DOCTOR OF PHILOSOPHY

Reducing the Cost of Conversion Projects through Design for Ship Conversion

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Abstract

The Thesis develops design and production methods to reduce cost, duration and risks of conversions.

It reviews the literature on the nature of conversion and its correlation to ship-repair and shipbuilding. It examines the market, in particular for tanker to bulk carrier conversions. Literature on ship design for production, project management and risk is reviewed to identify potentially valuable ideas to improve the conversion process.

The case study conversion was completed in a conversion yard, using conventional techniques and planning. The design of the final bulk carrier was also conventional. The work was completed afloat, creating potential risk of structural damage which required carefully managed actions, e.g. work inside cargo holds to be carried out sequentially. A project completion review identified this and access difficulties as slowing the work. A number of cost inducing conversion bottlenecks had not been obvious at the start.

An alternative design is proposed for subsequent projects, moving strength members above deck, minimizing bottlenecks present with the initial design. Indicatively, by providing adequate deck strength early in the conversion, work in the cargo holds could proceed more quickly. A plan for conversion is developed alongside the design.

The alternative design shows a significant cost and time saving. The results are developed to offer a general basis for design for conversion, adapting shiprepair and design for production principles and proposes the following:

- The need to understand conversions in depth and improve planning.
- The need to engage all parties (design and production) in a collaborative project.
- Mitigation of risks focusing on production methods.
- A dedicated Goal-Based Design for Conversion approach that avoids, where possible, difficult internal structural work.
- Evaluating the need for Dry Dock in major conversions; it may not always be necessary or beneficial, contrary to popular belief and current Bibliography.

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Chapter 1. Introduction

The Thesis has the objective of identifying ways of reducing the cost of ship conversions, primarily by studying the interaction of design and production methods. This is by reference to a number of conversion contracts completed by Salamis Shipyards, mostly in particular the conversion of single hull oil tankers to bulk carriers, in which the Author of this Thesis was Project Manager, and which form the case study of the Thesis.

The literature review begins with background on the ship conversion market. The basic motivation for a conversion is to create a reconfigured ship that can produce a better return for the ship-owner than what it would if it continued trading as is, or sold as a going concern or scrapped. Conversions come in many forms and can be extensive or relatively minor in scope. They may be carried out to meet medium to long term changes in trading conditions, to comply with new regulations, or they may be opportunistic to take advantage of a short term situation.

Some conditions for conversion are then considered:

- Complying with new regulations to continue trading
- Increasing ship capacity to satisfy increased demand for carriage of goods
- Making use of obsolescent ships which still have life, a condition present in the case study.

Conversion can be considered to be somewhere on a spectrum between construction of a new ship and ship repair. Construction is generally well organised and planned, and in advanced companies uses designs which are well suited to the production facilities and specialised facilities for different operations, often with a degree of automation. Ship design for production is a well-accepted basis for efficient ship construction. The principles can be summarized as:

- Standardizing ship components and production methods
- Simplifying structures to reduce work content
- Specialized production facilities to take advantage of the two above.

Ship-repair is generally considered to be labour intensive, less easy to plan and not able to take advantage of specialised production facilities. It also carries many constraints in nature.

Project management is fundamental to ship-repair and conversion. Where ship construction can be organised, and often is, on an industrial basis, with specialised, automated production systems, repair and conversion are closer to a classic “project” and are subject to uncertainties.

Conversions, on the basis of short term conditions, carry a degree of commercial risk, in that the trading conditions can change in a short time period. All conversions carry some risk, for example because of the age of the ship to be converted, which may be in worse condition than expected. Also there may be technical risk, basically that the converted ship does not perform as required.

In the terms of this thesis, once the conversion decision is taken, and the risks accepted, then the objective is to complete the work as quickly and at as low a cost as possible.

Taking into account the above, along with findings from the case study, this Thesis was able to produce a list of principles aimed for a dedicated approach to Design for Conversion.

Chapter 2. Literature Review

2.1 Ship Conversion

Most ships are designed, built and operated through their life in a single configuration. They will almost always change owners several times and will incur considerable maintenance and repair costs to keep them in good operating condition. Over a typical twenty-five year life, ships will usually be upgraded in some way. This need for upgrading can be for any of a number of reasons, including:

- Changes in regulations requiring equipment upgrade. Fire regulations on passenger ships are one example requiring changes.
- Changes in equipment to adapt to different trading conditions. For example the fitting of deck cranes.
- Safety upgrades. An example is the fitting of flood barriers on roll-on roll-off ferry vehicle decks.
- Re-engining to improve fuel economy

In their "Guidance for Conversion" Germanischer Lloyd define a conversion. "A 'Conversion' does include but is not limited to -any modifications on board of a GL classed ship which deviates from the approved drawings." (www.Gl-group.com)

Some examples are given, which include an increase in the maximum allowable draft and changing the ship type class notation e.g. from Container Ship to General Cargo Ship.

Some examples of conversions are:

- Changes to the deckhouse and/or of arrangements within Accommodation Areas,
- Outfitting with Cargo Cranes,
- Modifications of Cargo Hold Structure, or to tanks
- Change of Main Engines / Aux. Diesel Generators etc. with a different type

Considering the various scope of conversion issues it is noted that some modifications may be regarded to be of 'major' character, for example a draught increase may require clarification on a case by case basis if it results in a large change in capacity for a bulk carrier or oil tanker.

A 'Major Conversion' is considered to be different from the above definition. It can include but is not limited to:

- Changing the type of ship for a new operation
- Work which substantially alters the capacity of the ship

Major conversions normally require application of classification rules effective at the time of conversion. GL recommend clarification of all relevant details by means of a meeting with all parties concerned. (www.Gl-group.com)

A number of ships undergo more significant changes, usually to adapt to new trading or economic conditions. Various changes to the ships may be made, for example:

- Lengthening to increase earning capacity (Weston, 1999)
- Additional superstructure for a roll-on roll-off ferry to provide better accommodation, or to provide for sleeping passengers on overnight voyages (Koros, 2006a)

Weston describes a roll on roll off ferry project where the ship was lengthened to provide additional cargo capacity. In addition the accommodation was increased and systems upgraded, including fire detection and air conditioning. (Weston, 1999)

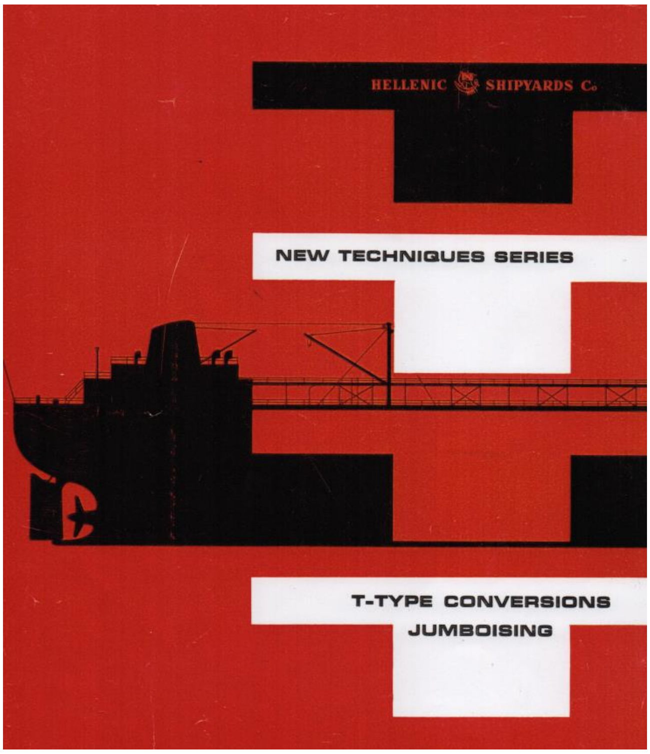
At the time of conversion the ship was 23 years old, and had previously been lengthened. Following the conversion, the ship traded for 6 years with its then owner, and was subsequently resold several times. The ship was finally sold for scrapping in 2014, having operated for 39 years.

While Weston describes a one off conversion, Lloyd Werft in Bremerhaven have specialised in lengthening of passenger ships. They also carry out the work by cutting the ship in half in a dry dock, then floating out one part, introducing a ready built mid-ship section, then aligning the three sections before draining the dock for completion. (Bruce, Luken)

A series of relevant conversions were also undertaken in Hellenic Shipyards (Skaramanga Shipyards) in the 1960's. The owners at the time, who were also shipowners (Niarchos family), performed a number of jumboizations by fabricating a completely new mid-ship part on the yard's slipway, which was then connected to the fore and aft part of the ship, as Lloyd Werft do, in the yard's floating dock. The picture below shows the newly built mid-part of M/T WORLD CHARITY, being launched.

Picture 1 Launching of new Mid-Section for Tanker M/T WORLD CHARITY Jumboisation
(Hellenic Shipyards, 1967)

Hellenic shipyards also introduced the idea of T-type Jumboisations, whereby in addition to the middle part, they would also increase the draught of the vessel by adding an extra longitudinal part, thus raising the deck, as shown in the picture below. They performed in total 19 normal and T-type conversions between 1961 and 1967. (Hellenic Shipyards, 1967)



Picture 2 T-Type Jumboisation
(Hellenic Shipyards, 1967)

The method has been used successfully for many years and could be considered an example of a distinct project strategy for such conversions. Conversely, in Weston's paper it is apparent that some problems were not anticipated. It is the Author's opinion that conversions in general are projects of partially unpredictable nature. This is because even if the scope of work is similar in some cases, as in the lengthening conversions mentioned above, mistakes made in the previous conversion dictate change of strategy in the next conversion, but that does not necessarily mean that the new strategy is without fault. Also, even if the basic scope of work of two conversions is similar, the specification and the strategy resulting thereof may not be, meaning that different equipment might be installed and perhaps in a different order. Furthermore, no two sister-ships are identical twins. In the author's experience, sister vessels can have differences between them which may affect a conversion, and such differences may not also be shown in the "as built" drawings of a vessel. Such may be the misalignment of stiffeners, different pipelines and others. Also, the maintenance that two sister vessels may have had over the years is most likely to differ from one another. If a vessel is older, or has been poorly maintained, it may present the conversion undertaking party with surprises. The original state/shape of the vessel to be converted must be taken into consideration and perhaps the strategy of conversion or even the "shape" of the desired outcome of conversion may have to be altered to take into account the state of the "donor" vessel, in order to reduce conversion problems.

Another similar but one-off conversion was that of the vessel "Gariep". This was a conversion carried out at A & P Tyne, which created a diamond mining vessel from a survey vessel. (Bruce, Gariep). The conversion also required an additional mid-ship section, in this case including a moonpool and processing equipment. As the risk of working afloat was considered to be unacceptable, the fore and aft parts of the ship were separated, skidded apart and the new section was lifted into place by crane. This required hire of a large mobile crane to make the single large lift. This is an example of how a similar conversion to the others mentioned above can be very different. In this case the mid-part of the vessel was lifted in place rather than on skids or floating. This difference in strategy is sure to have created different problems and obstacles to the other conversions.

Coming back to discussing conversions in general, it can perhaps be argued that some conversions can fall into the sphere of shiprepair, in the sense that they can be undertaken by many shiprepair companies located around the world and clustering in ports and on trade routes.

It is a less often phenomenon that more extensive works are carried out on ships, such as Major Conversions. These fall firmly into the category of ship conversion rather than repair. They are carried out to prepare a ship for a significantly different role.

Some consideration of the nature of shiprepair and conversion is appropriate, since most ship conversions take place in shiprepair companies. One report by the Organization for Economic

Cooperation and Development, referred to also as OECD, (OECD, 2008) considers the differences between the two sectors of the marine industry. It states:

"Importantly, ship repair does not necessarily imply the need for a dock, as work (even complex underwater work) can often be undertaken alongside at berths. This, of course, greatly increases the flexibility with which ship repair service can be delivered, and minimizes the need for extensive (and expensive) fixed installations. On the other hand, ship conversion services alter the structure and/or configuration of vessels in order to enable them to carry out a different purpose than was originally intended when the vessel was built. The conversion of tankers to operate as bulk carriers is an example of such a conversion. These conversions are generally substantial in nature, and require the availability of extensive facilities and labour skills that are often indistinguishable from those required for a new vessel.

Ship repair work is by nature labour intensive and not prone to automation. This provides an immediate advantage to developing economies that have an abundant supply of low cost labour. On the other hand, as already noted, ship conversion work has significant common characteristics with shipbuilding, including automation and outsourcing and so this sector does not automatically share this natural advantage."(OECD, 2008)

The implications of this, which reflects conventional views on the sectors, are that ship repair is flexible and may be done with limited facilities, i.e. without a dock and that as conversion is more complex, significant facilities, in particular where significant steelwork is done, including a dry dock, are required.

Low cost labour is noted as beneficial, in particular for repair work, which is more labour intensive, but also in general. The author's shipyard experience is that speed of work and location of work are factors that can offset the labour cost, by reducing the man-hours required to perform tasks, as explained later in the Thesis.

OECD consider that some automation, and as a minimum, improved working practices to improve productivity, need to be adopted for ship-conversion. This in fact, according to the Author, is correct. For example, the use of a CNC cutting table and simple mechanical welding tractors, may reduce the conversion time and cost significantly, as there will always be similar shapes to be cut and numerous longitudinal seems to be welded.

The most well reported conversions in recent years have been from tankers or bulk carriers to Floating Production Storage and Offloading (FPSO) vessels. The basic ship is acquired and repaired to bring it to a suitable standard and to ensure a sufficiently long useful future life (Biasotto *et al.*, 2005). This is often a separate contract. Once the ship is prepared, the main conversion contract is then started. This usually requires installation of the process and storage equipment for the ship to receive, manage and store oil. The work also requires a turret mooring system to allow the vessel to "weathervane" or rotate about its mooring under the influence of wind and currents. There is also the fitting of additional accommodation and a helicopter landing platform, among other smaller works. The majority of FPSO conversions are carried out in Singapore. According to the Association of Singapore Marine Industries, Singapore is the "conversion capital" for FPSO claiming some 70% of the world market(www.Asmi.com). Singapore is one of the world's premier shiprepair centres and a world leader in the conversion of Floating Production, Storage and Offloading (FPSO) and Floating Storage and Offloading (FSO) units.

Ship conversion is highly dependent on the state of the market, taking into account ship construction, ship operation, recycling. At the time of the conversions in the case study for this thesis, the OECD noted the importance of the market. During the course of 2007, the order book for the world merchant fleet grew to a record high level, four times more tonnage on order than in 2003 (See table 2-1). The demand for new ships was in excess of capacity of world shipbuilding. As a result the shipyard order backlog grew with shipowners placing orders for delivery up to four years later. (*OECD*, 2008)

Year	2000	2001	2002	2003	2004	2005	2006	2007
CGT (million)	42.90	48.20	48.90	70.80	92.80	107.2	138.0	177.7

Table 2-1 Shipbuilding new orders in million CGT (2000-2007)

OECD also noted that from 2003 ship recycling had averaged around 10% of new orders, compared to 70% during the previous cycle. Therefore the world fleet was growing with new ships and older ships remaining in service, particularly in the dry bulk sector where charter rates were strong. In 2007 scrapping (recycling) was noted as 5.7 million dwt, which was stated to be the lowest level for around ten years.

The OECD report also quoted Platou Brokers and showed steel and scraps prices rising at the time when the conversions described in the case study of this Thesis were carried out.

The report identified some conversions as being driven by the prices, freight rates and shipbuilding market conditions. "Conversions are becoming increasingly popular as ship owners try to overcome high newbuild prices and long delivery times by adapting existing vessels for different roles, as the relatively short time required for a conversion is preferable in many cases to bulk carrier newbuilding lead times of up to four years. This has encouraged, for example, the conversion of single hull tankers (due to be out of service in 2010 because of IMO regulations) to operate in the dry bulk trades. " (*OECD*, 2008)

Furthermore, there was a significant increase in 2007 in the number of contracts for conversion of single hull VLCCs into VLOCs. At the end of the 2007, there were over fifty VLCCs scheduled to start a 'second life' as bulk carriers in 2008 and 2009 as well as a number of Suezmax and Aframax vessels (Barry Rogliano Salles, 2008).

