fire protection, fire detection and fire extinction*, of the International Convention for the Safety of Life at Sea (SOLAS), 1974 and its related Fire Safety Systems Code that entered into force in July 1, 2002 is intended to be clear, concise and user-friendly, incorporating substantial changes introduced in recent years following a number of serious fire casualties [2].

The changes included a new Part F, *Alternative design and arrangements*, which addresses the requirements for engineering analyses conducted in support of an alternative design.

To complement the new Part F, the Maritime Safety Committee (MSC) published MSC/Circ.1002, *Guidelines on alternative design and arrangements for fire safety*, in June 2001.

The guidelines given in MSC/Circ.1002 are intended for the application of fire safety engineering design to provide technical justification for alternative design and arrangements to the prescriptive requirements in SOLAS chapter II-2. The guidelines outline the methodology for the engineering analysis required by SOLAS regulation II-2/17 “Alternative design and arrangements”, applying to a specific fire safety system, design or arrangement.

The guidelines address the requirements for engineering analysis, including preliminary analysis, development of fire scenarios and performance criteria, quantitative analysis, evaluation of trial designs and documentation requirements [3].

One very important aspect of any alternative design following these guidelines is the establishment of a design team with fire safety engineering expertise, communicating with the maritime administration having jurisdiction and preparing the necessary documentation.

In addition, the approving administration should report relevant information about the approved alternative design to the IMO for circulation to member governments.

The guidelines are not intended to be used as a stand alone document, but should be used in conjunction with fire safety engineering design guides and engineering literature acceptable to the maritime administration, for example the SFPE Handbook on Fire Protection Engineering or the International Standards Organisation (ISO) fire safety engineering standards ISO/TR 13387-1 to 13387-8.

1.2.3 Upcoming regulatory requirements

1.2.3.1 The safe area concept

Future large passenger ships should be designed for improved survivability so that, in the event of a casualty, passengers and crew members can stay safely on board as the ship proceeds to port. Fire protection and prevention measures are therefore currently considered in order to minimizing the need to abandon the ship.

One important measure to achieve improved survivability is the “safe area” concept. At its seventy-eighth session [4] in May 2004 the Maritime Safety Committee (MSC) agreed to the following definition:

”Safe area in the context of a fire casualty, is, from the perspective of habitability, any area outside the main vertical zone(s) in which a fire has occurred such that it can safely accommodate all the persons onboard to protect them from hazards to life or health and provide them with basic services”.

From this definition, it is clear that the “safe area” is not intended to be a single area or space outside the main vertical zone affected by the fire. It can also be assumed that a fire has resulted in the loss of the main vertical zone in which it has occurred.

MSC 78 endorsed the Fire Protection Sub-Committee to develop functional requirements, fire scenarios and performance standards in support of the “safe area” concept. At its forty-ninth session [5] in January 2005 the Fire Protection Sub-Committee agreed on the following text relating to the size and location of a “safe area”:

”The safe area should generally be an internal space, however, the use of an external space as a safe area may be allowed by any Administration taking into account any restriction to the area of operation and relevant expected environmental conditions”

The group also agreed on the following functional requirements:

"The safe area(s) should provide all occupants with the following basic services to ensure that the health of the passengers and crew are maintained:

1. *sanitation;*
2. *water;*
3. *food;*
4. *alternative space for medical care;*
5. *shelter from the weather;*
6. *means preventing heat stress and hypothermia;*
7. *light;*
8. *ventilation;*
9. *internal communications, such as public address systems, internal phones, radio communications and battery powered voice amplifiers; and*
10. *adequate rest facilities."*

The intention is that the safe area(s) should keep the passengers and crew members safe from a fire. This intent was described using the following text:

"The amount of smoke and hot gases reaching the safe area should be limited through the use of ventilation design, smoke barriers, etc."

It was also recognized that in the event of abandoning a vessel, the availability of and access to all possible means of escape should be ensured. This intent was described using the following text:

"Adequate means of egress/escape to life saving appliances should be provided from each area identified or used as a safe area taking into account that a main vertical zone may not be available for internal transit."

1.2.3.2 On-board safety centre

Although the monitoring and control of several safety systems can be carried out from the navigation bridge, should an emergency occur, a situation may develop where management of the emergency could distract watch officer from the navigational duties. Therefore, the provision of a "safety centre" adjacent to or within, but distinct from the navigation bridge, could assist in the management of an emergency. The intent has been described using the following text.

"Safety centre is a control station dedicated to management of emergency situations. Safety systems control and/or monitoring is an integral part of the safety centre."

"The following safety systems shall be capable of being controlled and/or monitored, as appropriate, from the safety centre:

1. *power ventilation system;*
2. *fire doors;*

3. *machinery spaces fire doors;*
4. *general emergency alarm system;*
5. *public address system;*
6. *evacuation guidance system;*
7. *watertight and semi-watertight doors;*
8. *indicators for shell doors, loading doors and other closing appliances;*
9. *water leakage of inner outer and bow doors, stern doors and other shell doors;*
10. *television surveillance system;*
11. *fire detection alarm system;*
12. *fixed local application system;*
13. *sprinkler system;*
14. *water based systems for machinery spaces and pump-rooms;*
15. *equivalent sprinkler systems;*
16. *alarm to summon the crew;*
17. *ventilation system for closed vehicle spaces, closed ro-ro spaces and special category spaces;*
18. *fire dampers, where a centralised control is foreseen;*
19. *activation ed of fixed fire extinguishing systems in general;*
20. *ER ventilation systems;*
21. *bilge system;*
22. *doors to restricted areas;*
23. *atrium smoke extraction system.*

Where the safety centre is located outside the navigation bridge, duplications monitoring/control functions required to be located at the navigating bridge or in a continuously manned control station shall be provided."

Discussions within IMO are currently ongoing in order to further develop the functional requirements and performance standards in support of the "safe area" concept [6].

1.3 The content of this report

Based on the results of this initial study, the current requirements of Chapter II-2 of SOLAS, the FSS Code, the FTP Code, etc for the specific type of ship and the associated fire test procedures related to the three categories of spaces described above have been summarised. This summary is given in Appendix A of the report.

It is expected that improved fire prevention, detection and mitigation will require high standards of design and that changes will be suggested to better address a modern sea situation to enable performance of a ship as its own lifeboat. The prescriptive requirements given in the documents described above have therefore been analysed and their utility determined. The outcome is presented within the report.

Computational Fluid Dynamics (CFD) modelling has been used to demonstrate the effects, temperatures and smoke spread from fires in ro-ro cargo decks and the effect from water-based fire protection systems. The outcome from the study is presented within the report, refer to Appendix B.

An experimental survey of the fire characteristics of six mattresses, five of which are approved according to SOLAS regulations for use on passenger ships, i.e. FTP Code Part 9, has also been undertaken, refer to Appendix C. The full-scale test followed a recently adopted Swedish standard for fire safety of mattresses in health-care applications, SS 876 00 10. Two of the approved mattresses failed according to the full-scale criteria, one due to too high smoke production and one due to too high heat release and smoke production. The other three mattresses showed good fire performance and two of them present a very high level of fire safety.

Computational Fluid Dynamics (CFD) modelling was also used to design an active smoke control system for the accommodation spaces of the ship, refer to Appendix D.

The detailed fire protection design of the concept ship is described within this report. In addition, fire protection features such as the location of the Main Vertical Zones, the sprinkler system piping, the fire barriers on the ro-ro cargo decks, the ventilation ducts for the active smoke control system, etc. are given in the drawing of the ship.

1.4 A general description of the DESSO ROPAX

The DESSO ROPAX contains eight decks, including three decks for accommodation and service for the passengers and three ro-ro cargo decks. Given below are the main statistics:

Dimensions
L.O.A.: 189,5 m
L.B.P.: 179,5 m
B.O.A.: 32,1 m

Depth to dk 1: 3,75 m
Depth to dk 2: 10,0 m
Depth to dk 3: 15,95 m
Depth to dk 4: 21,40 m

Design draft: 6,80 m
Scantling draft: 7,00 m

DWTmax: abt. 8 000 t

Main engines: abt. 28 000 kW

Speed
Service Speed at 6,8 m: abt. 24 kn. 85% MCR.

Cargo Deck Loads

Axle load: 15 t.

Uniform load: Deck 1 and 2: 3 t/sqm.
Deck 3 and 4: 2,2 t/sqm.

Capacities, trailer lane meter
Deck 1: 410 lm
Deck 2: 1214 lm
Deck 3: 1376 lm
Deck 5: 400 lm
Total: 3 400 lm

Accommodation
Passengers total: 1 500 pax
Air seats: 300 seats
Cabins (2+2): 250 cabins
Crew cabins: 67 cabins

2 Accommodation and service spaces

2.1 Introduction

Fire within the accommodation and service spaces on board a ship will put many passengers at immediate risk. The following chapter describes the suggested fire safety approach made at the DESSO ROPAX for these spaces.

The first and foremost objective has been to improve the fire characteristics of combustibles as compared to the present regulatory requirements. All bedding material and all electrical cables fulfil requirements in excess of present requirements.

The means for escape has been improved through a simplistic lay-out of the cabin and corridors and all stairways lead directly to the internal assembly stations at the deck above the accommodation spaces. These spaces are considered ‘safe areas’ and can safely accommodate all the persons onboard to protect them from hazards to life or health and provide them with basic services.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems have been enhanced through improvements to design, performance, reliability and redundancy.

The use of an active smoke control system in the spaces will limit the spread of smoke and improve the possibilities for manual fire fighting.

2.2 Furniture and furnishings

2.2.1 Wall and ceiling linings

Today’s wall and ceiling surface linings consist of very thin, of the order of 50 to 150 µm, coatings. These coatings meet high standards for interior finishes, exhibiting good appearance (many different colours and printed patterns, are available), scratch resistance, reparability, etc. The film is bonded at high temperature to the top surface of the sheet steel. These coatings have good fire characteristics, well exceeding the present regulatory requirements due to the limited amount of combustibles.

However, concerns about the toxicity of PVC have prompted the development of several PVC-free alternatives from different manufacturers. These coatings are typically made from HMP or PET film.

For the DESSO ROPAX, PVC-free coatings will be used. In all other aspects the wall and ceiling linings will comply with the present regulatory requirements.

2.2.2 Floor coverings

The fire restrictions of floor coverings and primary deck coverings are specified in the FTP code. Approved material will not easily ignite or spread a fire. Neither will they give rise to smoke or toxic hazard at elevated temperature. The DESSO ROPAX floor coverings and primary deck coverings will comply with the present regulatory requirements.

2.2.3 Bedding components and upholstered furniture

For a passenger or crew cabin the mattress and the bedding components probably constitute the highest fire load of all items inside the cabin. It is therefore important that these components have as high resistance to ignition and flame spread as possible.

The fire tests described in Appendix C of this report indicate that compliance with the present regulatory requirements is not a guarantee that mattresses will not burn severely when ignited with a larger fire ignition source.

For the DESSO ROPAX "fire-resistant" mattresses are chosen, mattress that fulfill the requirements of SS 876 00 10, "Health care textiles - Fire requirements - Extra high resistance to ignition of mattresses intended for special purposes" [7] and therefore provide high protection against arson and decreased risk of rapid fire development in the cabins.

2.3 Electrical cables

There is limited information in SOLAS on the fire performance of electrical cables. Some requirements exist for cables in cargo spaces that can store dangerous goods but this is mainly protection against ignition.

Onboard a ship, many kilometres of cables are installed, from large power lines to small communication wires for all kinds of signals. There is always a risk of a fire starting in cables due to electrical shortage but the cables themselves also constitute a significant risk in case of fire, due to their high energy content (plastic) and the potency of creating large amounts of smoke while burning. They also represent a risk of fire spread through penetrations in main vertical fire zones.

Recently a proposal with new fire safety requirements for electrical cables in buildings was accepted by the European Commission (EN50399-1, $FIPEC_{20}$ Scenario 1 or 2). The system is yet to be finally implemented in the CPD regulations (Constructions Products Directive) but this will happen during 2006. The cables on board DESSO ROPAX should follow the requirements according to this system and comply with at least Euroclass C_{CA}-s1-d0. This means that the cables will not easily spread a fire themselves and the amount of smoke produced will be limited.

Concerning smoke toxicity the requirements are not set at this moment but if this demand is introduced in the CPD the DESSO ROPAX cables should comply with the highest class.

2.4 Fire detection and alarm

2.4.1 Fixed fire detection system

In addition to the requirements set out in SOLAS Chapter 2-II and in Chapter 9 of the FSS Code, the following measures have been taken on the DESSO ROPAX:

- Dual function / combination detectors are used throughout the accommodation and service spaces. These detectors detect both smoke and heat. In case of maintenance or other operations, which cause smoke or similar disturbances, disconnection of detectors might be desired. In such cases it is possible to temporarily disconnect the smoke detection function (only), leaving the heat detection active. The combination of smoke / heat sensors in the same combi-detectors is also used to automatically make the smoke sensing part of the detector more sensitive in case there is a temperature increase. The purpose of combining sensors in this way is to enhance the detection performance or its resistance to certain types of phenomena likely to cause a false alarm or both.

- Each detector is constantly adjusting its fire alarm / pre-alarm limit in relation to the surrounding environment. This ensures fast response for actual fires combined with high immunity to un-wanted alarms.

- The system is of a type capable of remotely and individually identifying each detector, i.e. an analogue, addressable system[1]. This will reduce the time necessary to identify the location of the fire.

- The system is designed as a "hot-standby" distributed system. In line with the safe areas concept, each distributed central covers one Main Vertical Zone. All distributed centrals are constantly updated with all information of the complete system. Should one distributed central be malfunction another central automatically takes over its tasks.

- Buzzers are installed inside each passenger and crew cabin, which emit an audible alarm[2] in the space. This will provide a very early warning for people in direct danger of exposure to a fire. Passenger cabins intended for disabled people are additionally fitted with flashlights.

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[1] Analogue, addressable systems fire detection systems are, although not required in the present regulatory requirements, common practice on board modern ships.

[2] About one-third of people over the age 70 have some form of hearing impairment and only 34% of those with hearing difficulties use hearing aids. Research shows that the frequency of residential smoke alarm horns typically range from 3,5 to 4 kHz, which is the same range in which older adults experience greater hearing loss. Lowering the frequency of an alarm horn, for example below 2 kHz, may make the sound audible for a much larger percentage of older adults. This is supported by research, including one study, which showed an improved performance in detection and localisation of an alarm sound if the sound decreased from 4 to 5 kHz and had a fast modulation rate. Source: "Setting the tone", Fire Prevention & Fire Engineers Journal, March 2005, pp. 30 - 32.

The fire detection system integrates with the supervision and control of fire doors, fire dampers, fans, the sprinkler systems, etc and the status of all functions is presented graphically at the navigation bridge.

2.4.2 Manually operated call points

Manually operated call points (i.e. alarm press buttons) complying with the FSS Code shall be installed throughout the accommodation spaces, service spaces and control stations. One manually operated call point shall be located at each exit. Manually operated call points shall be readily accessible in the corridors of each deck such that no part of the corridor is more than 20 m from a manually operated call point.

2.4.3 Notification of crew and passengers

To notify the crew and passengers of a fire for safe evacuation a general emergency alarm and public address system shall be provided as per the regulatory SOLAS requirements.