Many of the conversions performed in that period can be said to have been economic failures for the shipowners. This is because the market collapsed in late 2008. Many of the vessels were still undergoing conversion when the collapse happened.

In the Author's view, the "quality" of the market conditions during and after the conversion, plays a significant role in the cost effectiveness of the conversion from the Ship-owners' point of view. In fact the Author considers this to be one of the major risks in ship conversions in general, as even if the project may be a technical success, as well as a success in terms of correct estimation, budgeting and delivery time, the prevailing market conditions at the time of vessel redelivery, or the market conditions that follow shortly afterwards, may make the project a financial failure.

Market quality also affects the shipyards/converting parties. A good market may bring more conversions, a bad market will not, but a significant change in market quality during conversion may cause problems. These problems can be in the form of cancelations, inability of the customer to pay, legal disputes, etc.

In the Author's opinion, further to the quality of the market conditions, the demand for ship conversion services is also driven by a variety of factors, none of which are readily amenable to forecasting. In "normal" times, shipowners may elect to undertake a conversion in order to facilitate the entry of the vessel in a different market niche (for example, lengthening a tanker to increase its capacity). Such decisions are generally opportunistic, and impossible to predict.(*OECD*, 2008)

2.2 Why Convert?

As most owners are content to order and wait for a new ship, it is necessary to identify why conversion is sometimes the preferred route to a new acquisition. There are a number of motivations which persuade an owner to choose conversion over new construction. However there are two main reasons for conversion:

- Smaller over-all cost, since acquisition and conversion cost will most likely be less than that of a newbuilding, and,
- Shorter delivery time compared to a newbuilding.

Choosing a suitable older ship will usually be significantly less expensive than buying new. The ship will need repair work to improve its standard, but should be reasonably close to as new condition. A very careful inspection of the ship before the owner commits to the purchase is absolutely essential. For example, according to Caridis, corrosion which leads to strength reduction in steel members can be found in many forms in an oil tanker and can be caused by both the operating environment and the maintenance programme followed. Caridis stresses that it remains difficult to determine the exact locations where corrosion will make its appearance. It is equally difficult to identify the nature of the corrosion wastage since each vessel has its own particular features (Caridis, 2001). This is also discussed later.

The saving of time by carrying out a conversion can in some cases be a more significant benefit to the owner. As previously stated, the shipbuilding market in 2008 was extremely busy. The total ships on order were around 500,000,000 deadweight tonnes at mid-year (*Allied-Shipbroking*, 2015). The order book represented at least three years work for the world wide industry. As a result, an owner deciding on the need for a new ship would have to wait a minimum of three years before delivery. A project with an urgency to take advantage of an upswing in freight rates would not be feasible. On the other hand, finding an existing ship and bringing it to standard could possibly take only one or two months, after which the conversion work could start immediately.

Conversion can therefore be a very attractive option for a shipowner, in the right circumstances. A further benefit of conversion is that such a project may be able to make use of an older ship which is no longer suitable for its design role. A good example of this situation was the single hulled oil tanker. The increased concern about marine pollution within the international community had accelerated the phasing out of these ships. Starting in the USA after the Exxon Valdez incident, and continuing as a result of the Erika and Prestige, unilateral and then international actions had resulted in the phase out of the ships.

The result was a number of single hull tankers in the later part of the 2001-2010 decade, with considerable useful operating life still available, which had no suitable role as tankers. These ships had to be disposed of, which was at a considerable loss because of the relatively low level of return for a ship to be recycled rather than trade for a considerable number of years further. For example, a 40,000DWT single hull tanker trading in Nigeria, with a lightship of approximately 9000 tons, at an average scrap rate in Bangladesh of $350 per ton, would be worth off port limits (OPL) Bangladesh $3,150,000. Since the vessel would be trading in Nigeria, the transportation costs to Bangladesh would have to be taken into consideration, which approximated to $1,000,000. Therefore the ship would be worth approximately $2,000,000 net as scrap. The market value of such a vessel in 2010 (built 1990) would be approximately $6,000,000 if a willing buyer could be found. There was therefore a loss of $4,000,000 to be faced (Westfal-Larsen, 2010). A more favourable option would be present in the form of a conversion so that vessels such as this could keep trading.

2.3 The Effect of the Condition of the Vessel under Conversion

Conversion can be an attractive option for an owner requiring a ship quickly as stated previously. As the “donor” vessel for conversion will be one which has operated for a period of time, its condition will certainly have been affected. This may in turn affect the conversion.

A commercial ship has a typical life expectancy of twenty-five years. However, its life is largely dictated by the need to maintain structural integrity and the resulting inspection regime carried out by classification societies. A well maintained ship can have a longer life, an example being the ferry described by Weston. (Weston, 1999)

The basic requirements are set out in classification society rules. In summary, ships must be inspected on a regular basis, with the structure in particular requiring increasingly rigorous inspection as the ship ages. Annual surveys are carried out while the ship is afloat and are relatively limited, i.e. primarily visual inspection of the hull and fittings. Intermediate surveys include the annual survey requirements and additionally inspection of tanks and other spaces to identify corrosion. Where the protective coating is damaged and corrosion is evident then thickness measurements for the structure may also be required.

Special surveys are carried out at five year intervals (Caridis, 2001). At each inspection, samples of the structure are inspected for corrosion, coating breakdown and the thickness is measured. The sample size increases with each survey. The fifth special survey is often the trigger for a ship to be scrapped, because the results of the inspection will most likely require a significant programme of steel replacement. This may prove to be uneconomic. If a ship is maintained properly all year round by its crew and surface preparation and protective coatings applied at intermediate and special surveys at the areas where it may suffer the most, then it is quite possible that a 25 year old ship may not be in such a bad condition. Most likely though, this will not be the case. For example a 25 year old 40,000DWT bulk carrier may in some cases have up to 600 tons of steel that require replacement. These would mainly be on deck, especially if it is a log carrier, tank top due to the lack of coating and constant presence of cargo, top side tanks and other ballast spaces due to the lack of maintenance by the crew and very high cost of sandblasting in enclosed spaces, and finally the hatch covers due to their old age, fatigue and constant contact with sea water due to weather conditions (Salamis Shipyards, 2015).

Despite the survey programme it is very common to find ships with significant corrosion as a result of poor coatings, aggressive cargoes and operational damage. This will be picked up eventually and the ship structure will be repaired. However, where a ship changes owner, there is a danger that the real condition of the ship will be significantly worse than would be expected for the age of the ship.

Potentially, the repair work to bring the ship up to standard may be more than anticipated. The owner will commission a surveyor to inspect the ship, but there may be problems of access to some spaces and the inspection will rely on sampling the structure, guided by experience of the most common re-occurring problems.

All the above can have a significant effect if preparing a ship for conversion. In all conversions there are parts of the existing ship that must be cut and removed in order to allow the vessel to take its new form and fulfil its new purpose. Similarly new steel structures will be added to the vessel and joined with the remaining structures. This in theory would require that a strategy is prepared so that the above actions take place with maximum efficiency. In the case however that the vessel structures, which are to remain after the conversion, are not in a condition fit to remain, this must be taken into account. This would normally be added into the budget and the project strategy.

In the case however where the extent of the damage or the damage itself is not known, this creates a problem as it cannot be factored into the conversion until it is discovered. Unnoticed cracks in the vessel’s hull can mean more than just a plate change, as the root cause of the problem must be identified and rectified. This is common in high tensile steel plate areas according to the Author’s experience. Repairing the crack and its root cause could not have been in the conversion strategy and thus will create extra cost and delays.

Another example of unspecified repair work in conversions is water leakage in the accommodation areas which leads to corrosion or electrical damage. This in some cases can only be seen when removing the accommodation panels for the conversion in the particular area.

The condition of the bottom plating in some cases may be unknown, especially when the old age of a vessel is combined with poor coating and low quality steel, which all combined may lead to extensive pitting of the bottom plate. In cases where such vessels operate in tropical climates, or act as storage vessels, or have been laid up for a long time, an underwater inspection may not reveal the damage as marine fouling will have been formed on the hull. This is something that could lead to extensive steel replacement before the conversion is performed, a cost which if unknown beforehand, may make the donor vessel unsuitable for conversion.

The state of the donor vessel, and the thoroughness of its inspection, can be said to be of primary importance to conversions, as it cannot be determined by the vessel’s drawings which will be used for making the conversion drawings.

2.4 Conversion of Tanker to Bulk Carrier

As mentioned previously in brief, coincidentally with the phase out of the single hulled tankers, there was a buoyant market for bulk carriers and a full shipbuilding order book. This created conditions where the ability to obtain a bulk carrier quickly could be very profitable. On the other hand the shipbuilding market was such that delivery would take three years. Also the cost of second hand bulk carriers rose considerably because of their profitability so a purchase would have been very expensive.

For example, in mid 2007, a 15 year old Supramax bulk carrier had an asset value of approximately $40,000,000 and a newbuilding approximately $84,000,000, whereas a 15 year old MR tanker was worth approximately $25,000,000, as shown in Figures 2.1 and 2.2 below. What is interesting to note is that the two 17 year old single hull tanker vessels described in the case study of this Thesis, were purchased for approximately $15,000,000 each, (Westfal-Larsen, 2010) proving how valuable assets to conversion single hull tankers were at the time.

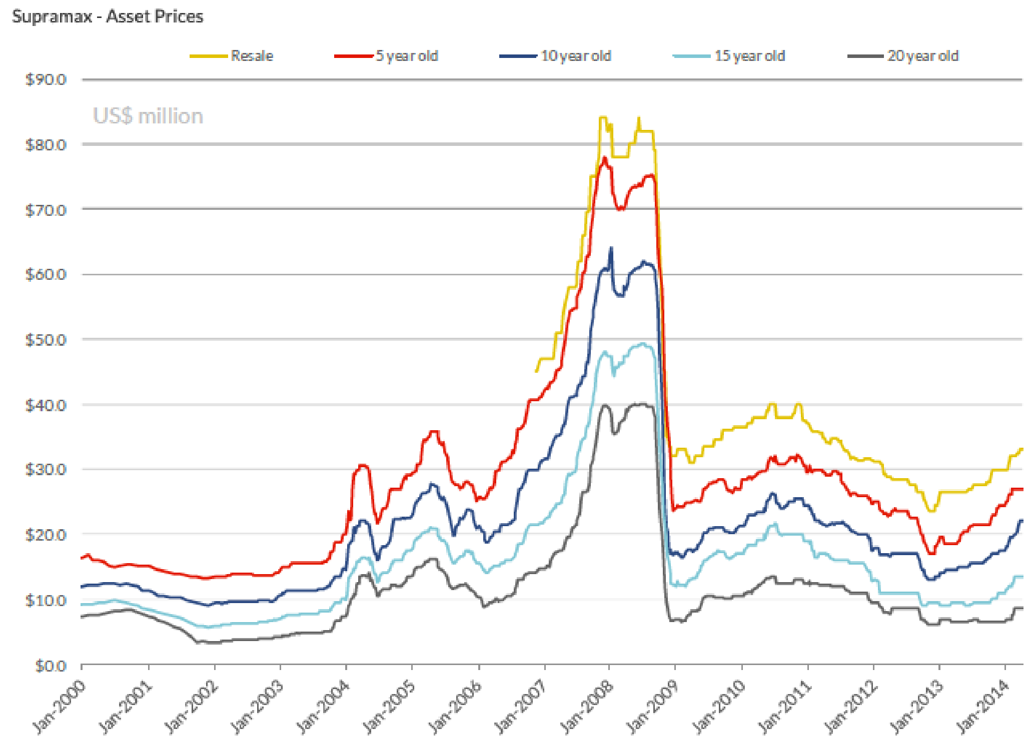


Figure 2-1 Supramax asset prices
(*Allied-Shipbroking*, 2015)

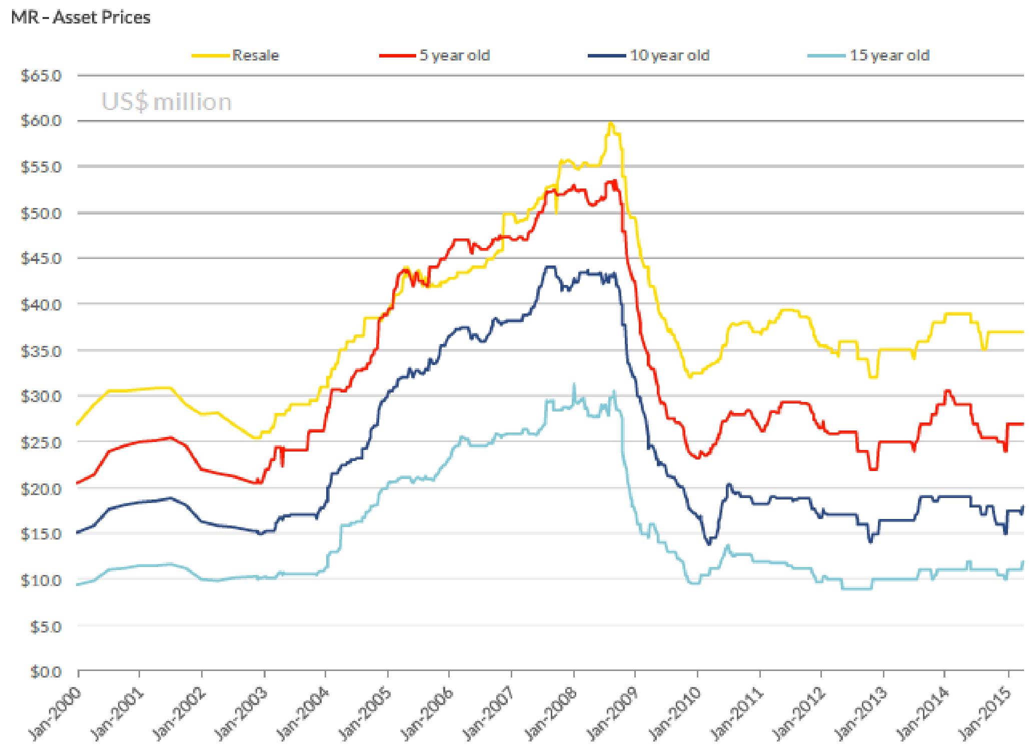


Figure 2-2 MR Tanker asset prices
(*Allied-Shipbroking*, 2015)

The conversion of single hull tankers to bulk carriers was therefore an attractive proposition in mid 2007.

2.5 Ship Design Considerations

Ship design is a subject covered in many ways. A starting point is the functional design of ships, which is achieving a design that will fulfil a set of owner or operator requirements. Eyres makes reference to the design spiral as a model of the design process (Eyres, 2007). This shows an essentially iterative process where the designer begins with a set of basic requirements and moves through a sequence of design procedures. Once these are set, then a second pass through the procedures is made, refining these and reaching a superior design. Several iterations may be needed before the best result is reached.

In the author's view this approach to describing design has two major shortfalls. The first is that the design process, as described, really only covers the ship function. That is, it creates suitable arrangements for the ship spaces, defines the power required, the hull form and so on. It does not go on to consider the detailed arrangements and takes no account of production requirements.

The second is that the "spiral" approach shows a sequential process, with the focus moving from issue to issue. In practice a designer, or design team, is likely to consider several factors together, with smaller iterations taking place between the main loops. This is difficult to model simply.

Zoolfakar describes an alternative approach which takes the main parameters for a particular ship design, in his case an LNG carrier, and creates a model which allows the designer to consider the interaction of these issues through a simulation process (Zoolfakar, 2012). In this he attempts to overcome the dangers of optimising only one or perhaps two ship parameters, especially where a design is incrementally changed from a previous or basis ship. He describes a holistic method, which also focuses on the need for a design to be optimised to keep capital and operational costs as low as possible, while meeting classification and other regulatory requirements.

For the LNG ship, the main parameters selected were:

- The LNG containment system
- The hull geometry (and implicitly the cost)
- The reliquifaction plant
- Power prediction
- Main propulsion system
- Mission profile variables

The combination of parameters results in a large number of options, and an Artificial Neural Network (ANN) was used to reduce these to a manageable set of feasible parameters for a given ship option. A mathematical model was then created to allow the designer to vary parameters incrementally to reach the best design. The result is a potentially useful decision support tool.

Based on the fact that LNG ships generally trade on specified routes, the model then attempted to optimise the overall fleet for a period of years.

While this is very different from the intended conversion design, and the method proposed did not take account of production issues, the gap between the simple spiral and the complex model show the difficulty of design optimisation and the potential limitations of a conventional approach.

Focussing on structural design, the starting point in most cases is a ship general arrangement, developed from the mission requirements. It is then normally the case that the design is progressed using the rules of a classification society or the IACS common rules. The usual procedure is to start with a basis ship, one similar in size and function to the proposed design and then modify this. The rules provide a simple approach to developing the structural design, and also offer a guarantee of compliance.

For most situations this offers a reasonably quick and efficient route to a satisfactory design, from the point of view of ship function. However, the requirements of the conversion, which is the subject of this thesis, include the need to minimise the costs of the work to be done, and this is often missing from conventional design. Where cost is considered, it is often assumed that the cost of the hull is a function of the steel weight. A common estimating measure is man-hours per tonne of steel, or in the case of repair and conversion, man-hours (and hence cost) per kilogramme (Bruce, 2008). Since minimum weight is a common functional design criterion, this is believed to provide a cost effective solution in the design process.

However, a simple measure based on weight generally takes a mean value, as in fact the man-hours vary according to the type of work undertaken. The total quantity of steel, whether it is thick or thin plate and the degree of curvature, all cause significant variations in the man-hours required. It is also possible to design a ship structure to be production kindly. The concept of “design for production” is adopted by many shipyards.

Lamb (Lamb, 1986) defines Design for Production as the deliberate act of designing a product to meet its specified technical and operational requirements and quality so that the production costs will be minimal through low work content and ease of fabrication.

Lamb further notes that “Design for production” as a term has been in use in production engineering since the late 195Os, (Lamb, 1986) where it applied to the linked functions of production design and process design. The production design covered the preparation of the engineering information that defined the production. The process design covered the development of the production plan.

Therefore, as originally conceived, design for production covered not only the design of the production but also the design or selection of tools, methods, and production sequence for least cost. Design for production is the correlation of production design with the available or planned facilities and production methods. As such, a designer could not perform well at it without knowing or being advised as to how the design would be produced.

Manuals were produced to assist ship designers in the application of design for production, for British Shipbuilders (Bethlehem Steel, 1986).

Early efforts in ship construction concentrated on optimising the hull structure by varying plate scantlings and associated stiffeners (Bong, 1987). Exploiting the capabilities of computer aided design (CAD), even at a relatively early stage of its shipbuilding application, many design variants, from a single starting point, could be evaluated.

Design for production generally includes:

- Standardisation of steel materials, steel parts, assemblies and potentially larger structures,
- Simplification of structure, for example by reducing hull curvature, especially double curvature which is generally avoidable, except for complex areas such as bulbous bows,
- Specialisation, where the structural elements have enough similarities to allow special work stations to be set up. These provide tailored equipment and a learning environment so that productivity can be improved.

A mid-ship section design model was created (Bong, 1987), which could incorporate the basic structural requirements and then include specific shipyard requirements, such as standard parts and arrangements. The initial design would then follow. This design could be modified by varying some of the structural arrangements, standardising details and varying, for example, frame spacing. The model used optimisation routines to identify the most cost-effective structure, taking production into consideration as well as functional requirements.

Further development of the design for production concept can be found in "Design for Production Manuals", the most comprehensive of which was developed for the US Maritime Administration (*Bethlehem Steel*, 1986). The manuals sought to take a holistic view of the shipbuilding process, essentially incorporating production requirements into the design process from the initial stages. The standard Design-for-Production principles, as give below, were retained but applied throughput the timescale of a shipbuilding project:

- Standardisation
- Simplification
- Specialisation

In general terms, for efficient production, there should be a close match between the facilities, methods to be utilised in a shipbuilding project, the interim products and the final ship product which is to be built. According to the Design for Production Manual, the concept of Design for Production (or Design/Production Integration) is to reduce production costs to a minimum while still ensuring that the ship to be built will be able to fulfill all its operational requirements. (*Bethlehem Steel*, 1986)

Another important point made in the Manual is that there is no necessary conflict between different design criteria:

- Design for operation is the traditional design process, and has been identified earlier in reference to the design spiral.
- Design for maintenance should be a serious consideration, although it is not normally referred to in descriptions of ship design.
- Design for production can be achieved, with the consequent cost savings, without any loss of performance.

A good design can satisfy all these requirements.

Furthermore, Larkins (Larkins, 2007), identifies 12 Design for Production Guiding principles:

1) Design for facility, workstation and equipment capabilities. The design should be optimised for the shipyard's capabilities and constrained to accommodate the shipyard's limitations.
2) Minimise number of parts. If parts can be eliminated through the design process, the handling and lifting will be minimised, the amount of welding will decrease, and overproduction will be minimised.
3) Standardise parts. Standardised parts enable shipyards to develop and optimise part construction processes, make them repeatable and predictable and minimise production cost and cycle time.
4) Standardise material types. Multiple materials handling through the production process hinders standardisation and optimisation of processes, and thus also makes production unable to benefit from a learning curve.

5) Minimise lifting and handling of parts. Lifting and handling of parts is labour intensive and non-value adding. When a part is too heavy to lift using standard means or its shape invokes extra handling requirements, an overburden is placed on production.

6) Minimise/optimise welding. Welding is one of the largest contributors to total labour cost, therefore the ability to decrease welding metres and increase weld efficiency, should lead to project cost reduction.

7) Simplify layout and measuring. Minimising component size and shape variations can improve layout and reduce measuring.

8) Minimise fabrication/assembly complexity. By limiting variation in the assembly process in materials and by reducing the number of jigs required to assemble a structure, man-hour and throughput time reductions can be achieved.

9) Optimise for outfitting and assembly. Outfitting and assembly should be performed as early in the production process as possible, to allow for ease of accessibility. Structural and outfitting design processes should be synchronized.

10) Apply shipyard standards. This makes quality assurance easier and thus reduces rectification costs.

11) Simplify engineering and design process. Receiving drawings on time is essential and therefore lean design techniques should be applied to eliminate waste.

12) Optimise for inspection and test. Design of systems should include a combination of in line components tests throughout the build.

The problems associated with a traditional approach to ship design, which does not consider the production requirements, have been eliminated from most shipbuilding companies. In particular the leading shipbuilding countries (Bruce, 2008) have taken turns to lead the way in increasing productivity through improved design and production processes. For example, Sumitomo Heavy Industries in Japan, who produce mainly a standard Aframax Tanker design, are said to have stretched the use of design for production to its limits, achieving maximum efficiency.

The changes made have been driven mainly by increasing competition from new entrants to the shipbuilding market with significantly lower labour costs. Early Design for Production exponents include Burmeister and Wain, (B & W) in Copenhagen. The company developed series of bulk carriers in the 1980s (J. Andersen and Sverdrup, 1992), which were optimised for production, while remaining attractive ships for owners. While the designs were not radical, features such as location and orientation of stiffeners, layouts and hatches were changed for the sake of efficient production.

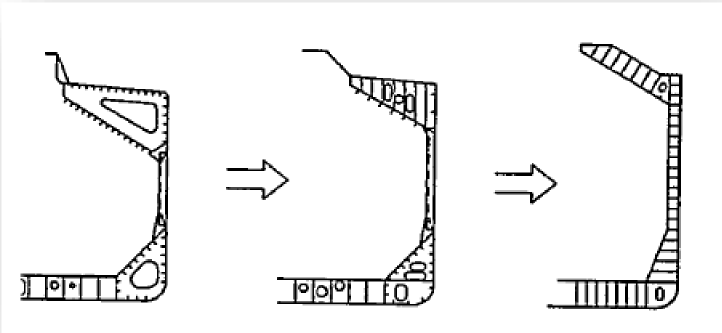


Figure 2-3 Development of B&W design
(J. Andersen and Sverdrup, 1992)

B & W reported significant productivity improvements, which were achieved primarily through integration for design for production (J. Andersen and Sverdrup, 1992). However, ultimately the shipyard closed in the early 1990's, because the low labour cost competition could always undercut the prices they could offer.

The Korean shipyards followed the Design for Production trend, one feature being the use of neat fitting stiffeners as they passed through transverse webs. This eliminated collars and made watertight structures easier to achieve. (Bruce, 2008)

Whilst Design for Production is a well established and widely accepted concept for ship-building, it is important to note that ship conversion can be fundamentally different to ship-building, even if it retains some of its major characteristics. Even if in many cases ship conversion requires the construction of a new major ship part, such as the jumboisations described previously, where it is obvious that Design for Production can and must be adopted, the most fundamental characteristic of ship conversion is that the project does not start from a "blank piece of paper"; rather it starts from a "donor vessel". It is the donor vessel that must be altered and this cannot happen technically without taking into account its structural characteristics and the limitations that they create.

For example, a ship-building strategy can identify works in the process which are likely to increase man-hours, such as the fitting of ballast pipes in the double bottom, and schedule it for when there is easy access to the double bottom area (pre-assembly and pre-outfitting stage). In ship conversion, this can indeed also take place when building the new hull part for a jumboisation. However, when there is pipe-work to be performed in the double bottom of the donor vessel, there can be no pre-erection and no pre-outfitting by definition. Here lies a major difference between shipbuilding and ship conversion which implies that Design for Production alone may not be enough on its own as a general guideline for design in ship conversion.

However, the basic principles of Design for Production, as given previously, can be used in ship conversion. Even in projects where a new hull part is not in the project specification, there will most likely be large straight/regular pieces of steel structure added to the ship, either to accommodate new trading requirements (e.g. accommodation extension) or to provide the newly required structural integrity (e.g. strengthening girders). Standardization, simplification and specialization in their production could only benefit the project.

However, in ship-conversion there may also be structures of irregular shape that require fabrication and installation, such as the turret structure in FPSO conversions which in order to be installed, the bow of the vessel must be strengthened. This is usually performed by cutting a piece of the bow and replacing it with a new bow piece on which the turret is installed. It is understandable that this new piece is irregular in shape and centre of gravity and is thus more difficult to handle than a standard straight piece.

Design for production suggests that in Unit Assembly and Ship Construction the units produced can be developed to be self-supporting, reducing the need for cranes to manipulate them. Staging and other access equipment can be reduced in quantity, and there should also be easier outfitting installation. These are principles that can be applied to the turret and bow construction and break it down to simpler pieces which can be more easily lifted and that are self supported, before being fitted on the donor vessel.

To introduce the process of design for production does require the designer to consider production from the start. As it has been stated, the Design for Production Manual emphasises that design can produce good functionality alongside good producibility and maintainability. However these additional desirable characteristics cannot simply be “bolted on” to an existing, conventional design.

In practice, and following the conventional approaches, the designer primarily considers the ship as a whole, or a collection of systems. These include

- hull structure, which is the main interest of this thesis
- cargo handling, which also has a significant influence on conversions
- propulsion
- and so on.

For effective production, a Product-oriented Work Breakdown Structure (PWBS) (Chirillo, 1980) is required.

The manual states that the decisions taken at an early design stage can influence production costs. That is, there are a number of arrangements, for example of structure, which will satisfy the structural strength and other needs of the ship, but of these some will have the capability to reduce production costs. So by considering a PWBS from the start of design, the impact on production costs can be minimized. Examples of how this can be achieved include:

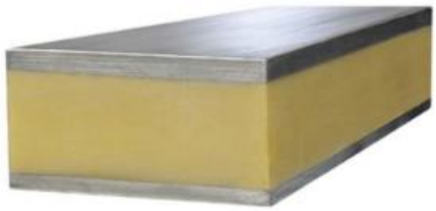
- how the structure can be split into blocks, which have the characteristics mentioned earlier
- how the number of such blocks, or units, can be reduced to maximise use of cranes and limit the numbers of large steel items to be taken to the building location
- How to simplify the connections between the blocks. Easier fit up is a critical element in efficient construction of the ship.

By considering the PWBS approach to ship conversion in order to reduce its cost, adopting solely design for production principles may not be as effective as required. As has been explained when creating a design for the conversion, the “blank sheet of paper” or “basis ship” approach will not be effective, as the donor vessel with its characteristics and constraints must be considered, and in the Author’s opinion, form the basis of conversion design.

As the existing structure of the donor vessel creates constraints, such as confined spaces, or spaces where staging is required, or extra lighting and air supply, it is becoming apparent that ship-conversion may in some cases resemble ship repair. In the relatively primitive operations of ship-repair steelwork, the ability to use repetitive production methods and Design for Production concepts is often limited.

As ship-conversion has characteristics which resemble both ship-building and ship-repair, it is the Author’s opinion that proven techniques used in both project types can be combined and used to reduce cost and throughput time in ship-conversion.

Referring to ship-repair, the use of a sandwich panel system to repair and strengthen damaged plating on ships has received much interest over the past years (www.ie-sps.com). A sandwich panel is a panel which comprises of two steel plates bonded using an elastomer. The theory is that it can successfully play the role of a normal steel panel with welded stiffeners. Over the years they have been used to repair damaged areas such as the tank top of bulk carries with claimed savings in time and cost. They have also been used to strengthen vessels’ hulls externally so to be upgraded to 1B Ice Class vessels with, as reported, minimal added internal hull stiffening. This work can certainly be classed as a conversion. As this is perhaps a proven ship-repair and conversion method, it could also perhaps be used more extensively in ship conversion and thus ship-conversion design, as the reduction in added stiffening may as well mean reduction of man-hours, reduction of work in less accessible areas (constraints of the donor vessel’s hull) and thus a possible reduction in delivery times and cost.



Picture 3 Sandwich Panel System
(www.ie-sps.com)

SPS could perhaps also be used to construct complete, or large parts of the mid-ship sections used for jumboisations, or even box girders for longitudinal stiffening of vessels, one such example being presented later in the Thesis, further to just being used as plain stiffened plating. As it will be discussed, the constraints of the donor vessel's hull played an important role in the case study. It was found that performing large structural works within the hull impeded the progress of work significantly. By correcting the conversion strategy, it was decided that wherever possible, the main structural works should take place in the outside areas of the hull, in this case the deck, where easy access was possible. SPS's purpose can be exactly that in conversions: reducing the work required inside the hull of a vessel by presenting a stiffening system which requires only topical joining work and provides the strength that multiple stiffeners welded in internal areas of the hull would. It is a method least invasive to the internal structure of the hull. Unfortunately, at the time of the conversions discussed in the Case Study, the benefits of SPS were not fully appreciated by the Author, who was project manager.

2.5.1 Regulation

The role of Classification Societies is well known (www.Iacs.org.uk) primarily to ensure the safety of ships as designed, constructed and maintained. Historically, design assurance has been based on the application of rules, developed by each society. These could be seen as rather prescriptive. Under the auspices of the International Association of Classification Societies (www.Iacs.org.uk) common rules have been and continue to be developed to ensure consistency of approach and standards.

More recently the idea of goal based standards has been developed. IMO's Maritime Safety Committee (MSC) has created what it states to be a historic change in the way international standards for ship construction are to be determined and implemented in the future.(Hoppe)

The adoption of so-called "goal-based standards" (GBS) for oil tankers and bulk carriers by the Maritime Safety Committee of the International Maritime Organisation at its 87th session on 20 May 2010 (MSC), means that newly-constructed vessels of these types will have to comply with structural standards conforming to functional requirements developed and agreed by the Committee. This means that, for the first time in its history, IMO would be setting standards for ship construction. The MSC, at its 82nd session held from 29 November to 8 December 2006, re-established the Working Group on Goal-based Standards and further progressed the work on the issue.