A public address system or other effective means of communication shall be available throughout the accommodation and service spaces, controls stations and open decks.

It is essential that the fire alarm and communications systems provide continuous, reliable and accurate information on life safety conditions.

2.5 Control of smoke spread

2.5.1 General

In addition to the regulatory SOLAS requirements the DESSO ROPAX should be designed to meet the guidelines for smoke control and ventilation systems for internal assembly stations and atriums contained in MSC/Circ. 1034. However, it is considered important that all accommodation and service spaces on the DESSO ROPAX have passive and active smoke control systems beyond the present regulatory requirements.

Passive smoke control implies the utilization of built-in barriers within the ship, as stipulated in SOLAS, such as fire resistant divisions at the main vertical zones, fire doors, draught stops and fire dampers in order to enclose the fire area and prevent smoke from spreading.

Active smoke control implies the utilization of mechanically created pressure differentials and flows between smoke control zones in order to prevent smoke from spreading as well as to remove smoke from the ship by extraction.

2.5.2 Passive smoke control

Each group of passenger cabins contains three parallel and separate corridors. The separation of the corridors will limit the number of cabins directly affected by smoke and toxic gases in case of fire.

The stairways lead directly to the internal assembly stations at the deck above the accommodation spaces.

The accommodation spaces for the crew are design in a similar manner. Each group of crew cabins contains two parallel and separate corridors.

2.5.3 Active smoke control

2.5.3.1 Active smoke control for the accommodation spaces

The philosophy for the active smoke control system [8, 9, 10] for the passenger accommodation spaces is that smoke should be extracted from the escape routes, i.e. the corridors, in order to keep them sufficiently free from smoke and toxic gases. Stairway enclosures and surrounding areas should be kept under overpressure by the ventilation supply air system in order to prevent smoke from spreading to these areas.

This philosophy, which is illustrated in figure 1, will improve the possibilities for safe evacuation of the passengers and allow for manual fire-fighting. Note that this system assumes that the fire is controlled within a rather short time, it is not intended to work for uncontrolled fires over a longer period of time.

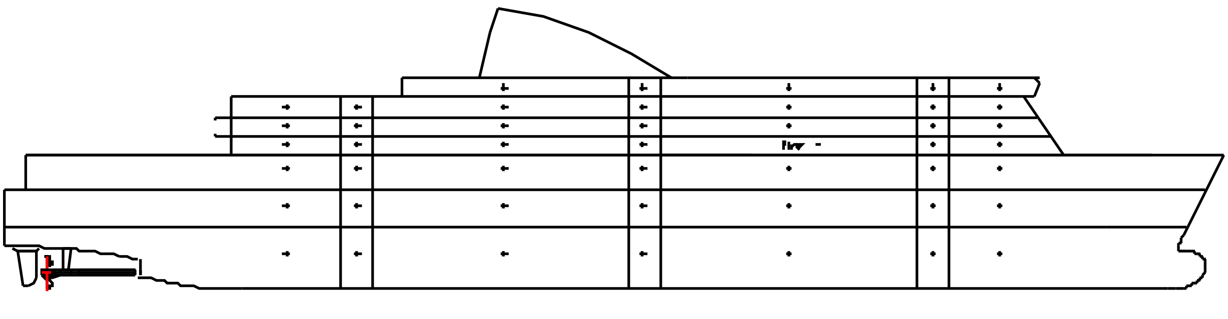

Figure 1 The philosophy of the active smoke control system for the accommodation spaces is that smoke should be extracted from the escape routes, i.e. the corridors. Stairway enclosures and surrounding areas should be kept under overpressure by the ventilation supply air system in order to prevent smoke from spreading to these areas.

The extraction of smoke from the corridors should be made by a dedicated ventilation system. The system is made relatively simple with a single, vertical ventilation shaft serving accommodation spaces on each of the decks. For every deck, a horizontal duct with a fire damper is connected to the shaft. Alternative arrangements are possible using separate ducts for each deck in order to avoid a complicated fire damper control system. Under normal conditions, all fire dampers are closed and the smoke extraction fan(s) are off. During fire conditions, the fire damper at the correct deck level is opened and the fan(s) are started. The ventilation system would only serve one main vertical zone, which would make any unwanted smoke spread to other fire zones impossible.

The exhausts are placed at the ceiling in order to have the best effect, since hot gases are concentrated at the ceiling. In addition, a high placement decreases the amount of fresh air that is extracted.

For the provision of replacement air and over-pressurization, the staircases at the ends of the corridor should be over-pressurized to allow sufficient inflow through the door openings. In addition, the ordinary HVAC system ducts and fans should be used to provide replacement air for the area where the smoke extraction system is started. Air is distributed through both the supply and the exhaust ducts. This is also the technique used for the over-pressurization of the adjacent spaces.

The actuation of the smoke control system should be made automatically, with the possibility for manual actuation, if considered necessary. The fixed fire detection system as described under Chapter 2.4.1 will assure the actuation of the system when smoke is detected in the corridors.

Fans and motors for the smoke extraction system should be designed for their purpose and fulfil the requirements of for example EN 12101-3, "Smoke and heat control systems - Part 3: Specification for powered smoke and heat exhaust ventilators". Positioning of the fans should be made to minimise the risk of smoke entering the fresh air intakes or assembly stations on deck 6. Starboard/port redundancy using duplicated fans is recommended.

The accommodation spaces for the crew are not fitted with an active smoke control system.

The proposals made in this chapter should be more thoroughly evaluated before being directly applied in practice. A case study simulation is presented in Appendix D.

2.5.3.2 Active smoke control for public spaces and service spaces

The active smoke control system for the public and service spaces are designed similarly to the system for the accommodation spaces, as described above.

2.5.3.3 Active smoke control for internal assembly stations

The active smoke control system for the internal assembly spaces is designed in accordance with the guidelines in MSC/Circ. 1034. The intention of the guidelines is to prevent smoke from entering the space and to maintain a positive pressure relative to the surrounding spaces. It should be verified that the positive pressure does not impair the operation of the escape doors.

Intakes for fresh-air should be doubled and positioned low so that any side of the ship can be selected depending on the wind direction, to prevent smoke from entering the fresh-air system.

The active smoke control and the ventilation system should be manually operated only. The control panel should be located in a central control station.

2.6 Fixed fire fighting system

2.6.1 General

The accommodation and service spaces on board the DESSO ROPAX will be protected by a high-pressure water mist system. The basic philosophy is that all spaces on the ship, the accommodation and service spaces, the machinery spaces and the ro-ro cargo decks are protected with the same type system. This will facilitate the installation and it provides the possibility to use the same water supply for the overall ship.

Spaces containing flammable liquids, such as paint lockers, will be protected with the same high-pressure water mist system protecting the rest of the ship. The system shall be operable from outside of the protected space.

Deep-fat cooking equipment shall be fitted with an automatic or manual fire-extinguishing system tested to the international standard ISO 15371:2000, have a primary and back-up thermostat to alert the operator in the event of failure of either thermostat and arrangements for automatically shutting down electrical power upon the activation of the fire-extinguishing system. Even these hazards are protected by the main high-pressure water mist system.

Ventilation ducts from the laundry and from the galley have nozzles, activated from heat detectors inside the duct.

2.6.2 The sectioning of the system

Each deck is divided into three sections, corresponding to the main vertical zones. The two rear sections on each deck include the accommodation area and staircase, the front sections only the accommodation and service areas.

2.6.3 Nozzle coverage areas and water discharge densities

The nozzle coverage areas and water discharge densities for high-pressure water mist systems; and other type systems considered as ‘equivalent’ to traditional sprinkler systems, are determined using the fire test procedures in IMO Resolution A.800(19).

The nozzle coverage areas and water discharge densities may therefore vary with the make of the system, and, in addition, the nozzle coverage areas and water discharge densities will vary with the hazard, i.e. the type of space. For example, storage spaces will require less nozzle coverage areas and higher water discharge densities compared to accommodation areas.

For accommodation and service spaces, the system should be designed for an area of operation corresponding to 280 m^2.

Table 1 provides a summary of the maximum nozzle coverage areas, the water discharge densities and the associated nominal total water flow rate for the DESSO ROPAX.

Table 1 The maximum nozzle coverage areas, water discharge densities and associated nominal total water flow rate for the accommodation and service spaces on board the DESSO ROPAX.

Deck	Space	Maximum nozzle coverage area [m^2]	Nominal water discharge density [mm/min]	Nominal total water flow rate* [L/min]
4	Passenger accommodation spaces, including stairwells	12	2	670
	Passenger seating areas, including cafeteria	12	2	670
	Laundry and store areas	9	3	1010
5	Passenger accommodation spaces, including stairwells	12	2	670
	Officer and crew mess	12	2	670
	Galley	9	3	1010
6	Restaurants, cinema and other public spaces	12	2	670
	Shops	9	3	1010
7	Crew accommodation and navigation bridge	12	2	670

*) The nominal total water flow rate was calculated as the [nominal water discharge density] × [280 m^2 operating area] × 1,2. The factor 1,2 represents the increase in total water flow rate, from the theoretical minimum, as nozzles usually are installed closer than their maximum nozzle coverage area and due to hydraulic imbalances in the piping system.

From Table 1 it can be determined that the design water flow rate for the accommodation and service spaces equals 1010 L/min.

2.6.4 The pump units and the water supply

The high-pressure system used for the ship has two redundant high-pressure pump units, each having 100% capacity, i.e. 2 x 100% capacity. Each pump unit consists of multiple pumps, driven by several electrical motors. Any failure of a single pump or a single electrical motor is therefore not detrimental to the function of the pump unit.

The pump units are located on Deck 0, in separate rooms, positioned on opposite sides of the ships. Each pump unit is connected to two separate fresh water tanks, with a possibility to switch over from one tank to the other.

2.6.5 Improvements beyond the present regulatory requirements

The system will comply with the installation guidelines, component tests and fire test procedures in IMO Resolution A.800(19). The installation requirements for such equivalent systems are in principle identical with the requirements in Chapter 8 of the FSS Code. However, the following improvements are made:

- It is required in the present resolution that the water supply shall equal a discharge duration time of at least 30 minutes. However, for the DESSO ROPAX, the discharge time (using fresh water) has been extended to 60 minutes. After this time the usual switch over to the sea water inlet is possible.

- The high-pressure pump unit is started upon a signal from the fire detection system, in order to have the system fully pressurised at the activation of the first sprinkler. In addition, it should be possible to manually start the high-pressure pump unit from the navigation bridge, if considered necessary.

- SOLAS Chapter II-2, regulation 10 allow that spaces having little or no fire risk, such as voids, public toilets, carbon dioxide rooms and similar spaces not to be fitted with sprinklers. However, in order to improve the level of fire safety, all such spaces on board the DESSO ROPAX are fitted with automatic nozzles.

- For the navigation bridge, where water may cause damage to essential equipment, a pre-action[3] type system will be used.

2.7 Fire mains and hydrants

The number, position and capacity of hydrants shall fulfill the present regulatory requirements; however, the hydrants shall be of the automatic fire hose reel type with 33 mm semi-rigid hose. The fire hose reels should be positioned inside cabinets where the doors should open approximately 180° to allow the hose to run freely in any direction.

The fire pumps should be started upon a signal from the fire detection system, in order to have the fire mains fully pressurised up to the inlet stop valve of the fire hose reels. In addition, it should be possible to manually start the fire pumps from the navigation bridge.

The benefit of the suggested solution is that it will reduce the time to tackle a fire.

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[3] A pre-action water mist system is defined as “A water mist system using automatic nozzles attached to a piping system that contain air that might or might not be under pressure, with a supplemental detection system installed in the same areas as the mist nozzles. The actuation of the detection systems opens a valve that allows water to flow into the piping system and discharges through all opened nozzles in the system” in the 2003 edition of NFPA 750, *Standard on Water Mist Fire Protection Systems.*

2.8 Means of escape

2.8.1 Introduction

The intention is that the DESSO ROPAX should fulfil all the present regulatory requirements related to means of escape. However, no evacuation analyses as per the interim guidelines for evacuation analyses given MSC/Circ. 1033 have been conducted. Currently, the revision of MSC/Circ. 1033 is under discussion within IMO [11, 12].

2.8.2 The lay-out of the cabins and corridors

For the DESSO ROPAX, the lay-out of the cabins and corridors on the decks that contain the accommodation area has been optimised in order to simplify the orientation for the passengers and to provide easy access to the stairways positioned at the end of each corridor. Each group of passenger cabins contains three parallel and separate corridors. The separation of the corridors will limit the number of cabins directly affected by smoke and toxic gases in case of fire.

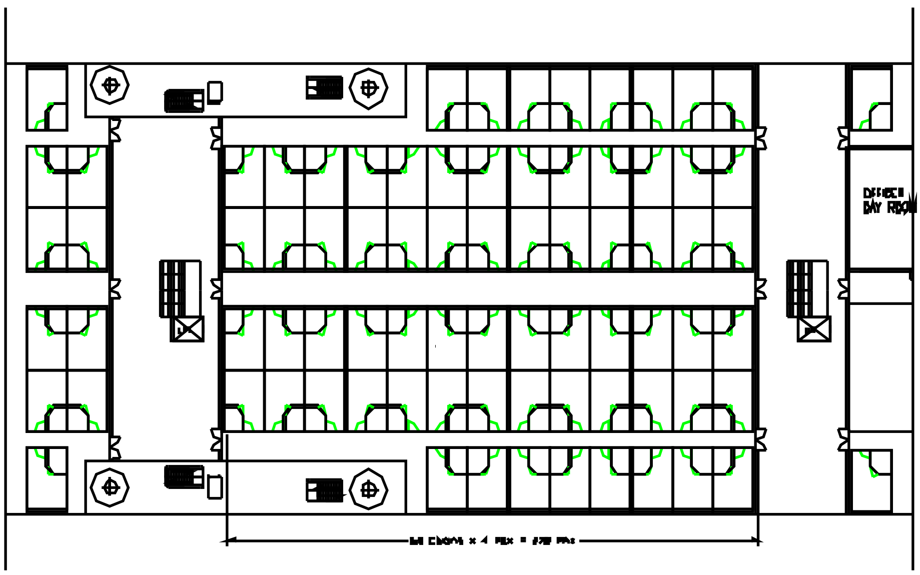

Figure 2 The principle lay-out of the cabins and corridors.

The stairways lead directly to the internal assembly stations at the deck above the accommodation spaces.

2.8.3 The width of the stairways

The widths of the stairways were dimensioned in accordance with the requirements in Chapter 13 of the FSS Code. The basic requirement is that the stairways shall not be less than 900 mm in clear width and increased by 10 mm for every one person provided for in excess of 90 persons.

The total number of persons to be evacuated from the stairways shall be assumed to be two-thirds of the crew and the total number of passengers in the area served by the stairways.

Table 2 summarizes the estimated number of passengers and crew members on decks 4 and 5, in each of the main vertical zones on the deck, respectively.

Table 2 The estimated number of passengers and crew members on decks 4 and 5, in each of the main vertical zones on the deck, respectively.