The notion of "goal-based ship construction standards" was introduced in IMO in November 2002, through a proposal by the Bahamas and Greece, suggesting that the Organization should develop ship construction standards that would permit innovation in design but ensure that ships are constructed in such a manner that, if properly maintained, they remain safe for their entire economic life. The standards would also have to ensure that all parts of a ship can be easily accessed to permit proper inspection and ease of maintenance.

Use of Goal based standards has potential to make the design process more flexible by focusing on the objectives of the design rather than on the specifics of the structure and other features of the ship.

In the Author’s opinion, the use of Goal Based design, as it will be explained later, can have a significantly positive effect on ship-conversion design. As ship-conversion has been said to combine both “worlds” of ship-building and ship-repair, a clear “set of rules” for effective design is not currently present and the adoption of the Goal Based Design concept could add flexibility and benefit design.

2.6 Project Management

Young identifies five key document sets which should be available prior to the commencement of a project (Young, 2003). These are:

- A statement of requirements
- A stakeholder list
- A project Brief
- A scope of work statement
- A risk assessment

Young places considerable emphasis on the business case for a project and this leads to the statement of requirements. In the case of a newbuilding project this will be found in the specification, prepared after analysis of the trading and other operating requirements. For a bulk carrier, the requirements for a new ship can be summarized as cargo capacity, speed, loading/discharging particulars, dimensions (if restrictions exist) and other operating characteristics. From these a conventional bulk carrier design can readily be developed.

For a conversion it has been argued that the current ship to be converted, the donor vessel, could and should be an influence on the requirements.

The stakeholder list identifies any person or organisation with an interest in, or influence on, the project. The obvious stakeholders are the customer (shipowner), end user (cargo owner) and contractor (who will carry out the work). Then major suppliers, regulators, classification, and the list can be extended to include workers, crews, environmentalists and any other minor players.

For a conversion there may need to be particular consideration of some, for example designers, production engineers and classification, in particular where an unusual design or procedure is proposed.

The project brief outlines what the project consists of. For a newbuilding project the equivalent is a build strategy which identifies the project sponsor, manager, objectives, start and finish dates and deliverables. It also identifies how the work will be carried out, what specialised skills and methods are needed (especially if from outside the company carrying out the work), costs and key risks. Where the project has unusual elements, in methods or design, the brief will require more than usual consideration.

The scope of work statement gives a narrative description of the project, including what will and what will not be done as part of it, and also identifies specifications and standards to be applied. It is intended to provide absolute clarity and ensure all stakeholder expectations are aligned. For most ship construction yards, the scope of work is usually part of company procedures (such as quality assurance). However for conversions, and particularly one-off projects, careful attention is needed to avoid any disputes as the work progresses.

Risk management is considered later.

Regarding stakeholders in a project, these can also be the different departments in the organisation that performs a project, for this thesis a conversion, and a very important aspect of project management that amplifies their role in a project is efficient communication and transfer of information.

According to Lamb (Lamb, 1986), an efficient, successfully operated company should be like a set of precision gears, each department like many input shafts with gears meshing with the production department, which of course is the output shaft. Communication is the necessary lubricant for the organization (gear) and the collection of the lubricating oil and its processing for return to the gear is the organization's feedback. For optimum performance, all service departments (input gears) must mesh with the production department (output gear) in exact accordance with the organization (gear) design. It must operate like a properly lubricated and maintained set of precision gears.

It is the author's view that this statement is correct in its entirety, a fact backed by occurrences in the case study where communication between the production department and the designers managed to produce a new conversion design which was much more efficient than the previous, as it will be explained.

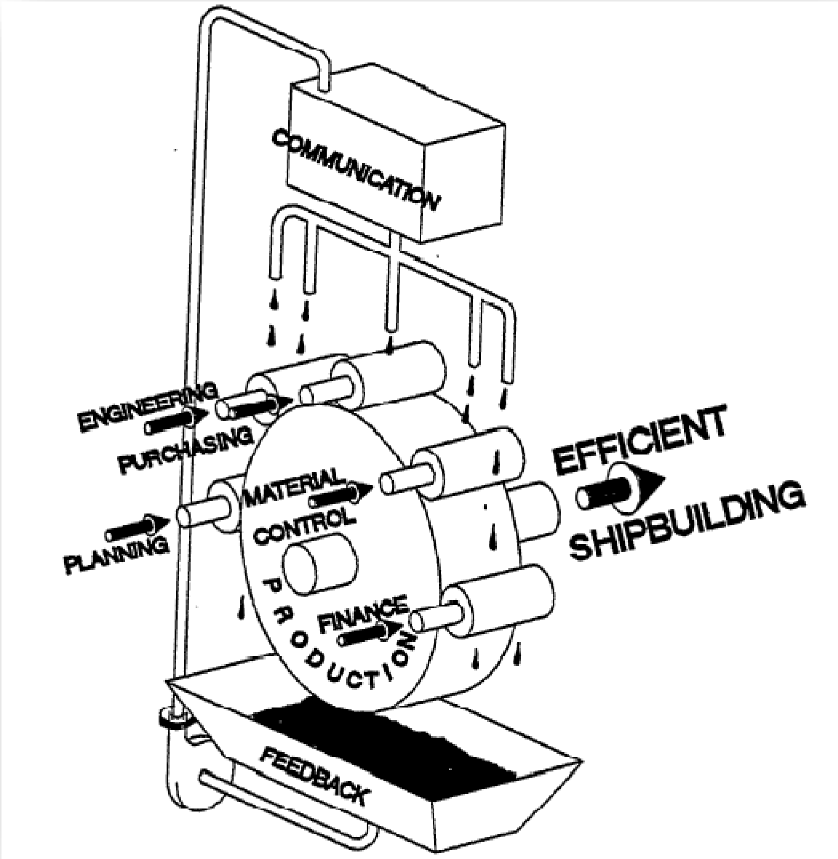


Figure 2-4 The company gear, Lamb, Engineering for Ship Production, 1986
(Lamb, 1986)

Any major conversion is a project, as defined by Young (Young, 2003). He states that a project has some specific characteristics.

A project is about significant change. It can be in an organisation – some form of restructuring – or the creation of a large, made-to-order product. Most organisations undertake projects from time to time. Some organisations are always engaged in projects.

What characterises a project is its difference from routine. In the case of an organisational change the difference is obvious, in that the organisation will emerge from the project in a different form and the project is the means of reaching that different form.

In the case of a major product, and examples are large civil engineering works, ships, offshore structures, the project element is in the way in which many different departments, sub-contractors and suppliers are coordinated.

Some of the differences between routine-work and project work are:

- Projects are about change. Projects create something which did not previously exist

- Once the change or work is complete the project stops – it has a finite life
- Projects have temporary and varying structures, unlike routine operations.

Ship conversion has to be managed as a project, although it is common for some aspects of project management to be difficult to implement. One major example is planning. Young puts a lot of stress on the need for accurate planning, based on very clear objectives. This requires the ability to predict with reasonable accuracy the duration and cost of activities (or tasks) defined by the work breakdown structure (WBS) of the project. Planning in shipbuilding is considered one of its integral parts. In ship-repair accurate estimating is often problematic. So although planning is recognized as important, it is also the case that the plans will change and the management of the project is in some cases done on a day by day basis. As mentioned previously, ship conversion carries characteristics of both repair and ship-building. In the Author's opinion planning therefore, whilst feasible, is often problematic, and most likely this may get better with repetition of similar projects, as in ship-building, but it is unlikely that it will reach ship-building levels of accuracy because of ship-conversion's close relation to ship repair.

A further element of project management which ship-repair has to cope with is increased risk. Young indicates that all risks should be identified, assessed and their probability and subsequent impact on the project determined. He proposes a form of matrix to compare risks, where the axes are probability of occurrence and impact on the project success. There are several sophisticated risk assessment methods to determine which risks exist and their potential consequences. However from the point of view of a project manager, the matter of risk is more about what to do once the risk is identified.

Young also makes the point strongly that in an ideal project, any risk will be assessed and a solution found which eliminates that risk.

	Project Impact			
		Low	Medium	High
Probability	0.7 - 0.9			1
	0.4 - 0.7		2	
	0.1 - 0.3	3		

Table 2-2 Risk table
(Young, 2003)

Risks rated 3 are considered to be minor and may be acceptable during the project as they can be managed as problems occur.

Risks rated 2 are more serious and should be eliminated during the project planning phase.

Risks rated 1 are potentially catastrophic, and must be completely removed or otherwise managed before the project can be considered viable.

Many project-based organizations use a formal risk analysis during the development and planning phases of their projects. Ship-repairers and converters are often less formal, but do make some analysis of potential risks before a project is undertaken. For example, as it will be discussed more thoroughly in the case study, not using a dry dock to perform the tanker to bulk carrier conversion was considered a manageable risk, and indeed it was. It was managed by ballasting and de-ballasting the vessel so that bending moments would not cause damage to the hull. Others would perhaps consider this risk more serious and may have decided to take a different course of action.

Risks may increase or decrease during the progress of a project. Also, new risks, not identified during the preparation of the project, may emerge. This is a particular feature of both ship-repair and conversion. As a simple example, the existing condition of a ship to be converted may be uncertain before detailed inspection can take place in dry-dock. As a result there is a risk of additional work being required to bring the ship to a suitable standard.

Risks can be categorized as:

A) Technical risks, which create the danger of a project not succeeding in its objective (Greville, 1999). In ship construction or conversion, typical technical risks would be:
   - Failure of the ship to achieve the intended (and contractual) service speed
   - Failure of the ship to meet cargo capacity
   - Excessive noise or vibration

B) Project risks, where the manner in which the project is planned and managed is at fault. Here the dangers are typically that:
   - The project will run over budget, caused by for example;
   - Late deliveries of materials or equipment
   - Lack of resources at the start of a project
   - Ineffective production leading to significant re-work

All conversions will entail a degree of risk, and this is discussed in papers in the RINA conference of 1999(Greville, 1999; Islam, 1999). These consider risk from a legal viewpoint, where the realization of the risk leads to a project failure which may in turn lead to legal action(Greville, 1999). As with Young, the focus of the paper in proposing solutions is to eliminate the risk by careful project definition (including the contract). Also, building in risk mitigation where the risk cannot be entirely removed. This can be achieved by a carefully constructed contract where unknowns in the project are recognized and the potential need to spend more time or budget to overcome them, is shared between contractor and customer.

The principal conversion risk is identified as the ship not being in the condition expected, since the donor ship will be one which has been operating for some time. This can require more remedial repair work to bring it to a suitable standard which meets owner and classification requirements.

Other risks can be present, for example the ship structure may need more strengthening than was anticipated to support new equipment, or may be in fact constructed differently than shown in the drawings, which makes fitting new prefabricated steelwork difficult.

As an example, the risks addressed in this Thesis are technical risks. Major risks in the conversion of tanker to bulk carrier, as it will be explained later, were:

- Maintaining structural strength as many cut-outs of main strengthening members were performed
- Maintaining the longitudinal strength to avoiding deflections which could result in permanent deformation

In terms of the risk ratings described previously, both of the risks could have potentially been catastrophic if they were realized.

In practice, really large technical risks are so potentially dangerous to the project that there is little possibility that they will not be properly managed. An example would be the alignment of ship hull sections built in different locations and then joined together, or the vessel lengthening projects mentioned earlier. The project risk of misalignment is so dangerous that the project management will make absolutely certain that the sections match.

Smaller risks, non catastrophic in nature, can sometimes be misjudged and miscalculated. Their effect however, if realized, can still affect a project. Again, by using the case study as an example, an underestimated risk was in the difficulty of moving existing steel structures, notably longitudinal bulkheads, and the introduction of new structures (top side tanks), within the relatively inaccessible spaces of a cargo ship. This risk was not well quantified at the beginning of the project and managing it required careful day by day management, which as mentioned earlier is also the case with ship-repair projects. It was initially thought that as these structures are large (bulkheads) and can be prefabricated (top side tanks) the degree of difficulty would be reduced. This is a typical example of ship-conversion sharing characteristics of both ship-repair and ship-building, affecting planning and risks.

2.7 Conclusions

Most relevant literature considers ship construction rather than ship conversions, and in most cases the conversion is highly individual in character. There are papers discussing a particular conversion, for example Weston. These do discuss some of the technical issues found, risks and their mitigation. However, there is little detail and rarely any useful cost information.

Bulk carrier design is described in a number of publications, but in all cases found, the design is conventional. As will be described later, an unconventional design could offer significant benefits. Once the starting point for a design is not a new ship (a blank sheet of paper, or rather a basis ship) but rather the donor vessel, then the design will have a significant impact on the success of the project. This can be significantly aided by Goal Based Design principles.

Design for production has been discussed and the principles should be applied in a design for conversion which recognises the constraints imposed by the conversion process. Design for production has been applied to new construction, and is well established. It can be applied to ship-conversion but within limits because of ship-conversion's relation to ship-repair and the boundaries that entails.

These boundaries are basically difficulties met when working within the constraints of an existing hull. By working externally wherever possible will minimise these difficulties. SPS has been used as an overlay to strengthen steel plates, and can shorten time to complete a repair by avoiding the replacement of steel structure. More recently SPS have been promoting use of their product for ice strengthening, again avoiding the need to change complex structure and work inside a hull. This is a feature that could aid ship-conversions in general.

Ship-conversion is considered a project. Project management requires planning but recognising the need for flexibility in a conversion. It is also necessary to identify and as far as possible eliminate risks. Risks have been categorised and discussed and it has been explained that the most important (catastrophic) risks will certainly be managed but others, less important, may be misjudged and this may create problems.

Chapter 3. Cost Effectiveness in Ship Conversions

3.1 Introduction

This section discusses the nature of conversions and how this relates to measuring cost effectiveness in conversions. It states that cost effectiveness of conversions is sensitive to a number of risks, the most important of which are very closely related to the cost and duration of conversion, market conditions present during the conversion, as well as after to some extent, and the quality of the converted vessel. It ends by stating that this thesis will examine ways that reduce the risks internal to the ship conversion project by seeking ways to reduce the conversion cost and duration.

It is the Author's opinion that factors affecting the cost effectiveness of conversion for both Owners and Shipyard must be examined. Cost effectiveness from either perspective (Owners or shipyard) can have an effect on both parties. If external conditions to the shipyard alter the cost effectiveness of a conversion, such as negative market fluctuation, they can lead to cancelation of the project, especially if a series of vessels is to be converted, such as in the Case study, as explained later. The shipyard when quoting for the project, may have calculated a learning curve in the cost, which would now be not applicable, thus its internal cost effectiveness would be affected.

Equally, internal factors influencing the cost effectiveness of a conversion for a shipyard may influence Owners. If the shipyard goes over-budget for example, and is unable to complete the conversion, or forces the Owners to pay in excess of initial price, or completes the conversion after the contract date, at which point the markets have taken a negative turn, the Owners are affected. Another hypothetical example of external conditions affecting the internal cost effectiveness of a conversion is the following: a series of vessels being converted, belonging to the same Owners, the first being delivered for trade whilst the remaining vessels undergo conversion. Any shipyard would consider this an "en-bloc" project rather than a series of projects. Assuming that the Owners depend on the earnings of the first converted vessel to cover part of the conversion cost of the remaining vessels and there is a drop in earnings, this could affect the cash-flow of the project. This could create internal problems and delays in the project which could increase costs.

It is the Author's opinion that as the shipping markets can influence the progress of a project, their effect should be considered when examining the cost effectiveness of conversions. At the end of this section however, it is stated that since external conversion factors/risks cannot be managed, this Thesis will continue by focusing on internal risks, which can be managed.

3.2 The Nature of Conversions

It is a well-known fact that shipping is a cyclic market (Stopford, 2008). As such, different sectors react differently to different global conditions, market demands and supplies, environmental considerations and regulations and also several macroeconomic variables. Therefore, it is certain that different shipping sectors will have different peaks and troughs.

These differences between these peaks and troughs may create favourable conditions for conversion. As one market booms, another may not be following the same path, creating a value difference between vessels operating in these respective markets.

According to the OECD report (*OECD*, 2008), the demand for ship conversions is driven by a variety of factors, none of which are amenable to forecasting. In times when no out of the ordinary upward “surge” in markets is present, ship-owners may elect to undertake a conversion in order to facilitate the entry of the vessels in a different market niche, for example, lengthening a tanker to increase its capacity.

Conversions also occur when ship-owners need to fulfill certain contracts they may be holding, such as long time charters and COA’s for which they do not currently own the suitable vessel. An example of conversions occurring to fulfill contractual agreements, are FPSO and FLNG conversions. One such example is the conversion of a shuttle tanker to FPSO, owned by OOGTK Libra GmbH & Co KG, performed by Jurong Shipyard Pte Ltd, in late 2014. The vessel was to be converted to fulfill a 12 year time charter to Petrobras. (www.*Sembcorp.com*, 2014)

Conversions can also be performed speculatively, where the owner believes that the new trade for which the vessel will be converted, will produce adequate earnings in the future, without having a specific employment contract. An example of such a conversion is the Golar LNG carrier conversion to FLNG. (Pierce, 2012)

Conversions are particularly favoured when a type of vessel is about to become obsolete, due to new IMO regulations, or the market in which it is operating cannot provide it with enough income to justify operation. A recent such phenomenon was the case of single hull tankers in the decade between 2001 and 2010. Single hull tankers were converted to double hull tankers so that IMO regulations for 2010 scrapping would not affect vessels whose owners felt that they could trade further. The loss of the tanker “Erika” in December 1999 had a profound impact on the shipping industry. The IMO introduced new mandatory phase-out requirements which are contained within the revised MARPOL Annex I Regulation 13G which led to the 2010 scrap deadline. (*OECD*, 2008)

However, single hull tankers were used as donor tonnage for Bulk Carrier conversions. There was a significant increase in 2007 in the number of contracts that were being placed for the conversion of single hull VLCCs into VLOCs, to the extent that it is being reported that ship conversion yards had become saturated. At the end of 2007, there were over fifty VLCCs scheduled to start a 'second life' as a bulk carrier in 2008 or 2009 as well as a number of Suezmax and Aframax vessels.(*OECD*, 2008)

As it has been discussed in the Literature Review, in 2007 the difference in value between tankers and bulk carriers of the same size was growing in favour of bulk carriers. The same occurred with the earning capacity of the said vessels at the time. This difference in earning capacity and value is what drove Tanker to Bulk carrier conversions at the time, and it is what made the owners of the vessels described in the Case Study convert the said vessels to bulk carriers. It is also what made other owners order newbuildings, orders for which increased dramatically. This backlog in newbuildings also increased the demand for conversions which became increasingly popular in 2007 as shipowners tried to overcome high newbuilding prices and long delivery times by adapting existing vessels for different roles, as the relatively short time required for a conversion was preferable in many cases to bulk carrier newbuilding lead times of up to four years.(*OECD*, 2008)

It can therefore be seen that the nature of conversions can be:

- Opportunistic, driven by sudden market changes,
- Focused, performed for specific contract obligations
- Speculative

Ship Conversion is not a procedure that can be planned throughout the life cycle of a vessel. It is an action that makes sense when new factors arise which were not predetermined, nor predicted.

3.3 What Is Meant by Cost Effectiveness?

It is the author's opinion that, given the several different natures of conversion which rely at times on prevailing market conditions at the time they are considered, at times on specific obligations to provide services in the future and at other times on predicted future market conditions, cost effectiveness in conversions must be examined in two stages:

1) During the conversion period, from the conception of the project and the purchase of the to-be converted vessel/decision to convert an already owned vessel, to the delivery of the converted vessel, and
2) From delivery of the said converted vessel until the sale of the vessel from its current owners.

This differentiation is necessary to account for the Long-Term/Short-Term needs of the different natures of conversions and the fact that some ship-owners may realize the asset as soon as conversion is finished and others may trade the asset and liquidate later, regardless of commitments. A ship-owner may view a conversion as a totally opportunistic venture, as described in "the nature of conversions" section above, one which at its end will have increased the value of the vessel and may wish to liquidate the asset, realizing its increase in value at that time, with or without an employment contract attached to the vessel. Future fluctuations in the shipping market that will come throughout the vessel's operation are not the concern of the subject ship-owner. The market fluctuation from the time of purchase of the vessel to be converted, until the time of project end and vessel delivery, though is. These possible short term fluctuations in the market may make the conversion non cost effective if they reduce the value of the converted vessel significantly, as the case may be that the converted vessel cost more than buying a purpose built vessel of the same age, at a depreciated price at that time.

Another owner may view the converted vessel as an opportunity to trade in a market where other vessels, if ordered, are very expensive and delivery is many years later, or if bought second-hand, are more expensive than the cost they would have incurred for converting the subject vessel. Therefore they would be entering a market with the added benefit of excess asset value in their books, assuming that short term fluctuations during the conversion did not affect negatively the value of the vessel. This type of ship-owner is willing to take the risks of market fluctuations in the future, short-term or long-term.

In the first stage, the cost effectiveness of a conversion can be defined by the following simple equation:

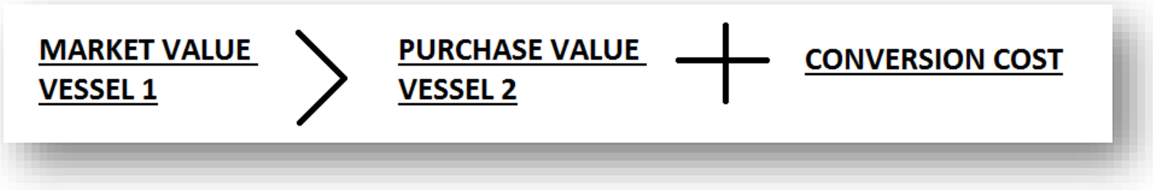


Figure 3-1, Cost effectiveness of a conversion, stage 1
(Author's figure)

Vessel 1 is a purpose built vessel and is the type of vessel whose market has increased its value and shipowners may want to convert vessel 2, which may be a vessel operating in a not so favoured market, into. Vessel 2 will therefore be the converted vessel. Both vessels have the same age and Deadweight. If the aggregate of conversion cost and purchase value of vessel 2 are smaller than the value of vessel 1 at conversion end and vessel delivery, then the conversion is cost effective.

In the second stage, the amortization through operation of the investment must be taken into account, which is largely affected by the income of the vessel for the period until its current ownership decides to sell it. In this situation, cost effectiveness of the conversion can be determined using the following equation:

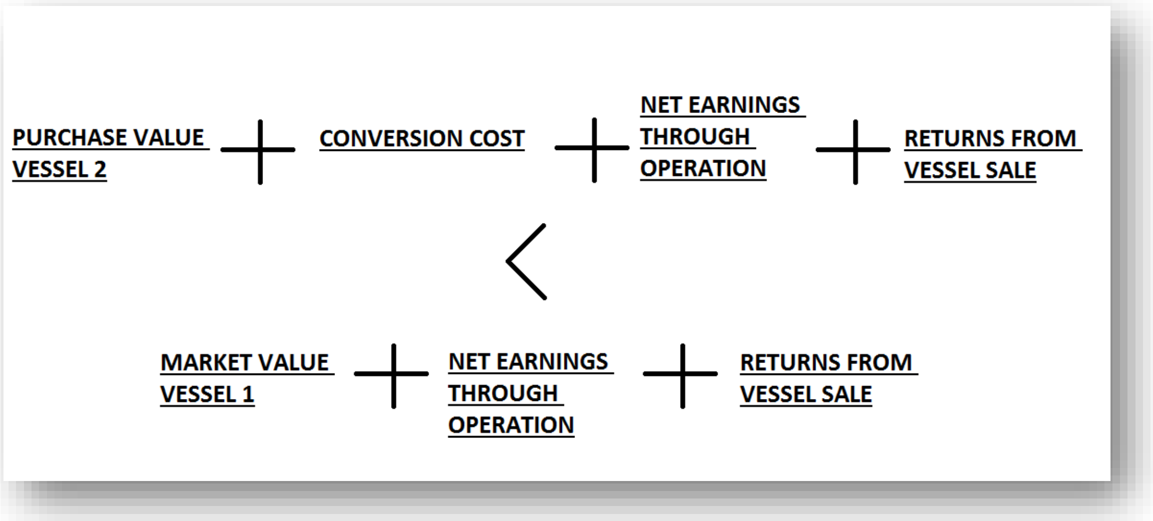


Figure 3-2, Cost effectiveness of a conversion, stage 2
(Author's figure)

Purchase value of vessel 2, is the purchase price of the vessel that is to be converted and market value of vessel 1 is the value of a purpose built vessel of the same age as vessel 2 and having same characteristics as vessel 2, after vessel 2 has been converted. The net earnings through operation are assumed to be for exactly the same period of time and the final sale of the vessel is assumed to be on exactly the same date for both vessels.

As it can be seen, the only difference between the two sides of the equation are the (Purchase Value of Vessel 2 + Conversion Cost) and (Market Value of Vessel 1). Earnings through operation and returns from sale will theoretically be equal for two similar vessels in capacity, age and trade if the trading period and date of sale is the same for both cases.

There may be differences as such between a converted vessel and a purpose built vessel, affected largely by the quality and the usability of the converted vessel and the condition of the purpose built vessel. Between similar vessels, a vessel that performs better when chartered is likely to bring better operating results throughout its trading lifetime.

However, the earnings of vessels through operation, as well as returns from the vessel sale, are affected largely by market conditions and supply and demand for these vessels in that market. Negative fluctuations in the market sector that the vessels are operating in, could leave owners with a loss from operation and sale. This would make the investment into this market sector non cost effective.

However, in this case, both vessels, converted and purpose built, would suffer loses. It is not the conversion that would not be cost effective; it is the venture into this market sector that was not prudent.

In this case, it is worth noting however, that if the (Purchase Value of Vessel 2 + Conversion Cost) are smaller than the purchase price of the equivalent purpose built Vessel 1 at the time that both vessels' operation starts, then the conversion option presents the owners of the converted vessel with less loss of capital than the owners of vessel 1, the purpose built vessel, which was purchased at full market price at the time.

The same would be true in a scenario where the market would be steady or booming. The converted vessel would present a more cost effective option.

By excluding any exogenous factors, such as the future of the shipping market that the vessels may trade in, which in any case cannot be predicted accurately, nor controlled and may even affect signed contracts, as severe market fluctuations may bankrupt charterers or force them to re-negotiate terms of employment of the chartered vessel (Wright and Tsui, 2012), Cost Effectiveness in both scenarios, is subject to many factors which are influenced by the conversion project itself.

Therefore, in order to maximize the chances of the cost effectiveness of conversions, the internal conversion risks must be minimized.

3.4 Internal Risks in Ship Conversions

Conversions, as any project, carry risks. These risks are multiple in nature and number and may affect the project differently, but all risks, if materialized, have an immediate effect in the conversion cost, duration and the quality of the converted vessel. All these directly affect the cost effectiveness of conversion. Such risks are:

- Short term market fluctuation risks. The market value of any vessel may vary with time and market fluctuations. These fluctuations are also likely to occur whilst the vessel is being converted, thus if negative, damaging the cost effectiveness of the conversion. In order therefore for such a risk to be minimized, the duration of the conversion must be kept to a minimum. By minimizing the conversion time, the converted vessel has more possibilities to be delivered to owners whilst market conditions are favourable for conversion. Once the vessel is delivered, owners have two options, to sell it and realize the excess in book value now, or carry the risk of future market fluctuations and operate the vessel.
- Excessive conversion cost. This can lead to non cost effectiveness of the conversion project if the sum of the cost of conversion and the purchase price of the to-be-converted vessel are higher than the purchase price of the equivalent purpose built vessel. Cost effectiveness is therefore conversion cost sensitive.
- High purchase price of Vessel 2. The vessel to be converted must be purchased, if not already owned, at a price favourable for conversion, a price which would allow as big a margin possible for profit. The importance of to-be-obsolete donor vessels is particularly significant at this stage. By using vessels which are about to become unable of further trade, or have already become unable to trade any longer, will significantly aid the cost effectiveness of the conversion. As demand for such vessels drops, so does their value. This was the case with single hull tankers towards the end of the 2001-2010 decade, as mentioned in the “nature of conversions” section above. Although this is not a pre-requisite for conversion, converting a vessel whose value has dropped because of lack of demand for said vessel, will increase the chances of conversion cost-effectiveness.
- Quality of the converted vessel. A converted vessel, in order to present value when compared to a purpose built vessel of the same age and characteristics, must not be limited in capacity and performance compared to the purpose built vessel. It must be safe for operation and acceptable for operation by market standards, i.e. must be easy to operate and

favoured by charterers. A converted vessel must be designed so as to increase the value and earning capacity of the vessel compared to a purpose built vessel of the same age and characteristics.

By minimizing the aforementioned risks, chances for conversion success and thus cost effectiveness are increased. With the exception of the risk associated with the purchase value of the to-be-converted vessel, the remaining risks are associated with conversion performance, and especially with the duration, cost, and the quality of the finished product of the conversion.

3.5 Synopsis and Prelude to the Next Chapters

In this section of the Thesis, the subject of cost effectiveness of conversions has been discussed and ways of measuring it have been presented, along with the reasoning behind the translation of the concept of cost effectiveness for ship conversions. The internal risks relevant to cost effectiveness have also been presented and the suggestion that minimizing these risks will increase the chances of cost effectiveness of conversion projects was made.

It is the author's opinion, who was project manager for the two Tanker-to-Bulk Carrier conversions that took place in Salamis Shipyards of Greece as described in the case study, that conversion cost and duration can be reduced with a dedicated design and strategy for conversion philosophy. The author also represented the ship-owners' and ship-managers' interests in these conversions as both parties had joined commercial interests with Salamis Shipyards at the time. In this respect, the author was appointed by all parties to be responsible for the conceptual design, design for conversion, conversion strategy as well as project management. The author was not responsible for the detailed design of the conversions as this was sub-contracted by Salamis Shipyards to external design offices.

In the following sections, this Thesis focuses on a discussion on what the Author considers to be the basic principles of design and planning for ship-conversions, then specifically Tanker to Bulk Carrier conversions, in an attempt to reduce the cost and the duration of the said conversions through design and strategy setting for these conversions and, more importantly, in order to be able to produce a set of "principles" for design and planning for conversion, which can be applied to all conversions to reduce conversion cost and duration.

The risk of high purchase value of the donor vessels is also considered, as the donor vessels in the case study were single hull tankers.

The risk of the quality of the conversion finished products was also considered, as described in appendix II, and quality of the converted vessels is validated in appendix I.

Chapter 4. Basic Principles of Conversion Design and Planning

4.1 Introduction

In this section, the basic principles of conversion design and planning according to the Author are presented. They are based on available knowledge from bibliography, which has been previously analysed, and the Author's personal conversion experience from managing different conversion projects. The reason that design and planning are considered together is that, according to the Author, they must. It is only through understanding the procedures used in conversion that the designer can produce a good design for conversion.

4.2 Goal Based Design

When the decision to convert a vessel is made, it is based on taking calculated risks, created through innovative actions, to produce profit. The innovative idea of changing a vessel's scope will eventually, if risk calculations are correct, lead to excess asset value, and higher operating returns. It is the author's view that the spirit of innovation should not be lacking from the design process of ship conversion, as it may benefit the conversion project. Innovation in design, rather than strictly following design norms, can lead to the solution of many problems which will be created when attempting to change the scope of a vessel, it may reduce cost and it may reduce the project's cycle time.

The International Maritime Organisation (IMO) has recognised an increasing need to adopt a Goal-based approach to regulation in general, and states that there are good technical and commercial reasons for believing that this approach to regulation setting is preferable to more prescriptive regulation (Hoppe). It also states that it is quite probable that prescriptive regulations, eventually prevent the marine industry from adopting current best practice and that there are clear benefits in adopting a goal based approach as it gives greater freedom in developing technical solutions and accommodating different standards. It also states that Goal-based standards for ship construction should form the foundation for the future advance of international regulatory standards in shipping.