Deck	Space	Number of passengers	Crew	Sum
4	Accommodation space	46 cabins × 4 pax. = 184	--	184
	Accommodation space	68 cabins × 4 pax. = 272	--	272
	Pullman seating area and service spaces	Approx. 500	20	520
		956 passengers	20 crew members	**976**
5	Accommodation space	46 cabins × 4 pax. = 184	--	184
	Accommodation space	68 cabins × 4 pax. = 272	--	272
	Accommodation space, crew area and galley	32 cabins × 4 pax. = 128	40	168
		584 passengers	40 crew members	**624**

The calculation of the stairway width shall be based upon crew and passenger load on each deck. The width of the stairways shall allow a timely flow of person evacuating from the decks below to the assembly stations on deck 6. For the DESSO ROPAX, the design of the width of the stairways is based on the situation that persons from two decks are using the stairways to reach the assembly stations.

The width of the stairways, when joining two decks shall be calculated using the following formula: $W = (N_1 + N_2) \times 10$ mm.

Where,

W = The required tread width between handrails of the stairway.

N = The total number of persons expected to use the stairway from each consecutive deck under consideration; N_1 is from the deck with the largest number of persons using the stairway; N_2 is taken from the deck with the next highest number of persons directly entering the stairway flow.

2.9 Containment of fire

2.9.1 General

In order to contain a fire in the space of origin, SOLAS Chapter II-2, regulation 9 specifies that the following three functional requirements shall be met:

1. the ship shall be subdivided by thermal and structural boundaries;
2. thermal insulation of the boundaries shall have due regard to the fire risk of the space and adjacent spaces; and
3. the fire integrity of the division shall be maintained at openings and penetrations.

2.9.2 Main vertical zones and horizontal zones

As per the present regulatory requirements.

2.9.3 Bulkheads within a main vertical zone

As per the present regulatory requirements.

2.10 Ventilation system

The ventilation system for the accommodation and service spaces should be designed as per the present regulatory requirements. However, an active smoke control system as described under Chapter 2.5 should be provided.

3 Machinery spaces

3.1 Introduction

About two-thirds of all fires on board ships start in the machinery space according to Det Norske Veritas (DNV). An estimation [13] made by DNV indicates that the direct cost for a fire is in the order of 1 - 4 million USD for a cargo vessel - and much more for a passenger vessel.

Statistics [14] from The Swedish Club from 1995 – 2004 reports 67 fires on board ships. Although few, they are very costly, amounting to 12% of the total damage cost for the period. The statistics indicate that almost half of all fires start in the engine room, but the share of the total cost is 67%. The average cost of the fires was 1 million USD.

Clearly, a fire in the machinery space also represents a hazard for the crew members and fire fighters and may lead to a situation where passengers need to be evacuated from the vessel.

For the DESSO ROPAX, a number of measures have been taken to improve the fire safety of the machinery spaces. First and foremost the fact that separate machinery space compartments are used represents an improvement.

Several different fire detection techniques are used in the machinery spaces, with the intention to detect a fire at an early stage, in a reliable fashion. The choice of fire detection techniques allows rapid detection of both flaming fires (flammable liquid spray fire or spill fires) and smouldering fires.

The high-pressure water mist system protecting the machinery space compartments activates automatically upon fire and a foam additive, of a film-forming type, should be mixed with the water using a foam proportioner, in certain sections of the system. The use of a foam additive enhances the performance on, e.g., flammable liquid fires.

3.2 The lay-out and position of the machinery space compartments

The DESSO ROPAX is equipped with four main diesel engines located inside four separate compartments, two compartments on each side of the ship. However, the two fore compartments are in open connection due to cross-flooding reasons.

3.3 Preventing fire from occurring

Measures in accordance with the present regulatory requirements should be taken.

3.4 Fire detection and alarm

SOLAS Chapter II-2, regulation 7.4 requires fire detectors to be positioned as to detect a fire rapidly. Smoke, heat and flame detectors are positioned so that they rapidly detect any fire in any part of the engine room spaces under any normal condition of operation of the machinery and variations of ventilation as required by the possible range of ambient temperatures. The use of only thermal detectors is not allowed. The detection system initiates audible and visual alarms in the main central panel on the navigation bridge. The alarm shall also sound in all distributed central panels as well as in repeater panels in the engine control room.

Additional flame detectors[4] are positioned above the top parts of the main engines.

The engine rooms are also supervised using standard closed-circuit television (CCTV). The video images are analysed using video smoke detection (VSD)[5] technology to automatically identify the presence of smoke in the engine room.

The activation of the fixed high-pressure water mist system installed in the machinery spaces is described under the section "Fixed fire fighting systems and equipment".

3.5 Control of smoke spread

SOLAS Chapter II-2, regulation 8 requires that Machinery spaces of category A shall have suitable arrangements to permit the release of smoke, in the event of fire. The normal ventilation system may be acceptable for this purpose.

Means of control shall be located outside the space. For passenger ships, the controls shall be positioned at one control position or grouped in as few positions as possible. Such positions shall have a safe access from the open deck.

For control stations outside machinery spaces, practical measures shall be taken to ensure that the ventilation, visibility and freedom from smoke is maintained so that, in the event of fire, the machinery and equipment contained therein may be supervised and continue to function effectively.

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[4] Flame detectors are designed to detect either the ultraviolet (UV) or infra-red (IR) radiation emitted by a fire and these types of detector can detect even gas fires which are not visible to the naked eye. They are effective in protecting areas where open flaming fires may be expected or where detection needs to be unaffected by air currents and tolerant of fumes, vapors and dust.

[5] Video smoke detection (VSD) technology was developed in the late 1990s and is a camera based fire detection system. Video images from standard closed-circuit television (CCTV) cameras are continuously analysed using advanced image processing technology and extensive detection and known false-alarm phenomena algorithms. The technology is able to identify the particular motion pattern of smoke and does not rely on the proximity of smoke to the detector. The effectiveness is therefore not affected by distance and can accurately detect smoke patterns and differentiate between them and other movement patterns. Source: "Picture perfect", Fire Prevention & Fire Engineers Journal, October 2005, p. 50.

The approach taken on the DESSO ROPAX is that the present regulatory requirements should be fulfilled.

3.6 Fixed fire fighting system

3.6.1 General

Traditionally, Halon and Carbon Dioxide (CO_2) gas extinguishing systems are those most commonly used in machinery spaces. With the phase-out of Halon and the increasing safety concerns regarding the use of CO_2, the need for alternative extinguishing agents has emerged. The developments during the 1990s have shown that water mist has the potential to replace, or to provide an alternative to, traditional fire protection systems. Water has many advantages as a fire extinguishant; it is inexpensive, non-toxic, and safe for personnel and does not represent a risk to the external environment.

3.6.2 The sectioning of the system

Each of the four main machinery spaces are protected by a system divided into three sections:

Section 1: One level of nozzles in the bilge area and one level of nozzles at mid-height of the machinery space compartment[6]. A foam additive of a film-forming type should be mixed to the water using a foam proportioner to this section of the system. The use of a foam additive enhances the performance on flammable liquid fires. The foam supply should be sufficient for a 15-minute duration time.
Section 2: One level of nozzles above the top of the engine[7].
Section 3: Multiple levels of nozzle throughout the casing[8].

Note: For passenger ships of 500 gross tonnage and above, and cargo ships of 2000 gross tonnage and above, Machinery spaces of category A, in excess of 500 m^3, shall, in addition to the 'total flooding system', be protected by an approved type of water-based or equivalent local application fire-extinguishing system. Section 2 of the system will address this regulatory requirement. The activation of the local application fire-extinguishing system should not require the engine shutdown, closing of fuel tank outlet valves, evacuation of personnel and sealing of the space.

Section valves for the entire system are positioned directly outside the machinery spaces and additional activation buttons are positioned inside the space, close to the

[6] Section 1 provides protection against fires in flammable liquid pool fires on and under the bilge plates of the machinery space compartment.

[7] Section 2 provides protection against flammable liquid spray fires, or similar fires, originating from pressurised flammable liquids igniting on hot surfaces on and around the engine.

[8] Section 3 provides protection against fire spreading up the casing.

emergency exit, as per the present regulatory requirements. These measures will provide means for manual activation of the system by crew member inside and directly outside the protected space.

Additional system activations buttons and system control panels are positioned on the navigation bridge and at the onboard safety centre(s). Note: The DESSO ROPAX has no “engine control room” at Deck 1; engine control is featured at the navigation bridge.

Means for automatic activation of the system is provided, upon signal from two independent fire detectors inside the space. Prior to the activation of the entire system, the engine is shutdown, all outlet valves for fuel, and other flammable liquids, are automatically closed, ventilation dampers are closed and fans are stopped.

3.6.3 Other protected spaces on decks 0 and 1

In addition to the protection of the main machinery spaces, the following spaces on decks 0 and 1 are provided with an automatic fire-fighting system (deluge type system or individually activated glass bulb nozzles, as indicated):

1) Purifier rooms (deluge type system),
2) Boiler rooms (deluge type system),
3) Workshops[9] (automatic nozzles),
4) Bow thrusters and pump rooms (deluge type system),
5) Steering gears (automatic nozzles), and,
6) Auxiliary spaces (automatic nozzles).

3.6.4 The pump units and the water supply

Refer to chapter 2.6.4.

[9] Additional nozzles are positioned above the area used for Hot Work.

4 Ro-ro cargo spaces

4.1 Introduction

Fires on ro-ro cargo decks are rare and, historically, have not represented a major risk for passenger and crew. However, the property loss can be large if the fire is not manually extinguished or if the fixed fire-fighting system fails to control the fire. There are cases where a fire has spread throughout the ship [15].

The ro-ro cargo spaces on the DESSO ROPAX are considered “special category spaces”, i.e. enclosed spaces on a deck intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion and to which the passengers have access. Therefore, SOLAS Chapter II-2, Regulation 20 requires that the deck shall be protected with an approved deluge type sprinkler system. Other types of fixed fire-fighting systems are in principle not allowed, due to the safety concerns for the passengers.

The main improvement on the DESSO ROPAX has been made by sub-dividing the ro-ro cargo spaces into smaller volumes by active fire-resistant smoke and fire barriers (traditionally known as fire curtains). These fire barriers are shut upon completion of loading and open during loading and unloading of the deck. Furthermore, the fire resistance between the individual ro-ro cargo decks and the ro-ro deck and the division between the upper ro-ro deck and the accommodation spaces above this deck has been improved.

In addition, it is possible to remotely close the aft port and the internal hoistable ramps in case of fire. The reason for the measures described above is to limit the availability of air to a fire and thereby reduce its size.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems, have been enhanced through improvements to design, performance, reliability and redundancy. The high-pressure water mist system is automatic and the pump capacity is sufficient to activate all the nozzles within the sub-divisions.

4.2 Fire detection and alarm

4.2.1 Fixed fire detection system

4.2.1.1 Detection of gas

The ro-ro decks are fitted with a fixed installed sequential gas sampling system in order to detect fumes from gasoline or diesel oil leaking from the vehicles on the deck.

4.2.1.2 Detection of fire

The ro-ro decks are fitted with an analogue addressable fire detection system using dual function / combination detectors. These detectors combine detection of smoke and heat. During loading or unloading or in case of maintenance or other operations, disconnection of part of the system may be desired. The smoke detection (only) function can, in such a case, be temporarily disconnected by means of a timer or by programming the central panel.

Each detector will cover a maximum area of 25 m^2, i.e. significantly less than the prescribed 37 m^2 (heat detectors) and 74 m^2 (smoke detectors). Detectors are installed with respect to the beams at the ceiling of each deck. The detectors are of normal IP55 type and to comply with SOLAS for enclosed ro-ro cargo space for carrying vehicles with fuel for their own propulsion the ventilation will ensure that at least 10 air changes per hour are made.

The activation of the fixed high-pressure water mist system installed on the ro-ro decks are described under section 4.3.

4.2.2 Manually operated call points

Manually operated call points are spaced so that no part of the space is more than 20 m from the manually operated call point, and one shall be placed close to each exit from such space, i.e. in accordance with the present regulatory requirements.

4.2.3 Fire patrols

As per the present regulatory requirements.

4.3 Fixed fire fighting system

4.3.1 General

The principle of the DESSO ROPAX is to use the same type system throughout the ship. The ro-ro decks will therefore be protected by a high-pressure water mist system.

4.3.2 The sectioning of the system

The system will be designed as a deluge type system, i.e. divided into sections where all nozzles within the section distribute water simultaneously. Each section correlates with the sub-division of the decks, respectively (see below).

4.3.3 Nozzle coverage areas and water discharge densities

Each nozzle cover a maximum area of 12 m^2 and the water discharge density equal 2,0 mm/min. The associated nominal total water flow rate for the ro-ro cargo spaces correlates with the sub-division of the decks, respectively.

Table 2 provides a summary of the maximum nozzle coverage areas, the water discharge densities and the associated nominal total water flow rate for the DESSO ROPAX.

Table 2 The size of the deluge sections, water discharge densities and associated nominal total water flow rate for the ro-ro cargo spaces on board the DESSO ROPAX.

Deck	Space	Size of section [m²]	Nominal water discharge density [mm/min]	Nominal total water flow rate* [L/min]
1	Lower hold (whole area)	1260	2,0	3020
2	Deck 2 (divided into three areas)	Rear section: 1550	2,0	3720
		Mid-section: 1400		3360
		Front section: 820		1970
3	Deck 3 (divided into three areas)	Rear section: 1550	2,0	3720
		Mid-section: 1400		3360
		Front section: 1450		3480

*) The nominal total water flow rate was calculated as the [nominal water discharge density] × [section area] × 1,2. The factor 1,2 represents the increase in total water flow rate, from the theoretical minimum, as nozzles usually are installed closer than their maximum nozzle coverage area and due to hydraulic imbalances in the piping system.

From Table 2 it can be determined that the design water flow rate for the ro-ro cargo spaces equals 3720 L/min. This is approximately 2/3 of the nominal total water flow rate used with a traditional deluge water spray system designed and installed in accordance with IMO Resolution A.123(V).

4.3.4 Improvements beyond the present regulatory requirements

The system shall have the possibilities to be both automatically or manually operated at any time:

- The system is automatically activated upon the detection of heat from a fire with a least two detectors within the section. The high-pressure pump unit is started upon a pre-alarm from the fire detection system, in order to have the system fully pressurised up to the section valve(s) minimize the delay time from automatic activation until water is discharged through the nozzles.

- The system is also possible to manually activate from any of the section valves or from the navigation bridge. The section valves for the system should be situated in an easy accessible position adjacent to, but outside the protected space.

- The system is always fully pressurised up to the section valve(s) during loading and unloading to minimize the delay time from automatic or manual activation until water is discharged through the nozzles.

- A foam additive of a film-forming type should be mixed to the water using a foam proportioner. The use of a foam additive enhances the performance on flammable liquid fires and fires in unexpanded plastics. The foam supply should be sufficient for a 15-minute duration time.

4.3.5 The pump units and the water supply

Refer to chapter 2.6.4.

4.4 Improving the fire resistance of decks and bulkheads

4.4.1 Sub-division of each of the ro-ro decks

The ro-ro decks on Deck 2 (the main deck) and Deck 3 is subdivided by active fire-resistant smoke and fire barriers (traditionally known as curtains) into smaller volumes. The volume of Deck 1 is lesser and this deck is therefore not sub-divided. The barriers[10] are moved into their fire operational position during loading and opened during unloading of the decks.

In addition, it should be possible to remotely close the aft port and the internal hoistable ramps in case of fire. The reason for the measures described above is to limit the availability of air to a fire.