This philosophy of Goal-based regulation can be translated to Goal-based design, whereby whilst following classification society regulations, the designer can use innovative ideas to address technical matters in a conversion.

Innovation does not always require designing something extravagant. Innovation in design can sometimes mean doing the least amount of work and using structures that are already existent to serve multiple purposes and generally maximise their use for the vessel's new scope. In order to bring innovation in the design however, the designer must have also good knowledge of the conversion process, which as the case study will show, may come through trial and error.

Trial and error is very common in ship-conversions. It is one of the strongest general points that distinguish it from ship-building, in terms of planning production. It is almost certain that the application of a rigid shipbuilding-like approach to project planning will fail, due to the uncertainties that are inherent in such major vessel modification projects (*OECD*, 2008).

4.3 The "Producibility" of the Design

For successful conversion, the design and the strategy of the conversion must be created in tandem, complement one another, for the sole purpose of conversion success, by minimising direct and indirect costs and reducing the cycle time of the project. A successful conversion design cannot be produced without the designer having knowledge of technical and planning details of a conversion project. Lamb (Lamb, 1986) suggested that ship designers take more responsibility for the producibility of their designs and to accomplish this, designers must be better educated in production processes and relative costs, a point which has been verified by the case study in this Thesis as will be discussed later.

Furthermore, it is the author's view that one of the most common mistakes that can be made by ship designers when working on a conversion design is to create a design without taking into consideration the existing form of the vessel to be converted.

This is not to criticise designers in particular. The education, training and experience of most designers, is in creating new ships. The starting point when designing a new ship is a "basis ship", a vessel that has been designed and built in the past and contains all the knowledge from trial and error obtained from its construction, operation etc. This provides a starting point for the design, which encapsulates a huge amount of previous knowledge. It avoids "reinventing the wheel". It is a perfectly legitimate and sensible way to design a new ship. However, if the starting point is an existing structure, especially one created for a different ship type than the one the conversion will produce, then the normal approach to ship design may not be appropriate.

A good example of such a scenario is given in Appendix III, where a conversion of a Panamax (LR1) Tanker to Bulk carrier is discussed. The design created for the conversion does not take into consideration the existing shape of the vessel and thus the changes it requires are major, multilevel, complicated, whilst the specification containing the design fails to explain why the design has incorporated all these radical changes. This conversion never took place because of its complexity which resulted in excessive cost and time required to be performed, as explained by the vessel's owners.

By examining the basic Design for Production Guiding Principles as taken from Larkins (Larkins, 2007), it can be seen that simplicity is one of the foundations of design for production. Simplicity must also be one of the foundations of design for conversion. As it will be shown later in the Thesis when discussing and comparing the application of different methods to address design and planning issues applicable to the Case Study, as simplicity in structures and procedures increases, cost and cycle time of the conversion are reduced.

The fundamental principles of design for production must be applied when designing for conversion according to the author, as while there are differences between the activities of ship-building and ship-conversion, there are a number of similarities and these similarities, rather than the differences, are the dominant elements that need to be considered when looking at possible interactions between these two sectors, according to the Organisation for Economic Cooperation and Development (*OECD*, 2008).

The main similarity is the production of flat panels. Steel additions in many conversions are usually primarily in the form of panels to create bulkheads, decks etc. Flat panel prefabrication is one of the main activities of shipbuilding prefabrication. They mainly comprise of flat plates, longitudinal and transverse stiffeners.

By creating panels designed for production, according to the Guiding Principles as given by Larkins (Larkins, 2007) and thus share the same components when designing for conversion, all the benefits of repetitive production will eventually reduce cost and cycle time.

Shipyards are set up in such a way so as to produce structures by dividing them is smaller simple repetitive tasks/structures which are fabricated in different work stations and then assembled and welded together to make up the desired final structure. This allows for continuous flow of material and non disrupted input of labour into the tasks. Because of this repetition in tasks, many shipyards have invested in fabrication automation to some extent.

Using panel lines, shipyards have been able to reduce steel throughput times and eliminate unnecessary man-hour consumption. Panel lines are mainly used by shipbuilding yards due to the immense volume of standardised steelwork required for ship production. Other shipyards however, such as Salamis Shipyards that mainly deal with ship-conversion, have also decided to invest in smaller panel lines as they have adopted the design for production approach when designing for conversion, as it has been proven, in cases such as the box girder application, which is discussed later, and fitting new bulkheads in a tanker (Koros, 2009b), as well as in the case of the ferry garage conversion (Koros, 2006b) also discussed later, that design for production and design for conversion can complement each other to produce the best result possible in conversions.

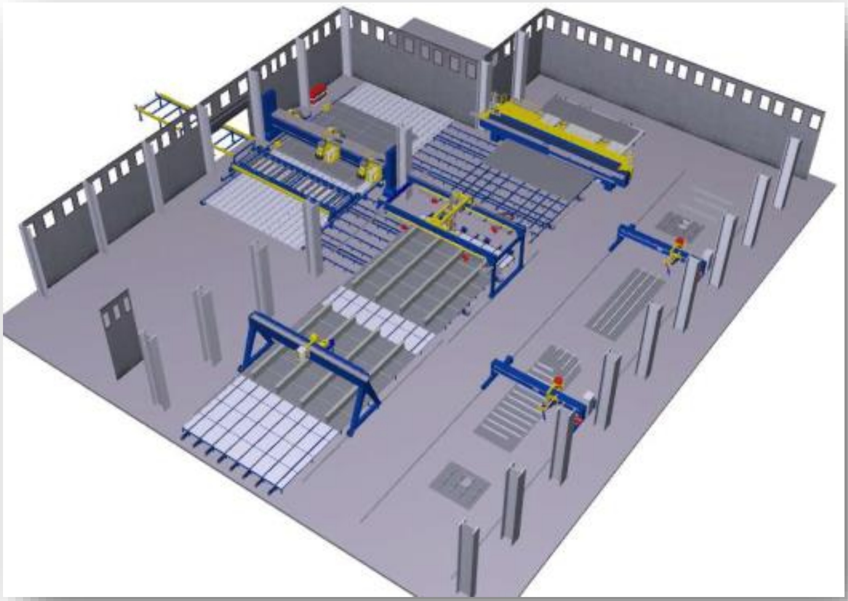


Figure 4-1 Panel Line
(Pemamek, 2013)

Panel lines allow shipyards to perform works previously performed in manual work stations during prefabrication, with maximum automation, using mechanisation and robotisation of activities, whilst maintaining process sequence and philosophy. This drastically reduces man-hours and thus cost. Panel lines are considered the most efficient means of standardised steel production.

When designing for conversion, if the designer focuses on repetitive simple structures tailored to the production facilities' capabilities, they are on the right path for producing a design which will increase the conversion project's chances of success and viability.

4.4 Design for Production and Design for Conversion – Major Differences

The main difference between standard design for production and design for conversion, which may also become a determining factor of design for conversion success, is that interim products will not be made into blocks which will be joined together to make a hull structure, but rather interim products may or may not be joined to create structures and will be fitted on an existing hull in the form of structures as small as brackets and as large as bulkheads or deck sections (with the exception of jumboisations).

This suggests that while design for conversion and design for production can share the same basic principles (simplification of structures, work stations, repetitive standardised products, etc.), in fact they can be different from one another.

The fact that products have to be fitted into an already existing structure directly implies that there will be constraints. When building a hull, in essence steel blocks are joined on the building berth without any constraints, other than the lifting capacity of the crane etc. The movement of the blocks is in essence towards each other until they meet to be joined together. The blocks have been prefabricated and pre-outfitted with all the components required so that work can be minimised on the berth (Lamb, 1986).

Ship Conversion can mean a number of things. Throughout history there have been many examples of ship conversions very different to one another, such as:

- Ship lengthening conversions, where vessels were lengthened whilst in dry dock, to increase their cargo carrying capacity. (Hellenic Shipyards, 1967)
- RORO/Passenger ferry deck extension, where decks were lengthened to create new garage and accommodation areas so that the vessels would fit more cars/lorries and passengers (Koros, 2006b)
- Tanker double hull conversion, where tankers with single skin would be fitted with a double hull structure to comply with modern regulations. (Koros, 2009a)
- Bulk carrier to cattle carrier, where dry cargo vessels would be fitted with suitable areas and equipment for the transportation of livestock (www.Chengxi.cssc.net.cn)
- Tanker to FPSO, where tankers would be fitted with oil producing equipment to produce and store oil offshore (www.*Sembcorp.com*, 2014)
- LNG vessel to FLNG, where LNG carrying vessels were converted to be able to produce and store LNG offshore (Hand, 2015)
- Tanker to shuttle tanker, were tanker vessels were converted to be able to load and discharge cargo offshore. (Gdansk Shiprepar Yard, 2007)

Whilst these conversions may be different to each other and thus require different things done to the vessels:

- deck strengthening for fitting top-sides/ oil production equipment
- propulsion equipment removal and fitting boilers in their place
- fitting a turret structure

- fitting longitudinal bulkheads and tank top
- Fitting LNG liquefaction and re-gasification equipment etc.

They all have things in common.

All these conversions require structural works and systems outfitting which can be fabricated to some extent in standard repetitive sections (Design for Production is applicable). These conversions however also share the same common problem, being the existing structures that the work must be carried out in, the vessel's hull, which creates "bottlenecks".

Bottlenecks can be defined as situations in conversions whose presence affects the progress of conversion in a negative way.

Bottlenecks can be faced to some extent in all conversions because all conversion projects occur, by definition, within the confines of a vessel's hull and as it has been seen in this thesis, all these common conversion bottlenecks are not created during the prefabrication stages, where most of the attention is paid when designing for production, but on board the ship.

It has been found, as later explained in the Thesis, that design for production alone does not guarantee the absence of bottlenecks as design for production was used to the maximum extent in all procedures of the conversions in the Case Study. In this respect, new procedures were created after the first had partially failed, taking into account the existence of bottlenecks, but designed in such a way that their implementation eliminated or reduced bottlenecks. It must be noted that these procedures, were also designed for production. It was found that by eliminating or minimising the conversion bottlenecks, the conversion project was aided significantly in terms of cost saving and reduction of cycle time.

When considering that ship conversion can be said to be the bridge between ship repair and shipbuilding, the existence of bottlenecks is not surprising. Ship repair, by default, only occurs in the vessel's hull, which as discussed, creates constraints; hence bottlenecks are an inherent part of ship repair. The fact that bottlenecks were proven to exist in the case study, and the fact that design for production (a dedicated shipbuilding design philosophy) was also proven to be able to be used effectively in ship conversion, support this statement in the OECD report. It also supports the fact that design for production alone is not sufficient and that since conversion bottlenecks can be present to some extent in all conversion projects, given their nature as described above, design for conversion in general must be performed with the aim of eliminating or reducing them, whilst being complemented by design for production. This is a fundamental difference between Design for Production and dedicated Design for Conversion.

4.5 Ship-Conversion "Bottlenecks"

4.5.1 Work in confined spaces

As in ship-repair, conversion presents many challenges in material flow. This is because prefabricated products have to be fitted in areas where access is not always easy. Access to these areas is what will define, in most cases, the size, weight and shape of the prefabricated piece to be fitted.

Ship conversion, by definition is changing the role/carrying capacity/cargo of a ship, which always creates structural issues. These structural issues are mainly, but not always, created in the hull sections that play the most important role in cargo containment, for example, the tank top. In cases where the new cargo presents a more demanding containment reality, the tank top must be strengthened. Therefore, the stiffener, which could range from a flat bar to a whole new floor or girder, will have to be passed through an access point, which in most cases does not exist and has to be created, in order to be fitted in place. This access point may determine the size of the prefabricated piece, as the stiffener may have to be cut in smaller pieces in order to fit through. It may then have to also pass through a number of manholes to reach its final place. In confined spaces, lifting for fitting can only be performed by hand and chain blocks. This is another constraint on its own, which as it will be seen, is common in most typical conversion bottlenecks.

Picture 4 Manhole in double bottom
(Koros, 2010)

Picture 5 Access cut out of tank top
(Koros, 2010)

In confined spaces, such as the double bottom, there are always more obstructions, other than the arrangement of the ship structure, such as piping networks for ballast. The prefabricated piece may have to be cut in situ in several smaller pieces so that it can fit around a pipe.

Picture 6 Floor re-built around pipe
(Koros, 2010)

When working in confined spaces and have to fit steel structures through obstacles and thus cut them in pieces, it is quite an often phenomenon to make mistakes and cut the wrong prefabricated piece. As the piece must be used, it will have to be mended and find a place to be fitted, usually another piece's place which was not placed there due to another mistake.

Picture 7 Re-built floor due to mistake
(Koros, 2010)

Another very important constraint when working in confined spaces has to do with welding. Welding will hinder the task time-cycle, as confined spaces present difficulties in welders manoeuvring, create fatigue to the welders, present fume extraction and lighting difficulties, which increase the risk of accidents and thus protective measures required etc. Such situations make conversions resemble more ship-repair projects rather than ship-building projects.

4.5.2 Work on staging

Staging is required when having to fit sub-products in heights greater than a person's reach. Staging can therefore be required when having to work in the under-deck area, as in the case study to fit the top-side tanks, around the accommodation of a vessel (externally), when having to work on a sloped bulkhead, or on the ceiling of the engine room, etc. Working on staging is inevitable in almost every conversion project. The erection of staging alone creates extra man-hours in a project which will slow the project down and increase its cost. Staging, however, increases man-hours indirectly as well. Working on staging to fit steel components, pipes, lights, cable trays etc, is in its nature a procedure carrying many constraints.

Picture 8 Staging
(Koros, 2010)

In terms of component weight, the component meant for fitting must not weigh more than the staging planks can hold (including a large safety margin) and must also be able to be manoeuvred, even partially, manually. Chain blocks are always used, but a good percentage of the piece's movement for alignment and final fitting is done by hand, and must therefore be subject to as small an effort as possible.

Picture 9 Brackets and girders fitted by workers on staging
(Koros, 2010)

There are however some cases where large and heavy structures must be fitted below deck. These structures are too heavy to be placed on the staging planks and then be lifted in place by chain blocks. Therefore another way must be found. Usually, if not always, this is in the form of a cut access point on deck (or tank top etc) through which the structure is lowered with the help of a crane. The structure is never left to rest on the planks. Instead it is held in position by the crane until the workers working on the staging have attached the chain blocks on the structure and it is ready to be lifted in place using the said chain blocks. Therefore a separate issue arises, that of the access point and all the difficulties that that entails.

In all cases working on staging is constrained by many ways.

The constant problem with working on staging is that work must be performed over-head and gravity is working against the workers, work is slow due to size and weight restrictions of work pieces, work can be slowed due to interference of existing structures around the work area which create a form of confined space and very importantly, it takes many man-hours to set up and then take down staging; not to mention that while that is being performed, work at that particular area of the ship cannot be performed.

4.5.3 Steelwork in-situ

In almost certainly all conversions it is possible that work has to be carried out in spaces which are covered overhead and therefore have no access to crane. Many such cases were present in the Case Study, but also elsewhere, such as in the garage of a passenger ferry, in a tanker's cargo tank, ballast tanks etc.

Having no access to a crane means that other lifting means will have to be used. Depending on the accessibility of the area, these could range from nothing at all to chain blocks or in some cases where there is adequate space, fork-lifts. Immediately it is understandable that this issue creates constraints. These constraints mainly refer to the size and weight of the prefabricated pieces to be fitted. If the prefabricated pieces cannot reach the area intended for fitting as whole pieces, due to access and size restrictions, they will have to reach it in smaller pieces and be fabricated or re-fabricated in situ.

An example of a situation where work in situ is required is fitting a second garage deck in a passenger ferry (Koros, 2006b). Decks are generally prefabricated in flat panels and then fitted in place with the aid of a crane. In the garage compartment of a ferry though, access to crane facilities is impossible, as the passenger decks are right above.

Picture 10 Garage deck fitted in aluminium catamaran ferry
(Koros, 2006b)

The deck panel therefore has to be fabricated to some extent in situ using only some prefabricated pieces, such as transverse T beams etc. The same goes for outfitting the deck with fire fighting and other systems. As the deck panels cannot be fully prefabricated, the deck can only be outfitted once it is completely installed in place in situ. It is obvious that this situation creates constraints which have an immediate effect in cost and cycle-time.

In this particular example, avoiding working in an area which is covered over-head is impossible since the objective it to create a new deck inside a garage. However, the designer can reduce the amount of work having to be carried out in situ and increase the work which can be performed in the workshop while prefabricating parts of the deck. For example, the designer could reduce the number of brackets fitted to the panels and replace the lost strength by redesigning the longitudinal or transverse stiffeners. Since stiffeners are prefabricated, the total cost, and time required for the job would decrease as the prefabricated pieces are produced in organised work stations.

This is an example of design for production complementing design for conversion for improvement, as by minimizing and simplifying the number of components in a panel (Larkins, 2007), a bottleneck of conversion would be reduced. It is also a good example of how understanding conversion procedures can improve conversion design.

4.6 Reusing Material

During conversions a large portion of existing steel structures has to be cropped. The most common reason is that, in their current form, they cannot serve a meaningful purpose in the vessel's new scope and can also be obstructing the vessel's new operations.

However, when the vessel was being built, many man-hours were put into creating these structures, including materials, which would be worth saving.

There is a possibility that some of these structures may be re-used in the vessel, perhaps not as they are, but after they have been modified, they could serve a meaningful purpose again, given that they are in a condition, in terms of wear, that allows re-use.

Modifying existing structures however apart from direct costs, such as cropping and relocating the structures, may create indirect costs as well, such as straightening the components to be refitted etc, which may render the procedure non viable in terms of cost.

4.7 Using a Dry Dock to Perform Major Conversions

Some conversions require major modifications to be performed on the vessel being converted, which may lead to loss of longitudinal strength, loss of stability or loss of water tightness during the conversion project. It is common practice to deal with these issues using a dry dock. For some conversions, such as the jumboisations described earlier in the Thesis, the use of a dry dock is a must. In conversions of tankers to bulk carriers, such as these in the case study, the current bibliography states that the use of dry dock is necessary (OECD, 2008). This is an understandable statement as the conversion requires major modifications to the vessel's hull which definitely affect its structural integrity and most importantly its longitudinal strength. As the vessel rests on the dry dock, it relies on the longitudinal strength of the dock and therefore major modifications on its hull which affect longitudinal strength can be performed with safety.

A common problem with performing conversions in a dry dock can be the crane capacity available, which directly affects the flow and size of prefabricated structures to be fitted into the hull. Many dry docks are fitted with 5 to 10 ton cranes, with minimal outreach. Such cranes are very inefficient in large scale conversions. Unless the dry dock is right next to a pier, on which there is a crane of significant lifting capacity, or has significantly higher crane capacity itself, a floating crane will have to be used in order for the flow of prefabricated structures to not be impeded, thus slowing down the conversion. If this matter can be addressed, then performing major conversions in a dry dock can prove both safe and efficient in terms of material flow. There are however dry docks available with cranes of higher lifting capacity and these would prove more suitable for such major conversions.

If such a dry dock is not available in the converting facility, the conversion can still take place, as long as the water tightness of the hull is not compromised. The longitudinal strength of the vessel can be monitored throughout the conversion process and the bending moments on the vessel can be temporarily decreased. This can be done by managing the ballast system of the vessel to counteract the hogging forces, or by adding stiffening structures on the vessel to increase its strength, or both.

4.8 Synopsis

In this section the basic principles of design and planning for conversion have been presented and discussed. These are the result of the extraction of relevant knowledge from the existing bibliography, common practices in ship conversion projects and the Author's own experience from managing ship conversions. This theory was applied to the design and strategy set out for the tanker to bulk carrier conversion which is presented in the next section. As it will be shown later in the case study, knowing and applying the theory is not always enough for a successful conversion. It has been explained that even as conversions share characteristics, conversions are never the same with one another. It is therefore expected that errors will be made and improvements are always possible. The methods used in a conversion may be designed and performed according to the relevant theory but with moderate success. This is because knowledge of the theory and general conversion experience do not guarantee that all method parameters have been thought of thoroughly.

By re-designing the said methods this partial failure may be avoided; but often redesigning the methods is possible only after seeing them fail.

Chapter 5. Design and Strategy for the Tanker to Bulk Carrier Conversion

5.1 Introduction

This section discusses the main design and planning issues when having to convert tankers to double hull bulk carriers. It addresses the issues that play the most important role in the said conversions.

It also presents the main conversion strategy issues, identifying four main conversion steps. It discusses the technical challenges associated with those steps while presenting the options available to satisfy the requirements of each conversion step.

This section forms the basis for the design and the conversion strategy presented in the case study.

5.2 Main Design Issues

5.2.1 Extent of modification to the donor vessel's cargo tank layout

The author and Salamis Shipyards, being the conceptual and main designers behind these conversions, were well aware that creating a design that required the least amount of work, would increase the chances of success of these conversions. Therefore, the similarity of the existing tanker layout, to the desired bulk carrier layout, especially in terms of cargo hold subdivision, was desired. The logic behind this strategy, as simple as it may be, can play a determining role in the project's success, as the less work required, the less man-hours are to be consumed and thus, the cost is reduced.

The shipyard, prior to performing the conversions discussed in the Case Study, had been asked to provide a preliminary quotation on a Tanker to Bulk Carrier conversion, the design for which was created by a third party and a brief specification and commentary for the said design is presented in appendix III. That design incorporated many fundamental changes to the vessel's hull including scrapping all existing cargo transverse bulkheads and fitting new ones to create a completely different hold arrangement to the existing tank arrangement (5 existing transverse bulkheads to be removed and 8 fitted in different locations). That design was very intrusive to the existing structure of the ship which, as it was understood at the time, made the cost of conversion too high for the vessel owners to be willing to proceed. (APPENDIX I)

Despite the changes that might have been required by her owners at the time, such as tank top reinforcement to carry heavier cargos etc, the yard, after carefully studying the specification, was of the opinion that there was no need for scrapping all the transverse bulkheads, as after removing the longitudinal bulkhead that the vessel had in the centerline, the vessel would have been capable of performing her new duties with six cargo holds, a number of cargo holds which is usual in modern vessels of such size. The shipyard felt that this work would have been excessive and incurring costs that could be avoided.

It is the Author’s opinion that transverse bulkheads, unless affecting the trading ability of a vessel, should be left intact or, if that proves not feasible, undergo the least amount of work possible.

5.2.2 Dealing with the loss of longitudinal strength

The biggest problem faced when designing the conversion from tanker to bulk carrier, is the loss of longitudinal strength of the vessel. The main deck of the tanker will have to be cut in order to create the cargo hold openings. This instantly reduces the vessel’s longitudinal strength since the section modulus of the vessel is altered. Therefore regaining the lost value of the section modulus is a priority.

In this respect, and since parts of the deck have to be cut out to create the hatch openings, the strength lost from the cut out material will have to be regained in the remaining part of the deck. There are some options presented to designers:

5.2.2.1 Enhancing the remaining existing deck stiffener matrix

In the case when the conversion candidate is a tanker with stiffening above deck, such as the one shown in the picture below, enhancing the remaining deck stiffener matrix implies adding longitudinal stiffeners on the deck to compensate for the loss of the deck material and continuity of the stiffeners. These stiffeners though will have to be of adequate size and thickness to be effective. It is not uncommon to see main longitudinal stiffeners on deck structures of 1000mm height in the said tankers.

Picture 11 Tanker with stiffening structure above deck

(www.*Dynamicco.com*, 2015)

This option also implies that the stiffeners to be added will be of the same philosophy as the existing stiffener matrix, for example main stiffeners to be T bars and secondary stiffeners bulb flats when the candidate vessel follows this design philosophy. In this case, enhancing the matrix could for instance mean adding more bulb flats between the existing ones and increasing the height of the T bars by cutting out the flange, increasing the main body height and then adding another flange at the top. Or the existing flange can remain intact and an additional T beam be added on top.

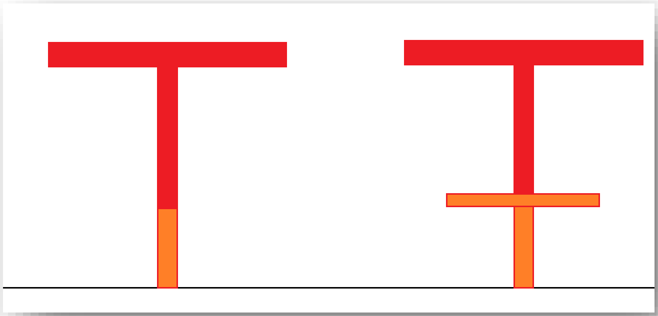


Figure 5-1 Two options for enhancing existing T stiffeners

(Author's figure)

A "stiffeners-on-deck" philosophy, however, implies difficulty in accessibility of areas on the main deck. This is mitigated by fitting catwalks around the main areas of concern on the deck. This would however not cease to be an "odd looking" bulk carrier and also further steelwork would be required to fabricate the catwalks. Further to this point, lack of ease of accessibility in areas of interest on the main deck could raise operation reliability issues.

In the case of tankers with the stiffening matrix below deck, the same stiffening philosophy would apply.

T stiffeners however, when fitted in the cargo holds area present a problem. When bulk carriers are carrying less dense cargo, such as grain or woodchip, they tend to be laden up to the hatch coaming area, beneath the hatch covers. The cargo therefore will be covering in full the under deck stiffeners. When discharging cargo, a small amount of cargo would always remain above the flange bar of the T stiffener. This is not the case with bulb-flats, which are generally preferred as means of stiffening as they are readily available in different sizes whilst being the strongest type of stiffener whose structure does not create the said cargo problem. The problem with bulb flats is that they are not produced in sizes big enough that allow them to be used frequently as main longitudinal stiffeners, such as girders. T stiffeners on the other hand, if the size required is not available in the market, can be fabricated in any size and shape desired. Hence they are most commonly used as main stiffeners/girders.

Further to cargo loss, the cargo holds would require much more cleaning. The only way to avoid this problem, specifically when referring to main stiffeners of very big size where bulb-flats of equivalent strength do not exist, would be to avoid any horizontal plating on the stiffeners, which means that a standard T section stiffener could not be used; instead the flange plate of the stiffener would have to be fitted at an angle so as to allow the cargo to drop freely while discharging. This would of course alter the section modulus and thus the strength of the stiffener, making it lower than when in normal T form. This could be solved by adding a second, or more flange plates on the stiffener.

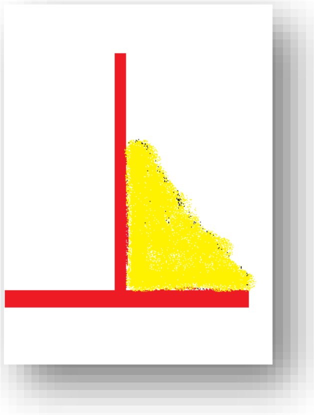


Figure 5-3 Underdeck T stiffener

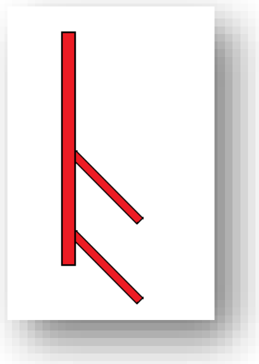


Figure 5-2 T stiffener equivalent

(Author's figures)

The figures above show the alternative arrangement of stiffeners, which assists cargo discharge but requires more man-hours for fit-up and welding than a normal T beam as the stiffeners are made of more components than a normal T bar.

5.2.2.2 Adding top-side tanks as main stiffening members

Top side tanks are most commonly used in bulk carriers as extra ballast space. Also, since they are fitted throughout the cargo hold area, they are almost always used as a means to add longitudinal strength to the vessel. The benefit that top side tanks have as compared to every common longitudinal stiffener is that because they are structures made of longitudinal and transverse components, they can provide much more longitudinal and local reinforcement than any common stiffener.

This option however, has some important technical issues that must be considered.

In terms of transverse strength, tankers are stiffened with transverse webs. These are positioned in respect to each other at a distance ranging from approximately 2.2 to 3.6 metres apart. The transverse stiffening in the topside tanks, as well as any other transverse stiffening for that matter, will have to follow that frame spacing. In order to be able to prefabricate the top side tanks and not build them in situ which will require much more man-hours than the prefabrication method, the transverse webs of the ship will have to be cropped or lengthened. This is because the height of the existing webs is not sufficient to reach the end of the slopping plate of the topside tank, thus leaving the bottom part of the tank not strengthened transversely.

If the topside tanks were to be fitted without any transverse stiffeners, the material required to be fitted to fill the gap between the existing webs and the top side tanks bottom, would have to be fitted in situ.

Therefore the tanks have to be designed to match the existing stiffening matrix of the vessel and also, as design for production would be beneficial, working in situ must be reduced and the tanks must be prefabricated to contain stiffeners that will replace the cropped-out stiffeners of the existing matrix.

5.2.3 Creating the double hull structure

A common feature that tankers share is that they rely for strength on their longitudinal bulkheads, be they single or double sided vessels. Tankers in most cases are fitted with longitudinal bulkheads to avoid the free surface effect. Even in the less likely scenario of double sided tankers without any other longitudinal bulkheads, these can rely for strength on their double side structure.

In case that a double skin vessel with no longitudinal bulkheads is to be converted, most probably the double side structure longitudinal bulkheads will not have to be moved or scrapped. Therefore the longitudinal strength obtained through those bulkheads will remain. The only alteration would occur only due to the deck crop-out for the creation of the hatches.

However, if that vessel had any other longitudinal bulkheads they would have to be cropped, to allow the vessel to use in full extent its capacity. There is no point in converting, for example, a 40,000 cubic metre vessel only to get a 20,000 cubic metre vessel in the end as this would seriously affect the quality of the converted product, which is one of the conversion risks that has to be minimised, as explained in the conversion internal risks section previously. Therefore a serious issue would now occur, the loss of the longitudinal strength of those bulkheads, which would have to be considered when performing longitudinal strength calculations, and the strength lost would have to be replaced.

In the case of double bottom – single sides vessels the above problem can be avoided partially. Since the aim is to convert to a double hull bulk carrier, which as explained in appendix II will add value to the conversion end product, thus reducing end product quality risks, a new double side structure will have to be created. This can either be achieved by building a new bulkhead on each side of the vessel and later cropping the existing longitudinal bulkheads, or, it can be achieved by moving the existing longitudinal bulkheads of the vessel towards each side.

This however by definition is not possible for single sided vessels with only a centreline bulkhead. The figures below illustrate how the two longitudinal bulkheads can be moved towards the side shell, or how they can be cropped and new ones fitted in to create the new double side structure for the conversion.