4.4.2 Improving the fire resistance between the individual ro-ro decks and adjacent spaces

Except for the cases where a category (5)[11], (9)[12] or (10)[13] space is on one side of the division, “A-60” class divisions are required to be used.

For the DESSO ROPAX, the following divisions should be used:

- “A-90” class division between Deck 3 and Deck 4 (the division between the upper ro-ro deck and the accommodation spaces above this deck).
- “A-60” class divisions between the individual ro-ro cargo decks.
- “A-60” class divisions (bulkheads) between the ro-ro decks and adjacent spaces.

4.5 The ventilation system

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[10] There are active barriers on the market that can provide full four-hour resistance; some of these can even provide two-hours insulation. Width of 50 metres and drops of 12 metres, all contained in housing are possible. Source: ”Smoke and fire barriers”, Fire Safety Engineering, May 2005, pp. 28-31.

[11] Open deck spaces.

[12] Sanitary and similar spaces.

[13] Tanks, voids and auxiliary machinery spaces having little or no fire risk.

The ventilation system for the ro-ro deck spaces should be designed as per the present regulatory requirements.

5 The safe area concept

5.1 Introduction

As mentioned previously, future large passenger ships should be designed for improved survivability so that, in the event of a casualty, passengers and crew members can stay safely on board as the ship proceeds to port.

One important measure to achieve improved survivability is the "safe area" concept. It should be underscored that the "safe area" is not intended to be a single area or space outside the main vertical zone affected by the fire; it is, rather, any area outside the main vertical zone(s) in which a fire has occurred that can safely accommodate all the persons onboard in order to protect them from hazards to life or health and provide them with basic services.

5.2 The safe area concept applied on the DESSO ROPAX

The overall fire safety approach on the DESSO ROPAX is in line with the safe area concept; if a fire occurs, its growth and spread should be as limited as possible and the spread of smoke should be limited. In addition, improved means for rapid fire detection, manual fire-fighting and the fixed fire-fighting system is suggested.

Deck 6 on the DESSO ROPAX is considered the evacuation deck, and on this deck, spaces are available to accommodate all the passengers in the case of an emergency and provide all necessary basic services.

The passenger and crew survival for the DESSO ROPAX was studied in detail under WP.8 and is reported in [16].

6 Summary and conclusions

6.1 General

The basics starting point of the work was that the DESSO ROPAX should fulfil all the prescriptive requirements given in SOLAS Chapter II-2, the FTP Code, the FSS Code and other relevant documents.

In addition to these measures, the intention has been to minimise the growth and spread of fire from its point of initiation, and/or maximise the time one can survive on the burning ship. Such improvements has been made by an astute design and lay-out of the ship, judicious selection of material in order to minimise the growth and spread of fire, rapid fire detection and response, coupled to fire mitigation or a combination of these activities. It is imperative that the reliability of active fire protection measures, such as fire detection systems or sprinkler systems, is high. Redundancy and reliability beyond the present regulatory requirements has therefore been sought.

The authors feel that all the suggestions and solutions presented within the report are realistic and achievable, probably without any dramatic impact on the overall cost of the ship.

Given below is a summary of the fire safety approach on the DESSO ROPAX.

6.2 Accommodation and service spaces

Fire within the accommodation and service spaces on board a ship will put many passengers at immediate risk. The following chapter describes the suggested fire safety approach made at the DESSO ROPAX for these spaces.

The first and foremost objective has been to improve the fire characteristics of combustibles as compared to the present regulatory requirements. All bedding material and all electrical cables fulfil requirements in excess of present requirements.

The means for escape has been improved through a simplistic lay-out of the cabin and corridors and all stairways lead directly to the internal assembly stations at the deck above the accommodation spaces. These spaces are considered ‘safe areas’ and can safely accommodate all the persons onboard to protect them from hazards to life or health and provide them with basic services.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems have been enhanced through improvements to design, performance, reliability and redundancy.

The use of an active smoke control system in the spaces will limit the spread of smoke and improve the possibilities for manual fire fighting.

6.3 Machinery spaces

For the DESSO ROPAX, a number of measures have been taken to improve the fire safety of the machinery spaces. First and foremost the fact that separate machinery space compartments are used represents an improvement.

Several different fire detection techniques are used in the machinery spaces, with the intention to detect a fire at an early stage, in a reliable fashion. The choice of fire detection techniques allows rapid detection of both flaming fires (flammable liquid spray fire or spill fires) and smouldering fires.

The high-pressure water mist system protecting the machinery space compartments activates automatically upon fire and a foam additive, of a film-forming type, should be mixed with the water using a foam proportioner, in certain sections of the system. The use of a foam additive enhances the performance on, e.g., flammable liquid fires.

6.4 Ro-ro cargo spaces

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In addition, it is possible to remotely close the aft port and the internal hoistable ramps in case of fire. The reason for the measures described above is to limit the availability of air to a fire and thereby reduce its size.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems, have been enhanced through improvements to design, performance, reliability and redundancy. The high-pressure water mist system is automatic and the pump capacity is sufficient to activate all the nozzles within the sub-divisions.

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APPENDIX E

Chalmers University of Technology,
Dept. of Shipping and Marine Technology

DESSO

"Design for Survival Onboard"

WP8. Passenger and Crew Survival –
planning of ship's lay-out and safety organisation

By
Olle Rutgersson, Elena Tsychkova, Monica Andersson,

Abstract

The project 'DESSO' was started from January 2003 in order to make the most of the research and development resources existing in Sweden and to combine it with international expertise for a radical RoRo-concept with a focus on safety. The ship research project DESSO aims at improving the safety of RoRo-ferries.

This report is a part report about WP8 and is based on investigation of feasibility using new developed evacuation systems and safety organisation on DESSO ship. The aim of DESSO project is to design a ship, which will be able stay afloat after a structural damage due to collision or grounding for at least 24 hours. The focus of this report has been the possible 24 hours wait which can be the reality for passengers and crew members. Which factors will influence the behaviour and how can the crew assist the passengers in this wait?

Time will always be crucial when it comes to clearing out the accommodation and preparing the passengers of the abandoning of the ship. The generic picture of the safe area will therefore be divided into three sections. Due to the development of the series of events the clearing out of the accommodation will be sequential and when the situation is very serious the passengers will only be allowed on the evacuation deck. Here will the actual preparation of the abandoning of the ship take place. This red alert area will have special demands and need to be designed with flexibility in mind. Parts of the area must in case of an emergency be used as coordination room, sick bay, rest areas and areas for passengers with special needs.

Information will be crucial and then not only the information given through the PA-system. If the passengers shall stay calm the bush telegraph must be inhibited. This is best done by making sure that updated information is provided at all times. This can be done by using viewing screens but also by making sure that the crew members which are in direct contact with the passengers have more information than the passengers about the development of the event.

This arrangement will change the requirements on the crew. Their tasks will be different, they will need additional training and education and the tasks will be divided differently and new functions will be added.

This report contains an inside design of the accommodation based on the above mentioned generic lay-out.

Contents

1 Introduction

The project 'DESSO' was organised in the autumn of 2003 in order to utilise the research and development existing in Sweden and to combine it with international expertise for a radical RoRo-concept with a focus on safety. Special funds have been allocated by the Swedish government to pursue safety research in shipping. The main funding comes from VINNOVA, The Swedish Maritime Administration and The Swedish Mercantile Marine Foundation.

The partners of the project are following:

- SSPA
- Globtech
- SP
- Chalmers Department of Shipping and Marine Technology
- Silja Line
- Stena
- The Swedish Club
- Lloyd’s Register
- Kockum Sonics

The project contains of following nine work packages:

- WP1: Project management
- WP2: Safety assessment of ships, concept generation and evaluation, Marin Teknik Chalmers.
- WP3: International Workshop and External Expertise, SSPA.
- WP4: Ro-pax Ship Design, Globtech.
- WP5: Staying Upright and Afloat, CHL.
- WP6: Decision Support, Kockumsonics.
- WP7: Passive and active fire protection, SP.
- WP8: Passenger and Crew Survival, Chalmers
- WP9: Concept Ship, SSPA.

To evacuate a large passenger ship by use of lifeboats, life rafts or other means is always a risky operation. In calm weather evacuation could be somewhat dangerous and it might be nearly impossible. It is better to stay onboard unless the ship is involved in a major fire or is about to sink, creating a larger risk to passengers and crew by staying onboard rather than leaving the ship. The idea behind the DESSO project is to create a ship design where means for evacuation should not be needed. The safety onboard therefore has to be increased substantially against fire. The idea put forward in the present project is to design shelters or "safe areas" where crew and passengers can stay safely for some time, if the rest of the ship would be on fire. When the fire in under control the passengers can go out again in the other parts of the ship, which might continue by it's own machines (if only slightly damaged) or abandon the ship by evacuation systems. Abandon the ship can be done by conventional evacuation systems, such as slide or chute with life rafts, or new designed system.

This report takes human behaviour in consideration when the design of the accommodation is determined. Stress reactions, group behaviour, wait and communication are a few key words which have been prominent throughout the design process.

2 Passenger and crew survival

One of the most crucial factors when it comes to evacuating a ship is time (Andersson, 2005). There must be enough time available to clear out the accommodation, to instruct and assist passengers, to prepare the equipment and so forth. In the aspect of the DESSO project where passengers and crew risk becoming locked up for a period as long as 24 hours, more aspects are then added and old ones are accentuated. One example of this is the importance of information and then especially continuous information to the passengers on the development of the series of events.

2.1 Passengers' reactions

Due to our own personality we are more or less resistant to the influence of stress. When the passengers and the crew for that matter arrive on board, they all carry a certain level of stress within themselves. This can be due to a number of different factors such as work related problems, daily hassles, family trouble etc. We are not equipped with different recourses to deal with different types of stress. No matter what the source is to what we experience as stress it will all add up. The more exposed to stressful events we are the less available resources are left to handle any further stressful situation. Factors which will affect the stress level are;

- Personality
- Previous experiences – have I been involved in any previous event which can be regarded as similar to this situation?
- The outcome of previous experiences – did I get hurt or did I escape from the event?
- The after-care of previous experiences - did I get sufficient help and support in order to help me deal with the event?
- The daily shape / stress load – how much stress is included in my daily life?
- The surrounding world – has there been a similar accident recently?

- Knowledge about stress and its expressions – am I aware of the effects stress can have on me and people around me?

This is the initial "stress value" of the passengers and the crew is something which can not be controlled or modified. Nevertheless, this level will affect the passengers' ability to stay calm and act rational in case of a serious accident.

There are however a number of things which can be influenced in order to assist the passengers in their struggle to try and manage their reactions once the accident has happened and they find themselves looked up in the accommodation on board the DESSO ship.

- Opportunity to be active – to have opportunity to stay occupied helps to manage stress
- Opportunity to talk about the event/information – to be given the opportunity to talk helps to make what is happening comprehensible, it also helps to make it tangible and therefore manageable
- Opportunity to rest – especially mild stress can be abated by rest
- Eat – occupies each and everyone
- Mental preparation – time to listen to information and/or to instructions
- Available time to prepare – time to get properly dressed, to don a life jacket etc.
- Grouping – time to find family, friends, work-mates etc.

The key factor here is, as mentioned before, time. Available time will enable most of the above mentioned activities to be performed.

When an accident or a major catastrophe have occurred the newspapers' headlines often describe a scenario where people are in distress and acting violently and/or with irrational behaviour. Harbst and Madsen (1976) have mapped out a reaction pattern for a group of people in an emergency situation (table 1).

Table 1 Reactions to stress found in a group of people involved in a crisis (Harbst, Madsen, 1976)

Group:	***Reactions:***	***Comment:***
I	People in this group react unpredictable.	This group need help and assistance.
II	People in this group tend to be paralysed.	This group need help and assistance.
III	People in this group tend to be perplexed, are not constructive-minded and await other people's initiative.	This group will be in majority, they need to be guided; they will follow orders and can be assigned to help.
IV	People in this group take independently initiative, acts logical and rationally.	This group need no guidance; can be helpful to the crew.

This investigation is based on generalisation of different types of accidents which all implied the evacuation of a crowd. Their conclusion also includes a distribution of percentage for each type of behaviour. However, crowd behaviour in a ships' accident will be dependent of many variables such as type of cause, weather, time of the day, time given to evacuate, means to evacuate, level of information given etc. why it is difficult to make sweeping statements for all emergencies (May, 2000). One of the largest problems during an evacuation will however be the initial inertia due to among other things denial of the threat and the consequences which this might imply in the passenger group (Wallenius, 2001; Enander, Jacobsen, 1996; Dyregrov, 2002; Leach, 1994, Chertoff , Kushigan, 1999) and the majority of passengers will belong to this group. Therefore again available time to prepare for an evacuation is valuable to every minute, and the impact which this inertia has must be reduced. The PA-system is here an important means of assistance for the crew to reach all spaces of the ship. Relevant and clear information of the situation and what to do accompanied by a safety organisation which makes crew members visible to the passengers together with an awareness in the passenger group on what to do in an emergency are the tools available to reduce the change-over time from denial to an apprehension of the situation followed by an urge to act. In addition to this continuous information about the development of the event and current status must at all times be provided on board the DESSO ship. If passengers are to stay calm during possible 24 hours wait sufficient information about the progress of the event must be provided. The bush telegraph is powerful and its effects must not be underestimated. Rumours will spread very quickly, especially when people feel insecure and worried (Dimbley, Burton, 1999). If the passengers are kept well informed they will more easily rely of the crew and their ability to handle the situation and the risk of mistrust and conflicts are reduced.

The earlier a clearing out of the accommodation can start the more time will be available for the crew to support passengers. Therefore a sequential evacuation of the ship will free time and give the crew an opportunity to prepare the passengers of an actual abandoning of the ship. The search of the cabin deck can be done thoroughly and the passengers have time to dress properly, find their family and friends and receive instructions on what to do. Furthermore, full scale trials have given proof of the passengers' difficulties in handling the donning of life vests (Andersson, 2005). It can not be taken for granted that the handling of life vests will be correct. Adult passengers have donned life vests designed for children and vice versa, the have donned the vests incorrectly and/or have had clear problems with the straps and clasps. Time will hence be helpful to properly inform, prepare and assist the passengers.

2.1.1 Panic

The fear of causing panic by informing the passengers is often given as an argument by those officers who are reluctant to inform the passengers. A number of criteria have to be present in order to get an outbreak of panic in a group of passengers. Panic rarely occurs (Leach, 1994; Chertoff, Kushigan, 1999) but when it does the consequences are serious. It is however necessary to separate panic within single individuals and panic within a group. Due to an overall stress load, personality and so forth a few individuals will appear being influenced by panic. This can be dealt with. A crewmember or a fellow passenger can grab hold of the person and calm him or her down. This does rarely happen and is not contagious. If there, on the other hand, should occur panic within the group the situation will become far more serious. This will no doubt spread out through the group and hamper everyone's chances to survival. However if this is to happen a lot of criteria will have to be present. The positive thing is that most of these criteria can be avoided. In a mob the emotions of one single person can spread out through the group (Taylor, Peplau, Sears, 2003). This can be due to a "social contagion" which enables a breakdown of normal control mechanisms. Our actions are usually controlled by values, ethics and social rules. In a crowd we sometimes risk loosing our sense of responsibility for our own actions; we are the subject of a deindividuation and among other impulses aggressiveness is free to be expressed. The presence of others can give a sense of crowding. Crowding refers to the psychological state of discomfort and stress associated with wanting more space than available (Taylor, Peplau, Sears, 2003).

Cherthoff and Kushigan (1999) have made conclusions from different case histories describing mainly fire scenarios which all included a crowd having to be evacuated from a building which can be compared to a ship's accommodation. They pointed out ten factors which contribute to a crowd behaving violently and divided them into three categories.

Preconditions

1. There are severe limitations on the amount of passage space and/or on the number, width, or location of exterior openings.

2. A large number of people are present.

3. There is a widespread lack of knowledge of some of the available paths and the location of some of the exterior openings.

4. There is a lack of an adequate emergency plan or the lack of an adequate training in the implementation of the plan.

Reactions to the precipitating events

5. There is the widespread perception of serious negative consequences for the failure to exit or enter by some kind of time limit.

6. There is the widespread perception of a severe limitation on the time available to exit or enter.

7. There is a strong response tendency to use the most familiar or most salient path and exterior opening.

8. There is an inability of potential leaders to exert influence.

Factors once the traffic flow is strong

9. The crowd density is so great that the independence of individual action is lost to a considerable extent.

10. There is a failure in keeping exterior openings clear beyond those openings

Most of these factors can be applied in an evacuation situation. Leach (1994) points out a remarkable degree of consistency in groups involved in unrelated events. The consistency lies in the events are threatening their lives. A few points, one, three and seven, apply mainly to the clearance of the accommodation whilst the rest apply both to the mustering phase and the evacuation phase. All these factors contribute to dysfunctional behaviour, "panic", in the flow of passengers. Dysfunctional behaviour, panic, means here violent highly contagious behaviour which will hamper the individual's and the group's chances of survival. Cherthoff and Kushigan (1999) found six out of ten of these factors present in the case histories investigated which did not succeed in evacuating the crowd. The rest of the factors contributed to a dysfunctional passenger flow when present. The two successful case histories accounted for, had only three respectively five of the factors present. Leach (1994) comes to a similar conclusion of panic; a restriction in space, the resources and means of escape are scare. People will become aggressively concerned for their own survival and any altruism is destroyed.

If we try to summarize the above mentioned factors we can yet again point out the importance of having enough time to move the crowd of passengers. The safety organization must also identify any critical space in the accommodation which might risk trigger of an unwanted behaviour, certify an even flow of passenger and inhibit any crowding. All evacuation paths and exterior openings must be distinctly marked and the spaces which the passengers are evacuated to sufficient with regards to space.

2.2 Information to the passengers

SOLAS (2001) state safety information shall be provided in passenger cabins, conspicuously displayed at muster stations and other passenger spaces informing passengers of their assembly station, essential actions to take in an emergency and the method of donning the life jacket. Information can also be found on the back of the ticket, in brochures, in the cabins, signs, videos, through the PA-system and on notices on board. An investigation carried out by Ohlsson and Johansson (2002) show that more than half of the passengers do not know what to do in case of an emergency. This investigation also shows that the information given on signs and in the cabins seems to have the most impact. 60 per cent of passengers asked gave this as the main source of information. The same investigation also states that 13 per cent of the passengers claims that they had not been given any safety related information at all. 56 per cent said they do not know what to do in case of an emergency and 43 per cent do not know were the life jackets are stowed. Not all of the results in this investigation were significant but the figures are still worth noticing. If the evacuation is to run as smoothly as possible the passengers must know what is expected of them.

All though the officers are used to communicate and doing announcements over the PA-systems they need to be aware of how a distress message should be presented and have a plan for how it should be accomplished. Our capacity of memory is limited and stress makes this even worse (Lundh, Montgomery, Waern, 1992). Wickens and Hollands (2000) describe how stress diminishes our cognitive capacities, it is difficult for us to take in information from the surrounding, and we can experience tunnelling, selective attention and so forth. There is all the more reason fore safety information to be salient and almost insistent.

Communication and information over the PA-system is often a subject of discussion. The PA-system is an important channel for the crew need to reach all passengers with important information. Full scale trials have proved this to be a problem (Andersson, 2005). Timstedt (2004) has in his report about the distress message over the ship's PA-system made several recommendations on how a distress message should be drawn up and what contents it should have. In general a distress message should have four purposes (Timstedt, 2004);

1. Make the situation comprehensible to the passengers
2. Help the passengers to interpret the degree of danger
3. Motivate the passengers to act according to the crew's orders
4. Instruct the passengers on what to do

The main purpose for the message must be to draw the passengers' attention to the situation. A sound reinforced by light attracts attention to the PA-system. The spoken message should then contain information on what has happened, a judgement of the seriousness of the situation and if possible some prediction of how the situation is likely to develop and instructions to the passengers on what to do. It is also necessary to be careful in the choice of words. The report includes a word comprehension test which notes it is far from certain that passengers do understand every maritime term which is used daily by the crew. The recommendation is therefore to try and use as much as possible of everyday language. The term "Emergency situation" also seems to be that word which best draws the passengers' attention and helps them realize the seriousness in the message. The investigation does not point out any significant difference in confidence between messages which start with a presentation such as "This is your captain speaking…" and those who did not have any presentation. There was however a significant difference in confidence between messages given by a female voice and messages given by a male voice. The passengers apprehended the male voice as more confident than the female.

2.3 A generic lay-out of the accomodation

The accommodation of the DESSO ship incorporates three different regions, yellow, orange and red code (see figure 1). Due to the development and seriousness of the series of event the crew will determine which code is valid.

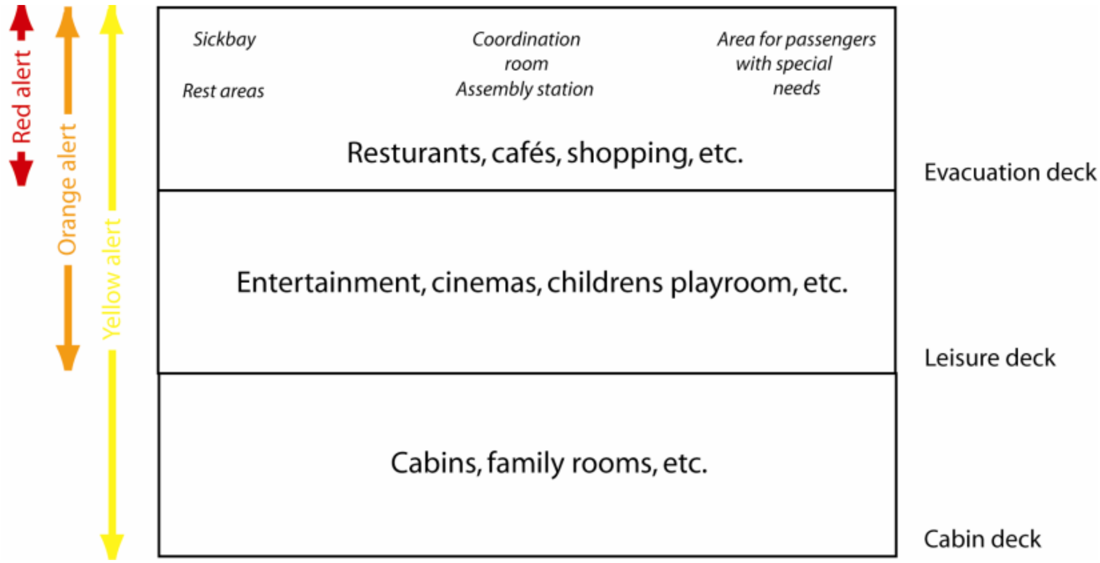


Figure 1 A generic lay-out

- **Yellow alert:** As long as the crew's estimation of the development of the situation is stable, passengers will be allowed to stay in all areas.

- **Orange alert:** A change of the situation to a more serious state will cause an orange alert. Passengers will have to be awakened and moved from cabins and family rooms and are allowed on the leisure and evacuation decks. The cabin decks will be searched by crew members and then closed.
- **Red alert:** An even more serious development of the situation will enable a clearing out and closing of the leisure decks. When all passengers are gathered at the evacuation deck an evacuation is to be prepared.

2.4 The evacuation deck

The cabin and leisure deck will probably have a more traditional lay-out. The evacuation deck should on the other hand need to be far more flexible. It should contain areas with special functions such as a coordination room, sickbay, rest areas and an area for passengers with special needs and will also function as the assembly station and hence need to be flexible. Passengers with special needs will not during the event be allowed at any deck other than the evacuation deck. An investigation carried out within the MEPdesign project (Jørgensen, May, 2002) pointed out as many as five percent of the passengers are disabled in some way. This area therefore needs to offer satisfactory comfort and opportunities to rest for these passengers for a 24 hour period. The demands of the evacuation deck are high. It must be possible to transform the “every-day” use of the deck to these specific functions and still keep their original function when it comes to serving food and drinks.

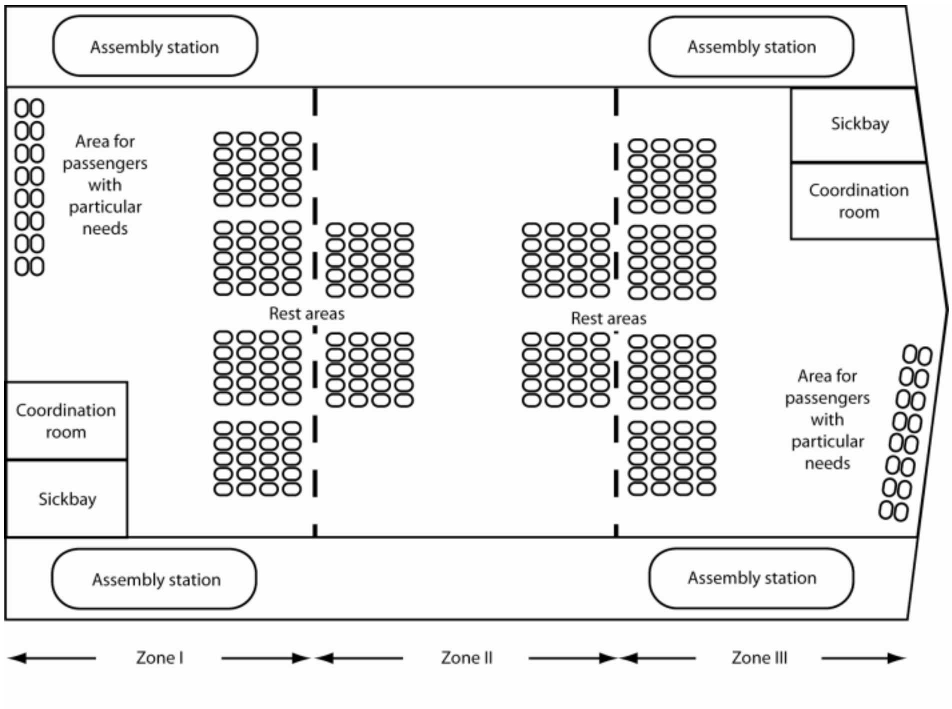


Figure 2 A generic lay-out of the evacuation deck

The generic lay-out has four assembly stations. The aim is not to determine the number of assembly stations but merely to point out that the evacuation is to be performed from this area. The number of assembly stations will be determined by the designer due to every stations capacity, there might therefore be motivated to increase the number of stations.

No matter which zone is closed down and isolated due to the event the passengers must have access to these areas which have been described earlier. This implies redundancy when it comes to the rest areas, the sickbay, coordination room and the areas for passengers with particular needs. No matter which zone, I, II or III is closed, these areas which meet the above mentioned demands must under all circumstances be accessible.

The sickbay shall be equipped according to existing legislation. The areas for passengers with particular need shall provide satisfactory comfort for a 24 hour wait. The area can be equipped with reclining passenger seat. In the vicinity of the area a few sickbeds must be accessible. These can during "normal" operation be hidden in cupboards. The crew must also have access to medical equipment which makes it possible to perform medical first aid. The rest areas shall provide satisfactory comfort for the passengers.

The planning and leading of the rescue party's work will take place in the coordination room. The person in charge of the information to passengers and crew will also be situated here in direct contact with the officers in charge.

Figure 2 gives a generic picture of the demands put on the area designated as "red alert". The relative placing of these areas in the GA will be optional for the designer. However the yellow, orange and red alert zones need to be defined together with the three different zones. And then also how these areas can be accessed independent of which zone which might be closed due to the development of the event.

2.5 The safety organization

The demands of the safety organization will be slightly different following the above made analysis. The officers and crew members who are assigned to fight the event will be more clearly assigned to lead and plan the rescue work rather then handling passengers, clearing out of the accommodation and preparing the evacuation equipment in the event of an abandoning of the ship. Therefore the demands put on the rest of the crewmembers will increase. There will be a need for all crewmembers which will be in the safe haven area together with the passengers to have at least a course in Crowd and Crisis Management. In order to certify an even passenger flow when clearing out the accommodation additional knowledge about which factors which risk trigger of violent behaviour must also be added (see page 7). The crewmembers which are assigned to take care of passengers with "special needs" as well as those who are going to manage the sick bay will have to have an extended training in medical issues like a course in Medical Firs Aid and for some even Medical Care. The more traditional tasks will not be eliminated but crew members will partly be assigned to slightly different tasks which will require additional training and education. The care of the passengers during the 24 hour period must be handled of the crew others than the officers and this will among other things include medical care, leadership, information to passengers, the handling of crowds and so forth.

In the light of the accentuation of the importance of information to passengers a special function must be assigned to handle the updating of the continuous information as well as the use of the PA-system. This can not be assigned to the captain or to any other officer who is a member of the team which plans and leads the rescue work. The information must be more detailed and also be continuously updated which implies that at least one, maybe two crew members must be assigned especially to this task.

3 Evacuation arrangement proposal for Desso ship evacuation systems

Main requirements for evacuation arrangement for DESSO ship are:

- Easy to gather passengers at assembly areas.
- Safe and comfortable to wait at assembly stations or in abandon equipment.
- Fitting for use for disable people.
- Fitting for use for children and older people.
- Feasibility for abandon the "mother" ship if it is necessary also in hard environment.
- Safe waiting in released "Safe Area" for assistance during at least 24 hours.
- Safe transfer from abandon units to protected place.
- Capabilities to using the unit in regular activities onboard.

The requirement about safe and comfortable waiting at assembly station means:

- Assembly areas and abandon equipment should be fire safe (materials, fire fighting systems, lock-doors between assembly areas and other spaces)
- Ventilation at assembly station.
- Own energy sources to provide all emergency systems at assembly stations and/or in abandon equipment.
- Information system at assembly stations and in abandon equipment.
- Food and water for occupants for at least 24 hours at assembly station and for 24 huors in abandon equipment.
- Transfer feasibility between abandon units without the need to go out from safe areas if using more than one unit.

Today SOLAS regulations require emergency training and drills of current evacuation systems. The goals of the emergency training and drills are following:

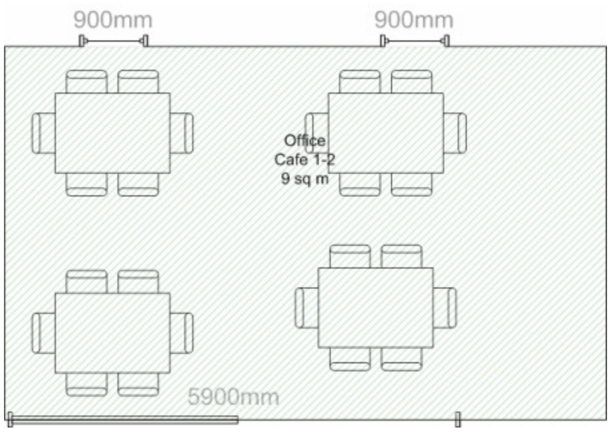
- Tests of system functionality.
- Training of crew members for using of equipment and management of passengers.

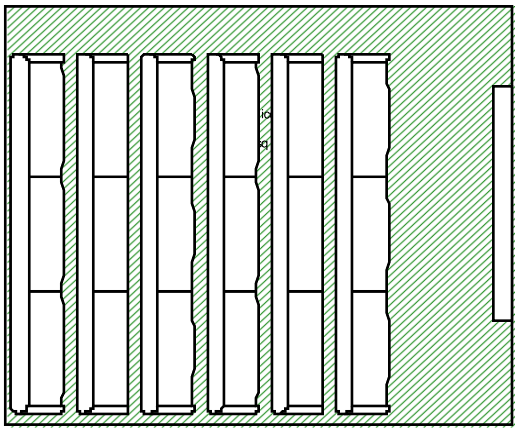
On DESSO ship both functional tests and assembly training should be carried out. However the test of functionality for two new systems investigated within this project should be done without launching of abandon units due to high cost of this operation.

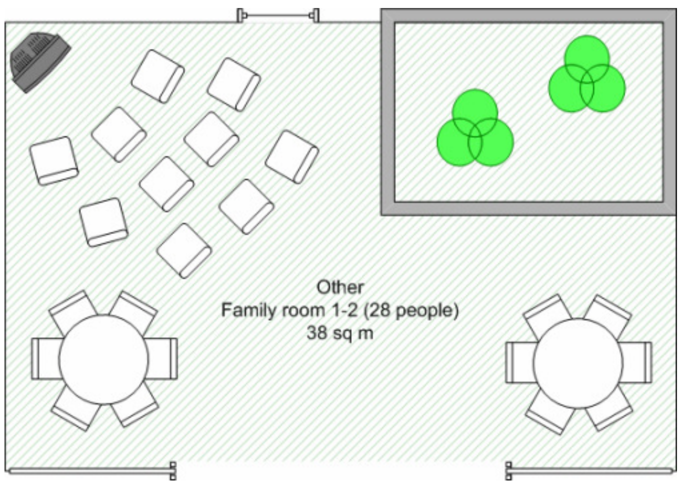
3.1.1 Inside design

The safe float-free units should provide all occupants with the following basic service to ensure that the health of the passengers and crew are maintained:

- Sanitation (dry toilets will be used only at an emergency situation, not during regular activities)
- Water
- Food
- Space for medical care
- Shelter from the weather
- Means preventing heat stress and hypothermia
- Lighting
- Ventilation
- Information equipment
- Adequate rest facilities


900mm
900mm
Office
Cafe 1-2
9 sq m
5900mm




Other
Family room 1-2 (28 people)
38 sq m

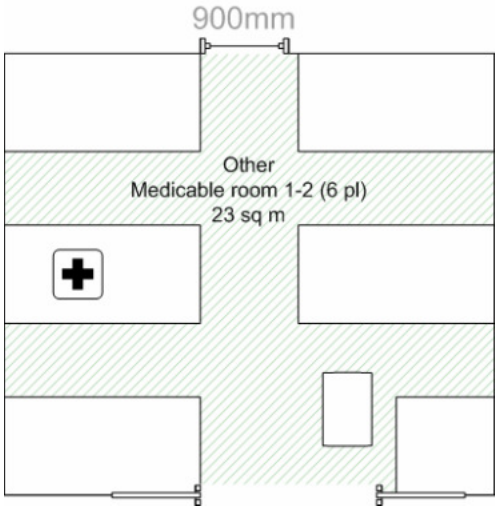
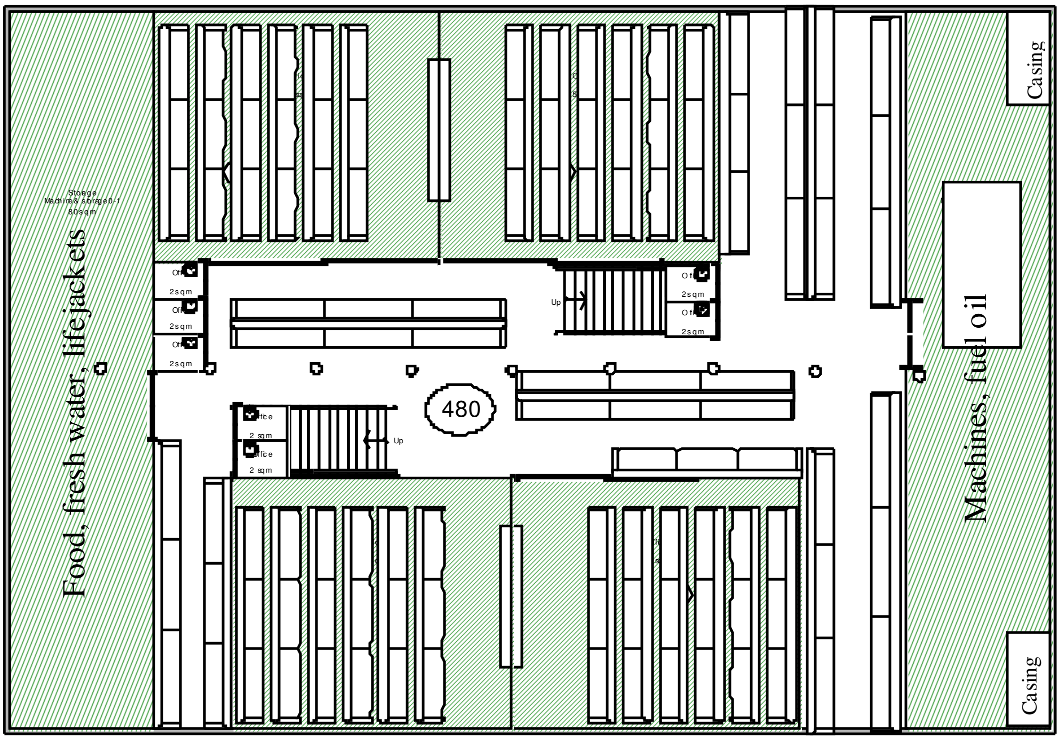


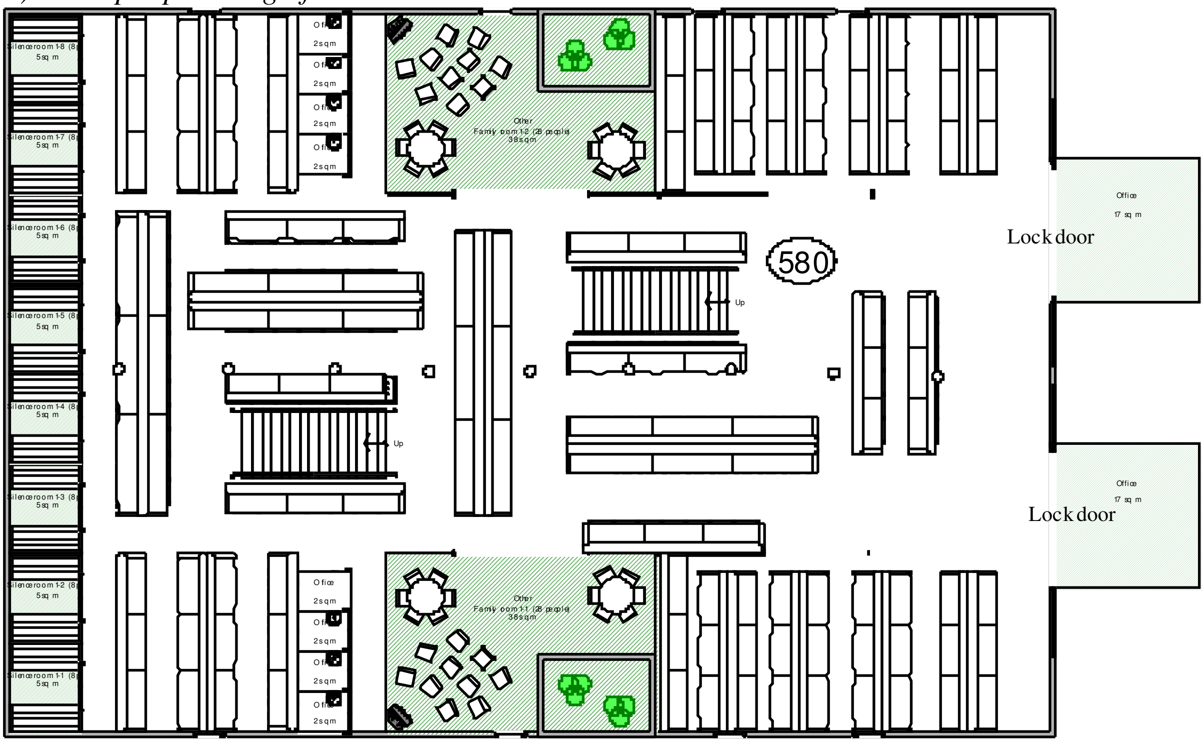
Figure 3 Example of different areas in the float free abandon capsule: café, cinema, family room and medical room.

In figure 3 examples of different passengers areas in the float free abandon capsule are presented.

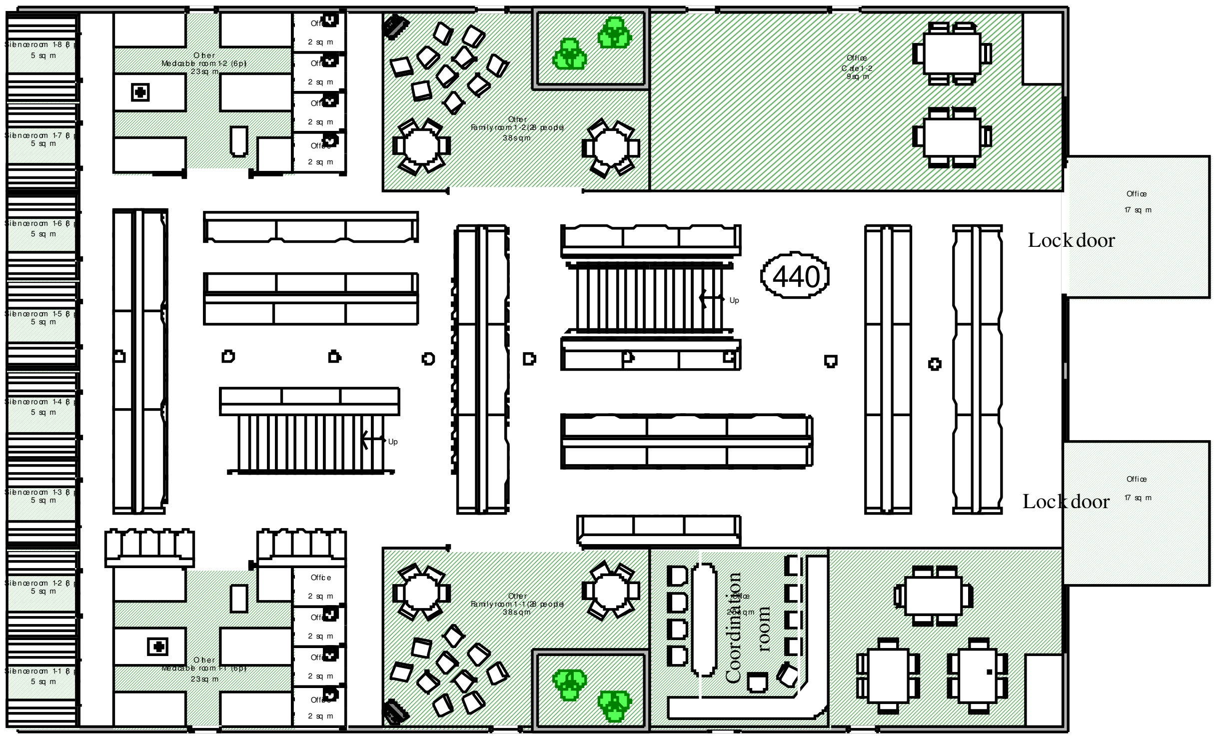
In Figure 4 principal planning for 1500 occupants in the float free abandon capsule on three decks is presented.



a) Principal planning of deck 1



b) Principal planning of deck 2



c) Principal planning of deck 3

Figure 4. Principal planning of decks 1 (a), 2(b) and 3(c) in Float free abandon capsule

3.1.2 Evacuation procedure

Generally evacuation process will be taken in four steps:

- Assembly (ship safety code will be activated, passengers will be informed, accident area will be evacuated and all passengers will be assembled at the fire safe assembly stations)
- Waiting (passengers will be informed about a course of events and crew actions)
- a) return to the ship or b) abandon the ship
- rescue from evacuation equipment to safe place if the ship was abandoned

First the passengers are assembled at the float free abandon capsule. After alarm the passengers will be leaded to one of two float free abandon capsules which are installed on Deck 4. There are entrances to deck 2 and 3 of the float free abandon capsule from Deck 5 and 6. Crewmembers count the passengers and control that no passengers left outside the float free abandon capsule. Secondly they will be waiting at the capsule (assembly station) for signal to return to the ship or abandon the ship. The third step is to return to the ship or abandon the ship. To abandon the ship by the float free capsule is possible only if the ship is sinking. The fourth step is to rescue the occupants of abandon capsule to save place (coast or other ships). That can be done by helicopters or by ramps when the abandon capsule is at the coast or moored to a assistance ship.

4 Conclusions

The generic lay-out of the accommodation implies a demand of flexibility. Parts of the “red alert” area must be able to change into areas were casualties, passengers with special needs etc. can be taken care of. There must also be areas which can function as coordination room, sickbays and rest areas. The design of the accommodation must also bear in mind the factors which risk contributing to an outbreak of violent behaviour such as passage space and/or number, with and locations of openings.

This report presents a generic picture of the demands put on the different areas. The relative placing of these areas in the GA will be optional for the designer. However the yellow, orange and red alert zones need to be defined together with the three different zones. There must also be clear which areas on the evacuation deck which are flexible and hence meet the special demands which must be fulfilled in case of an event. And then also show how these areas can be accessed independent of which zone which might be closed due to the development of the event.

Information must be provided through several channels, regular PA-announcements, continuous information via the viewing screens and oral information given by crew members in direct contact with the passengers. This is to prevent the bush telegraph to cause false rumors to spread and cause the passengers to worry.

This arrangement will change the requirements on the crew. Their tasks will be different, they will need a different training and education and the tasks will be divided differently and new functions will be added.

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APPENDIX F

DESSO

Design for Survival Onboard

Over the last few decades, roll-on/roll-off passenger vessels (ropax) have been involved in some serious accidents that resulted in many casualties. Although ropax vessels that are built today are considered to be much safer, a modern ship could still capsize if it is involved in a severe accident such as a high-speed collision. Abandoning ship for any reason, whether it is collision damage or fire, is a risky operation. The DESSO project resulted in the design of a concept ship, the DESSO ROPAX, that will stay upright and afloat for 24 hours even after sustaining severe damage. It also has fire safety measures that are better than state-of-the-art. This means that in the event of a serious accident, passengers can safely stay onboard the DESSO ROPAX while a safe means of rescue is arranged.

DESSO was funded primarily by VINNOVA, the Swedish Governmental Agency for Innovation Systems. Significant funding also came from the Swedish Maritime Administration and the Swedish Mercantile Marine Foundation, as well as from collaborating partners.

The main objectives of the project were:

- to create a template for the conceptual design of a roll-on/roll-off passenger ship that demonstrates the possibilities of "the ship serving as its own lifeboat";
- to significantly increase the current understanding of a ship's capacity to remain upright and afloat after suffering structural damage, fire or terrorist attacks;
- to establish a Swedish/European network of companies, research institutes and interested parties within the public sector;
- to study passenger and crew survival, both regarding moving large numbers of passengers onboard and accommodating passengers for extended periods in an emergency situation.

The research partners in DESSO were SSPA Sweden AB (Project Management), Chalmers University of Technology, SP Swedish National Testing and Research Institute (Fire Technology), Globtech Marine AB and Kockum Sonics AB. Collaborating partners were Stena, Silja Line, Lloyd's Register and The Swedish Club. The main sub-contractors were NAOS, MarDeQ, and Kattegatt Design.

An important finding of the safety assessment portion of the DESSO project was that a well organised safety management system and a highly skilled crew is probably the most cost effective way to avoid or limit the severity of ship accidents.

Some important features developed for the DESSO ROPAX concept ship are as follows:

- wide side casings to keep the vessel upright and afloat if severe structural damage occurs
- selection of interior materials that minimise the growth and spread of fire
- specification of systems to ensure rapid and effective fire detection and suppression
- onboard decision support system

SSPA · CHALMERS · SP · GLOBTECH MARINE AB · Kockum Sonics

Stena Rederi · SILJA LINE · Lloyd's Register · The Swedish Club

NAOS · MarDeQ AB · Kattegatt Design

VINNOVA · SJÖFARTSVERKET

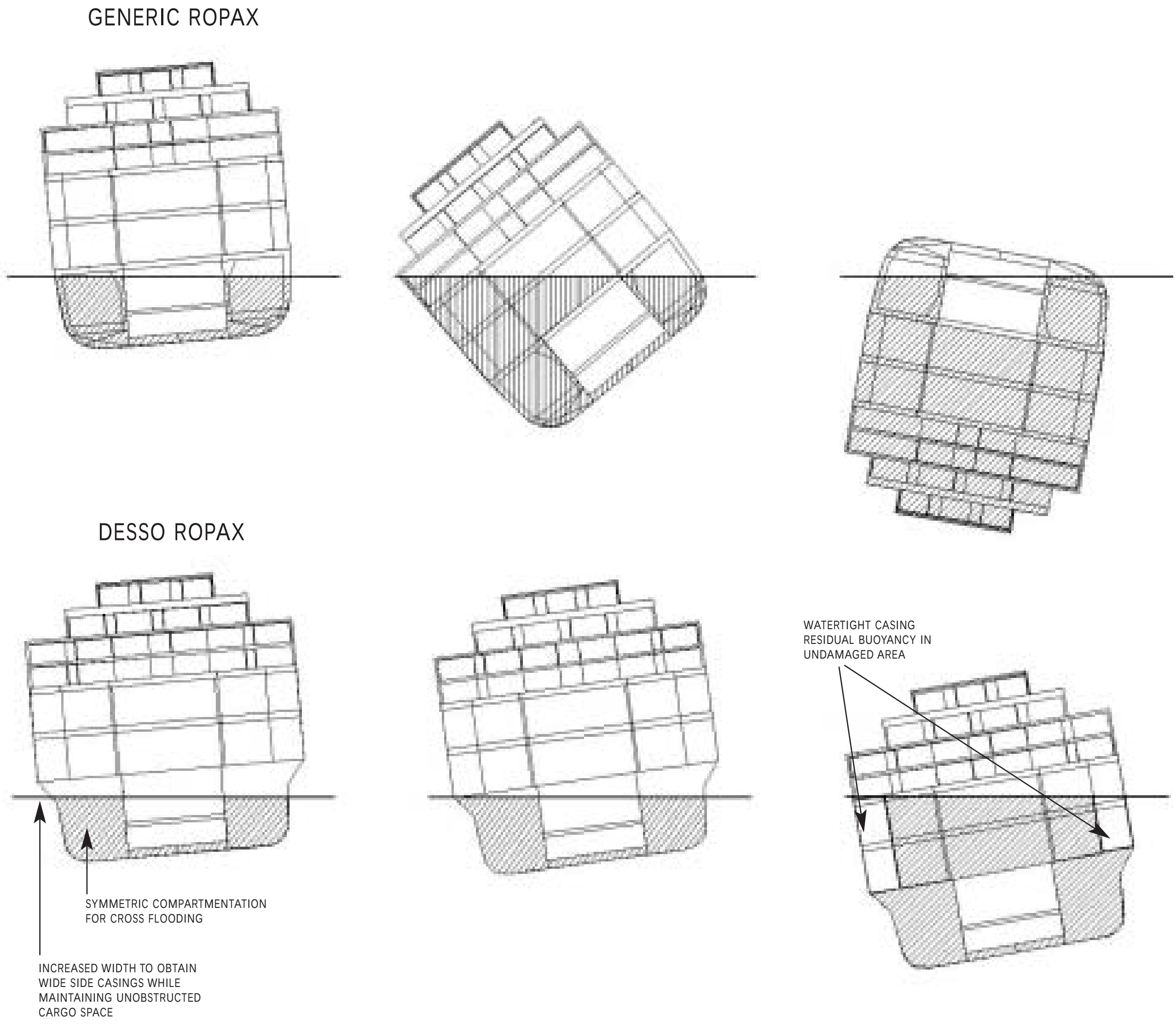
The DESSO upright and afloat concept

The goal of the DESSO project was to design a roll-on/roll-off passenger ship (ropax) that is superior in safety compared to current state-of-the-art ropax ships. This means that the ship will survive damages significantly more severe than those specified by current regulations governing ropax design. Survival means that the ship will neither capsize nor sink, i.e. it will stay upright and afloat. Furthermore, the DESSO ROPAX ship has a spatial layout that ensures redundancy of the propulsion, electric power supply and auxiliary systems.

The ability to stay upright is of paramount importance if the ship is to function as "its own lifeboat". To make the ship behave in this way, it is crucial that water entering the hull fills it as symmetrically as possible so that excessive heel is avoided. This means that the ship layout must be such that to the largest possible extent starboard and port side compartments are connected.

For the ship to stay afloat, there must be enough spare buoyancy above the waterline to compensate for compartments that are flooded during an accident. The spare buoyancy in the DESSO ROPAX is provided by enclosed watertight side casings that are maintained up to the first accommodation deck.

The ship width was increased to provide wider side casings while still maintaining an unobstructed cargo area. Most of the width increase is above the waterline – this means that the ship's intact stability and hydrodynamic properties are substantially maintained.



The DESSO redundancy concept

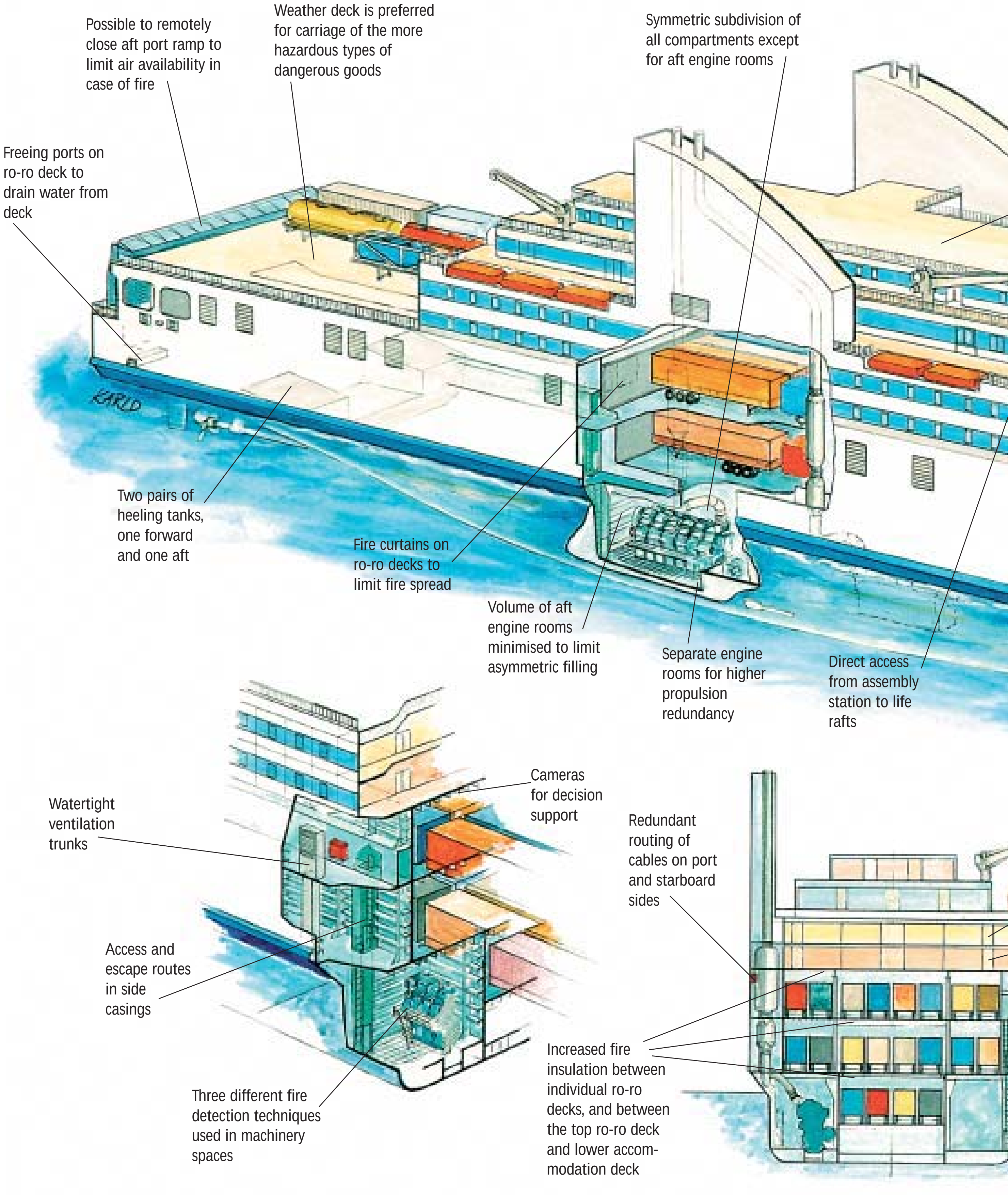
Redundancy of systems for electric power and for manoeuvrability was considered to be of high importance for the DESSO ROPAX. This will facilitate "safety by action" during incidents such as flooding of compartments or fire, or if the ship must be abandoned.

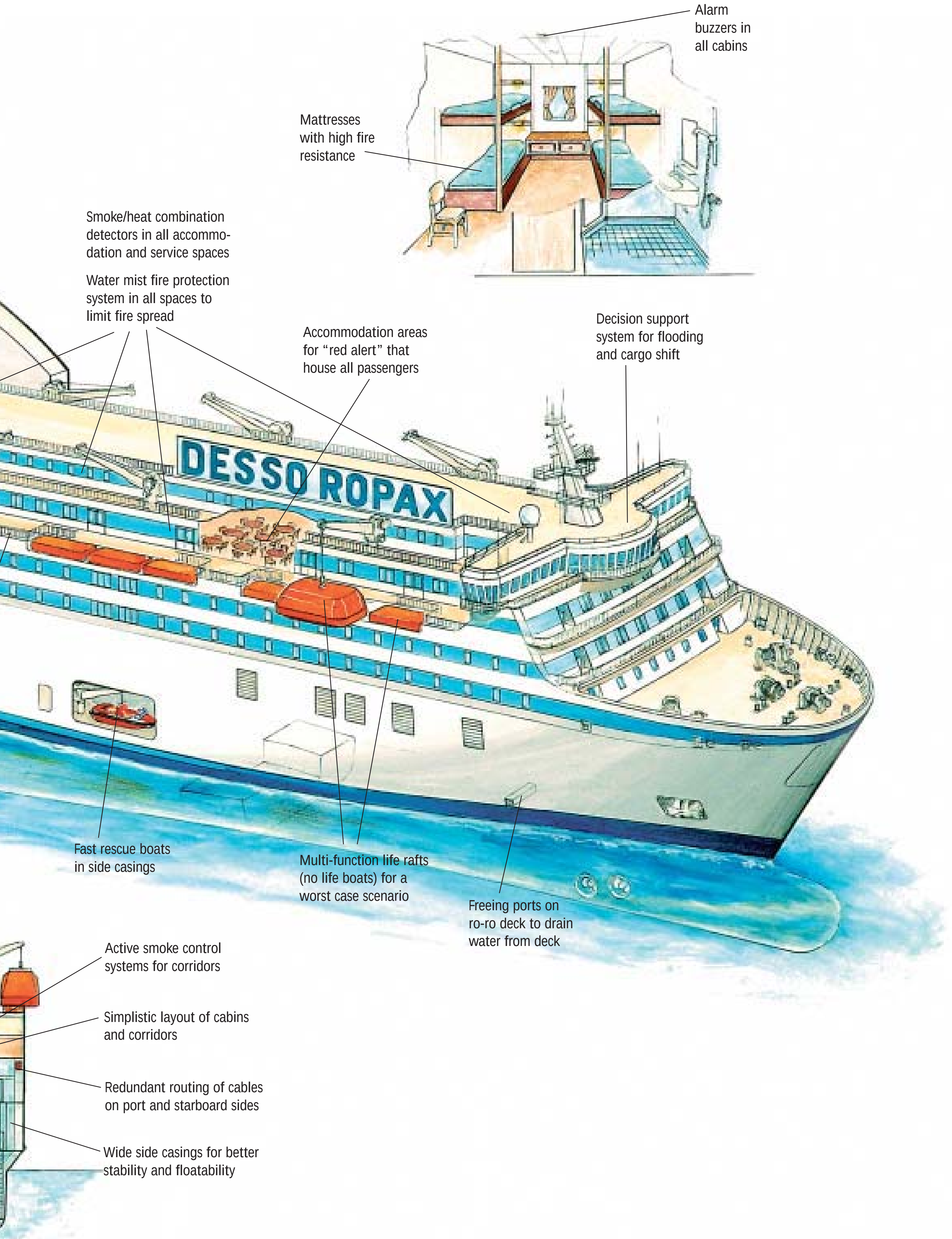
Maintaining manoeuvrability means that it may be possible to lessen the impact of waves, to avoid grounding during incidents that occur close to shore, to avoid collision if in proximity to other ships, to reach sheltered waters, etc.

For the DESSO ROPAX ship, propulsive redundancy shall also remain after incurring damage that extends along three adjacent compartments or after a rip-up that penetrates the double bottom over 65% of the ship's length. To achieve this, the engines have been arranged in separate compartments where the aft engine rooms are also separated transversely. This is an exception to the aforementioned principle of cross flooding arrangements. For all three-compartment damage cases and for the rip-up damage considered for the DESSO ROPAX, at least one of the aft engine rooms will stay dry and provide propulsive and electric power. The asymmetric filling will be limited to the volume of one aft engine room, which is not large enough to cause a critical heel angle of the ship.

If a collision affects any of the engine room bulkheads – a not so unlikely scenario – an arrangement where the forward and aft engine rooms are separated by two watertight bulkheads will significantly reduce the potential material damage (see picture below).

DESSO in a nutshell




Alarm buzzers in all cabins
Mattresses with high fire resistance
Smoke/heat combination detectors in all accommo-dation and service spaces
Water mist fire protection system in all spaces to limit fire spread
Accommodation areas for “red alert” that house all passengers
Decision support system for flooding and cargo shift
DESSO ROPAX
Fast rescue boats in side casings
Multi-function life rafts (no life boats) for a worst case scenario
Freeing ports on ro-ro deck to drain water from deck
Active smoke control systems for corridors
Simplistic layout of cabins and corridors
Redundant routing of cables on port and starboard sides
Wide side casings for better stability and floatability

The fire safety approach on the DESSO ROPAX

The present regulatory requirements provided the basic starting point for the fire safety measures recommended for the DESSO ROPAX. In addition to fulfilling the regulatory requirements, the intention was to minimise the growth and spread of fire from its point of initiation, and maximise the time one can survive on the burning ship.

Improvements were made by an astute design and layout of the ship, judicious selection of material in order to minimise the growth and spread of fire, and rapid fire detection and response coupled to fire mitigation, or a combination of these activities. It is imperative that the reliability of active fire protection measures, such as fire detection systems or sprinkler systems, is high. Therefore, redundancy and reliability beyond the present regulatory requirements was sought.

A summary of the measures that have been taken is given below.

Accommodation and service spaces

The main objective was to improve the fire characteristics of combustibles as compared to the present regulatory requirements. All bedding material and all electrical cables fulfil requirements in excess of present requirements.

The means for escape was improved through a simplistic layout of the cabin and corridors, and by having all stairways lead directly to the internal assembly stations located on the deck above the accommodation spaces. These spaces are considered "safe areas", and can accommodate all persons onboard, protect them from hazards to life or health, and provide them with basic services.

The use of an active smoke control system will limit the spread of smoke and improve possibilities for manual fire fighting.

Machinery spaces

For the DESSO ROPAX, a number of measures have been taken to improve the fire safety of the machinery spaces. First and foremost, separate machinery space compartments are used. The active fire protection systems, i.e. the fixed fire detection and fire suppression systems, have been enhanced through improvements to design, performance, reliability and redundancy.

Ro-ro cargo spaces

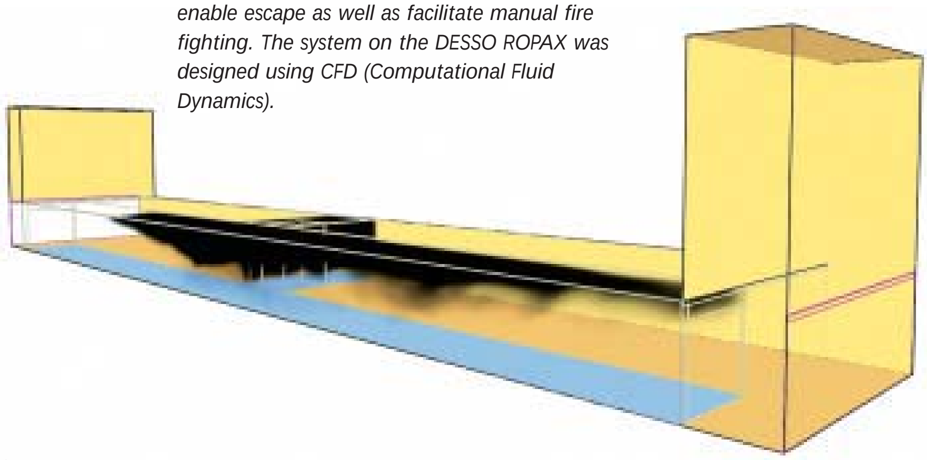
The main fire safety improvement on the DESSO ROPAX was achieved by sub-dividing the ro-ro cargo spaces into smaller volumes with active fire-resistant smoke and fire barriers (traditionally known as fire curtains). These fire barriers are shut upon completion of loading and opened during loading and unloading of the deck. Furthermore, the fire resistance between the individual ro-ro cargo decks and the division between the upper ro-ro deck and the accommodation spaces above this deck was improved.

In addition, it is possible to remotely close the aft port and the internal hoistable ramps in case of fire. The reason for the measures described above is to limit the availability of air to a fire and thereby reduce its size.

The active fire protection systems, i.e. the fixed fire detection and fire suppression systems, were enhanced through improvements to design, performance, reliability and redundancy.

Figure 2: The entire DESSO ROPAX is protected by a high-pressure water mist system. A fire in a machinery space is shown above immediately after engagement of the system, and before the fire has been fully controlled.

Figure 1: An active smoke control system keeps corridors free from toxic gases. This will enable escape as well as facilitate manual fire fighting. The system on the DESSO ROPAX was designed using CFD (Computational Fluid Dynamics).



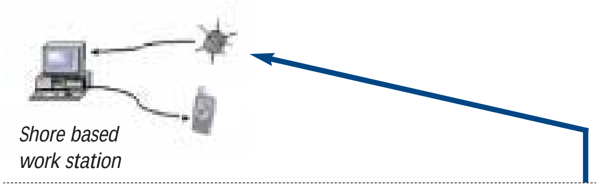
The DESSO Decision Support System

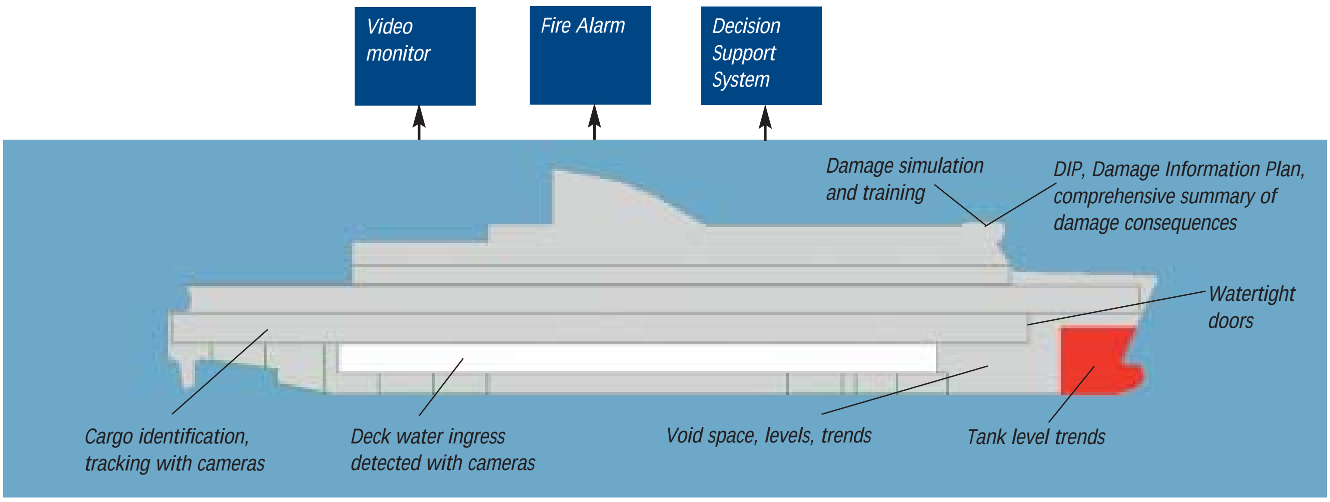
The DESSO Decision Support System will be continuously active and if water enters the vessel it will automatically calculate the vessel's stability and predict its future motions and state. Intact and damage stability will be calculated directly. Cargo shifting will also be included in the calculation. The vessel's entire geometric shape is entered into the system.

The system provides:

- early warnings of water ingress, cargo shifting, smoke and fire
- prediction of floating, capsizing or sinking conditions
- estimated time to reach these final states
- advice on ship handling (manoeuvring, water pumping, fire fighting)
- advice on evacuation, if necessary

The system will be connected to onboard video camera and fire alarm systems, and provides data to the shipping office and rescue centres. The system has a simulation mode for hands-on training to practice handling critical situations.

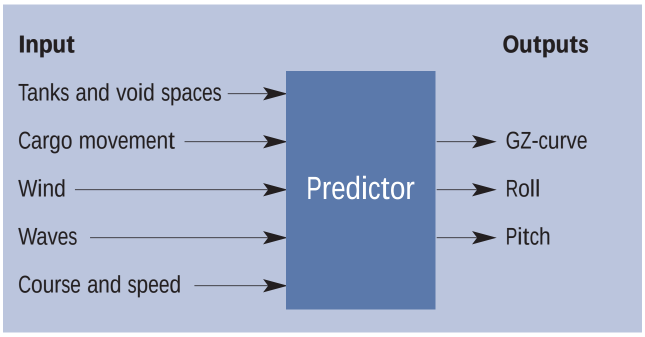




Predictor

Prediction of the ship's present and future motions and state is based on an advanced mathematical model and measurements of the following:

- fluid levels in tanks and void spaces obtained from sensors or video image processing
- cargo shifting obtained from video image processing
- wind speed and direction
- wave height and direction (indirect computation from the ship motions)
- ship's course and speed
- meteorological wind and wave prognoses



Loading program

The loading program performs a position check of the vessel's cargo, and provides information on ballast volumes and flow, as well as any water entering the vessel. The system compiles all the data available, performs a calculation and then gives advice to the vessel's officers about possible courses of action. Benefits of the loading program include the following:

- image processing from cameras to track cargo on deck
- automatic crosschecking of load condition
- damage simulation for training

Operations

If flooding occurs during the journey the real-time system emits an alarm. The crew on the bridge is also given an early indication of possible cargo movements and their effects on the vessel. Video cameras monitor doors, corridors, and the cargo on decks. Image processing software automatically recognises abnormal situations, such as cargo shifting, fire, smoke, water on deck, and passengers/crew in prohibited areas.

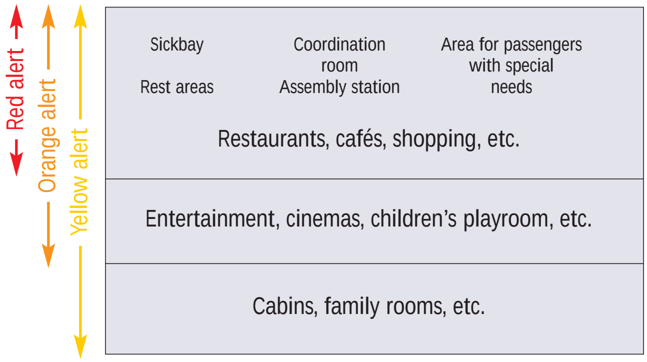
The system has four main functions:

- automatically calculating stability if water enters the vessel or if the cargo shifts
- monitoring of cargo and ballast via tank measurements and accelerating/lashing calculation
- constant monitoring of the vessel stability, and providing information and advice to the vessel's officers
- automatically transmitting the vessel's condition in real-time to the land-based organisation in the event of damage. The organisation can thus provide practical support to the ship's officers in an emergency situation

Passenger and Crew Survival

Time will always be a determining factor for the success of an evacuation. On board the DESSO ROPAX, passengers and crew might face a 24-hour wait. To be able to keep passengers and crew as comfortable as possible during this wait the ship's accommodation was divided into three areas: yellow, orange and red alert areas. This will enable a sequential clearing out of the accommodation based on the seriousness of the situation.

- **Yellow alert:** As long as the crew estimates the situation to be safe, passengers will be allowed to stay in all areas.
- **Orange alert:** A change of the situation to a more serious state will cause the alert level to be raised to orange. Passengers will have to be awakened and moved from cabins and family rooms, but will be allowed on the leisure and evacuation decks. The cabin decks will be searched by crewmembers and then closed.
- **Red alert:** An even more serious development of the situation will trigger a clearing out and closing of the leisure decks. When all passengers are gathered on the evacuation deck an evacuation will be initiated.



This sequential clearing out of the accommodation areas will provide the time necessary to inhibit crowding and to prepare passengers. If crowding is prevented most factors which risk triggering violent behaviour within the group are eliminated. The additional time will also give passengers the opportunity to group with family and friends, dress properly, receive information and mentally prepare themselves to evacuate the ship.

Information is another important factor. The provision of sufficient information will help keep the passengers calm and will lessen their worries. The crew must at all times be updated on the most recent developments. The continuous display of information on screens, etc., is also an important tool to make sure that each passenger can get information on the situation whenever they want.

These new demands that are required of the safety organisation will call for further training and education of the crewmembers. More crewmembers, in positions other than the traditional, will require medical training as well as training in handling crowds. New functions are also added; the responsibility of providing crewmembers and passengers with continuous information must be delegated to separate positions in the safety organisation.

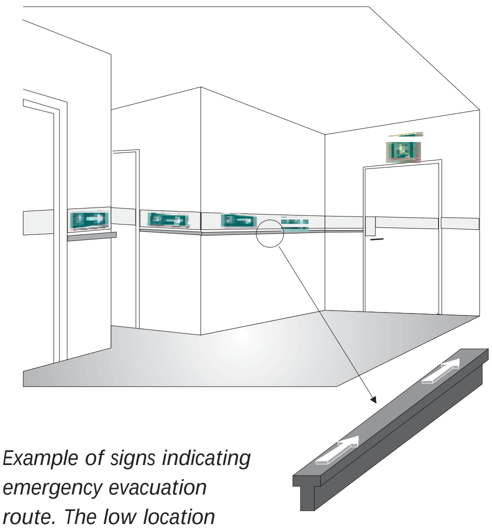
To facilitate the task of emergency evacuation for both passengers and crew, some improvements to the design of evacuation routes and technical support systems are suggested. The aim of these suggested improvements is to prevent problems that can occur during time limited evacuation. These problems include:

- breakdown of the safety organisation due to heavy workload and stress caused by the accident
- escape route identification difficulties caused by complex interiors and confusing signage
- difficulties with radio communication within the safety organisation
- difficulties searching cabins and public spaces
- public address system malfunctions and sound quality issues

Evacuation in smoke

The suggested improvements to facilitate evacuation can be summarized as follows:

- Install an interactive information system that supports passenger education and preparation for an effective evacuation. It can also support the passengers by providing information during an accident and be a complement to other sources of safety information, such as information broadcast over the PA system.
- Make improvements to signing and emergency lighting that take into account human factor aspects and evacuation strategies in smoke.
- Use directional sound as a complement or alternative to low location lighting.
- Provide emergency Escape Breathing Devices (EEBDs).
- Install a digital mobile communication system covering all communication needs including internal and external communication on a normal daily basis, as well as safety related and emergency communication.
- Implement a system for passenger surveillance using RFID (radio frequency identification) that can facilitate search tasks and give management the ability to identify bottlenecks and uneven distributions of passengers during evacuation.



Example of signs indicating emergency evacuation route. The low location light is at the height of the handrails that support an upright escape. The handrails are equipped with tactile signs that support evacuation in smoke and aid people with eye disabilities.

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