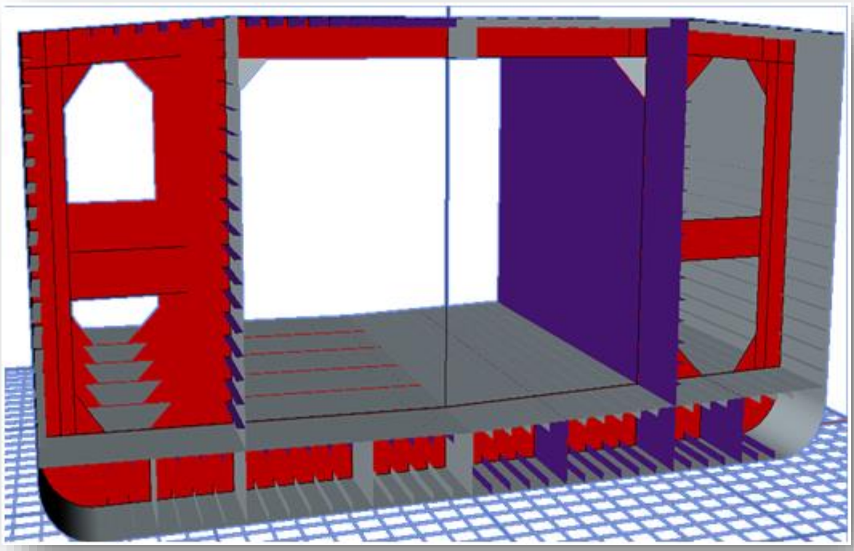


Figure 5-4 Typical single sides tanker with two longitudinal bulkheads

(Salamis Shipyards, 2007)

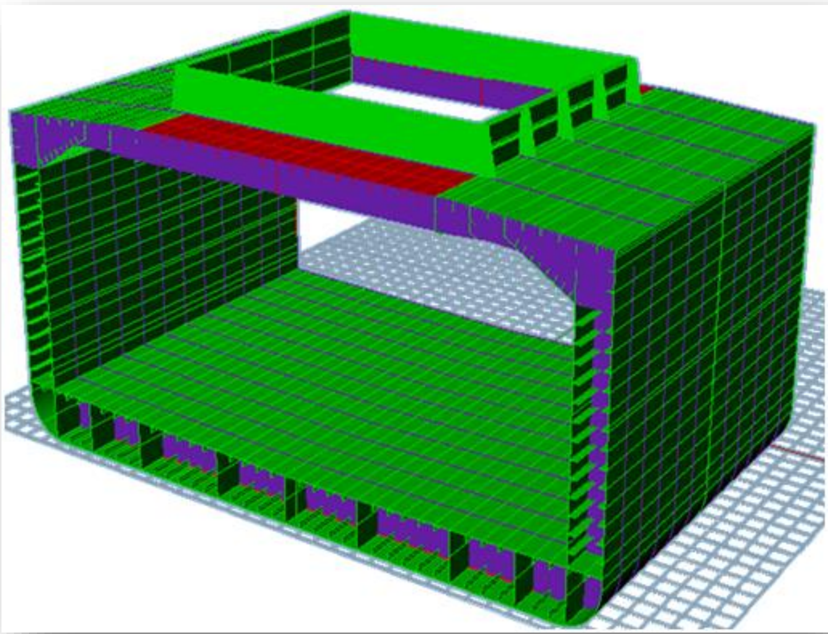


Figure 5-5 Mid-section of tanker converted to double hull bulk carrier

(Salamis Shipyards, 2007)

5.2.4 Tank top strength

In general, tankers carry less dense cargoes than bulk carriers and therefore their tank top strength is lower comparatively. Dry cargo, normally being denser, is much more aggressive on the tank top, except in cases such as woodchip, soybean meal, grain and others. A converted bulk carrier, in order to not be constrained in terms of carrying capacity, may have to undergo some work on its tank top. The amount of work is dictated by the difference in maximum allowable cargo density as it stands and maximum cargo density desired by the Owners.

In the case of tankers with no tank top (single bottom) any kind of work is relatively easy as there is easy access to the area of interest for new steel members to be added. In double bottom tankers the difficulty in adding strength members increases exponentially due to the difficulty of access to the areas of interest (confined space bottleneck). Several access points will have to be cut on the tank top.

The type of work to be carried out in the double bottom largely depends on the amount of strengthening required. The strength members could range from floors and girders to flat bars. The tank top plating may also require changing.

One very effective and simple way of tank top strengthening is applying SPS. It works by placing steel plates on the tank top after first having welded some spacers on the tank top to create a gap between it and the new plates. The top plates are welded together creating an airtight gap between the tank top and themselves. The polyurethane elastomer is then injected in that gap and left to solidify. The result is a very strong sandwich panel with very good buckling resistance properties.

5.3 Conversion Strategy

5.3.1 STEP 1: Extraction of all unnecessary equipment

The first action to be taken for the tanker to bulk carrier conversion would be to remove all the piping and tanker equipment on deck and in the cargo tanks. This is considered to be one of the most dangerous actions to be taken throughout the project lifeline. The cargo tanks and cargo pipes would normally be in a gas-free condition before commencement. However it is advisable that, even if the pipes have been gas-freed, flame should not be used upon them, as there may be residues of cargo somewhere in the system, producing gases and therefore accidents and explosions could be possible. The bolts on the pipe flanges should be cut using air driven saws and in that way the piping systems could be disassembled with relative safely.

Another risky procedure during this stage is the extraction of the cargo tank heating coils. Heating coils, as they age, tend to have leaks, thus allowing dangerous cargos to flow in and create residues. A method producing no flame and sparks must be used, such as the air driven saws as above.

Picture 13 Tanker before conversion

Picture 12 Tanker in process of pipes removal for conversion

(Koros, 2010)

Generally, it would be best, when engaging in this task, to start from the most hazardous components. These are the cargo lines, vapour return lines, stripping lines, heating coils and cargo pumps. The idea is that these jobs can be performed with the least possible manpower, so that they are carried out in a more controllable environment. Having less people working makes the difficult job of ensuring safety easier.

After the hazardous systems have been removed, more workers could be added and flame could be used. At this point, most of the pipes that have to be removed are fitted normally beneath the catwalks. Therefore, since the catwalks have to be removed as well, it would be best to cut the pipes and the catwalks at same lengths so that they could be removed together to save time. Also, since now would be the time to be cutting the angle bars on which the catwalks rest, it would be best to pay attention to the cutting on the deck and cut them carefully so that no further cutting of edges would be required at a later stage. This should reduce cost as the same job would not have to be done twice, as the deck would now be smooth and free of all unwanted edges.

There are 10 tasks associated with this part of the project:

1. Gas free
2. Cutting the screws and removing some pipe pieces of cargo pipes, stripping lines and vapour return lines for ventilation
3. Removal of cargo pipes, stripping pipes and vapour return lines
4. Cutting and removing the heating coils on deck
5. Cutting of heating coils in equal distances in cargo tanks and removing some pieces for ventilation
6. Removal of heating coils from cargo tanks
7. Removal or spool pieces from pump room
8. Gas freeing pump room again
9. Removal of cargo pumps and ejectors
10. Removal of catwalks and remaining pipes

The safest order for these tasks is as shown in the figure below.

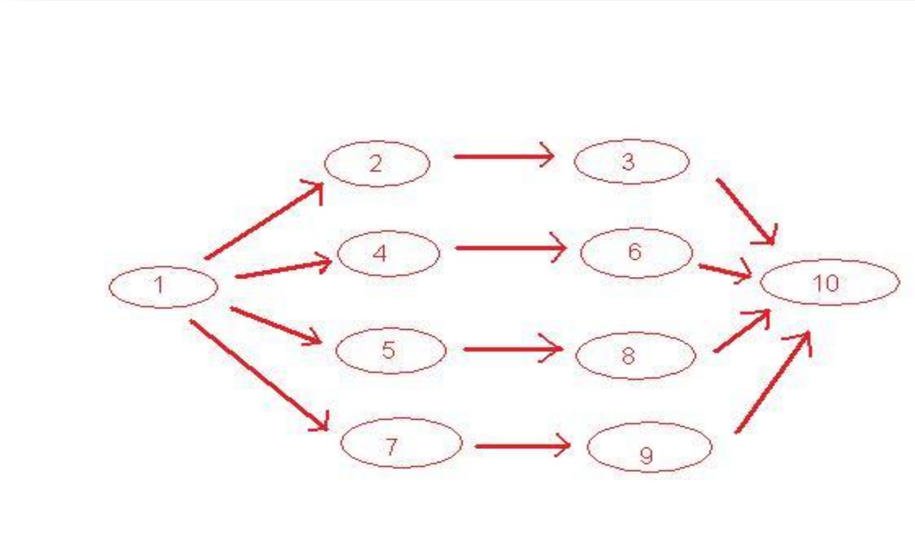


Figure 5-6 Systems removal sequence

(Author's figure)

5.3.2 STEP 2: Fitting structures on deck and creating the hatch openings

After removing all the pipes and other fittings from the deck, the next step would be to start fitting the relevant structures on deck for creating the bulk carrier.

Bulk carriers tend to have a protective member beneath the hatch coamings, both longitudinal and transverse. This protects the under-deck structure from coming in contact with crane grabs during loading and discharging. Such a protective member is shown in the picture below. As it can be seen, this particular member is buckled as it has come in contact with grabs during operation. This member also supports the hatch coamings. Therefore, deck openings should be created at this stage in order for this member to be fitted.

However, cutting and removing the deck to create all the hatch openings simultaneously would not be recommended, as it is important to monitor the vessel's stresses and hogging. By cutting the deck, the longitudinal strength of the vessel that relies on the deck is discontinued. By cutting all the openings at once, monitoring and managing the vessel's hogging would immediately become a much more complex issue to resolve during the stages of the project, than by cutting one at a time, or something equivalent. By keeping things as simple as possible, the risk of permanent deformations is minimized.

Picture 14 Typical bulk carrier under-deck coaming stiffener, buckled from coming in contact with grabs (Koros, 2010)

Since the deck opening procedure would have to take place at this stage, the hatch coamings would have to be fitted either way, as they would provide strengthening around the cut off area and in this way, local deformations would be avoided.

When creating the hatch openings, the edges of the deck around the cut area are left almost unsupported. It would be important at this stage, before cutting the deck off, to fit the stiffening girders beneath the hatch coamings, so that the edges of the deck around the cut area remained supported.

Picture 15 Under-deck stiffener fitting and deck opening in progress

(Koros, 2010)

The hatch coamings, themselves, also provide some strengthening, since they spread their load away from the cut area by means of their stay-brackets, and because longitudinally and transversely they extend further than the cut area. However, the question always remains if the local strength they provide is enough to withstand the weight of the deck edges, and also their own weight.

For this reason, before cutting the deck away, it would be wise to fit the underdeck girders that support the hatch coamings, and then the hatch coamings themselves.

Picture 16 Under-deck stiffener fitted

(Koros, 2010)

In order to fit the under-deck girders, a technical opening would be required and staging would need to be erected. The actions to be taken to create the hatch opening and the order that they must be taken are described below:

Creation of Hatch openings

1. Creation of technical opening on deck
2. Erecting staging below deck
3. Fitting of under-deck girders
4. Fitting hatch coamings
5. Removal of deck to create hatch opening

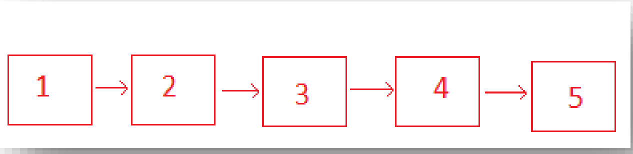


Figure 5-7, Procedure for creation of deck openings
(Author's figure)

In this way all possible deformation scenarios are eliminated and the project would now be able to proceed safely to the next level.

Picture 17 Deck cut out and removal
(Koros, 2010)

5.3.3 STEP 3: Creating the double-hull structure

Creating the double hull structure can be performed either by relocating the existing longitudinal bulkheads further to the sides of the vessel, or by scrapping the existing ones and fitting new prefabricated bulkheads to the side of the hull.

For either case, the vessel should have adequate longitudinal strength at the moment the bulkheads are cut. If the vessel were to be fitted with new bulkheads, then the logical procedure would be to fit the bulkheads in before cutting the existing ones. In the case that the old bulkheads would be relocated, all the longitudinal strength members the vessel would have as a bulk carrier should be fitted prior to the relocation, if possible.

5.3.4 STEP 4: Fitting Topside Tanks

Top side tanks are required for the longitudinal strength of the vessel. After the double hull structure has been created, the top side tanks must be fitted. It is assumed that just by enhancing the vessel’s existing remaining stiffener structure, the desired strength would not be achieved. Therefore the addition of Top Side tanks would be required.

5.4 Bulkheads Relocation

The procedure planning for bulkhead relocation is required to avoid permanent deformations on the ship's hull and deck caused by extreme stresses due to the bulkhead relocations. These deformations can occur on larger scale, such as permanent hogging of the vessel, or on a smaller scale, such as deck buckling.

In this section the bulkhead relocation procedure is going to be discussed and explained. After the procedure has been established, ways of avoiding deformations will be discussed.

The relocation procedure is affected largely by the lifting capacity of the cranes involved. If it is assumed that it is a normal new panel used for ship-conversion, then the size of the panel that is to be lifted and fitted in place solely relies upon the lifting capacity of the crane that is performing the lift. Therefore, upon planning the relocation, this must be taken into consideration to estimate the number of pieces that the bulkhead is going to be cut to be moved. This would be a simple job, considering that there is nothing else obstructing the move of the bulkhead.

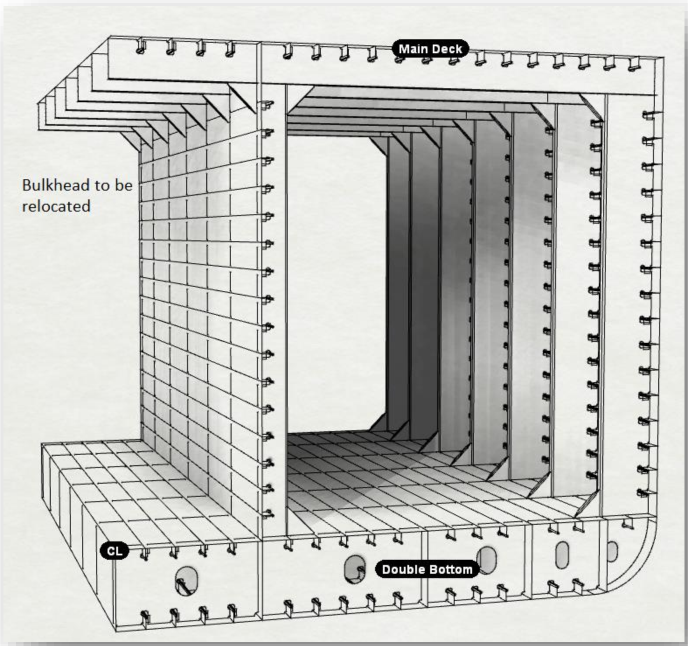


Figure 5-8 Tanker mid-ship section, bulkhead on the left to be relocated
(Koros, 2014)

Figure 5-8 illustrates a typical mid-ship section of a double bottom tanker (dimensions not in proportion). The bulkhead that is to be moved is in on the left as indicated.

Before the bulkhead is cut for relocation, a number of other actions must be taken beforehand:

- Staging must be raised on both sides of the bulkhead to be relocated, and also between the vertical webs of the side shell.
- The tie beams must be cropped
- The longitudinal stringer must be fitted, along with its supporting brackets (if any)
- Height issues to be considered for the maneuver.

The bulkhead must be free to move upwards and downwards, and thus moving the whole structure at once in one piece, height wise, is impossible. This is because the bulkhead will have to slide down from the webs beneath the deck in its initial position, and then slide up between the webs in its final position. Also because it will have to pivot, its bottom must be free to move. Therefore, one piece from its bottom will have to be cut and relocated at a later stage.

The stages for bulkhead relocation are described below:

- STAGE 1 – Releasing the longitudinal bulkhead from the surrounding structure

A section of the webs beneath the deck that house the longitudinal bulkhead must be cut. An adequate section of the webs must be cut because this will allow the bulkhead to pivot around its centre, which is essential for its relocation. By just cutting the webs locally where they are welded on the bulkhead, would not allow freedom of movement. Also cutting the whole web across would not benefit the move, since the deck would have to be seriously reinforced, and the webs would have to be refitted in place after the relocation had been performed. At this stage in the relocation it is best to calculate by approximation how the bulkhead is going to pivot and cut only the minimum material required, to avoid excessive reinforcement and unnecessary re-work.

The bulkhead at this stage also needs to be cut at the top and bottom in order to be relocated. It is important however, to leave a few “holding points” which will be cut at the next stage of the relocation. When cutting the bulkhead at the bottom, it is best to do it at an angle, since this will then aid the fitting of its lower part after it has been relocated, as illustrated in figures 5-9, 5-10, 5-11.

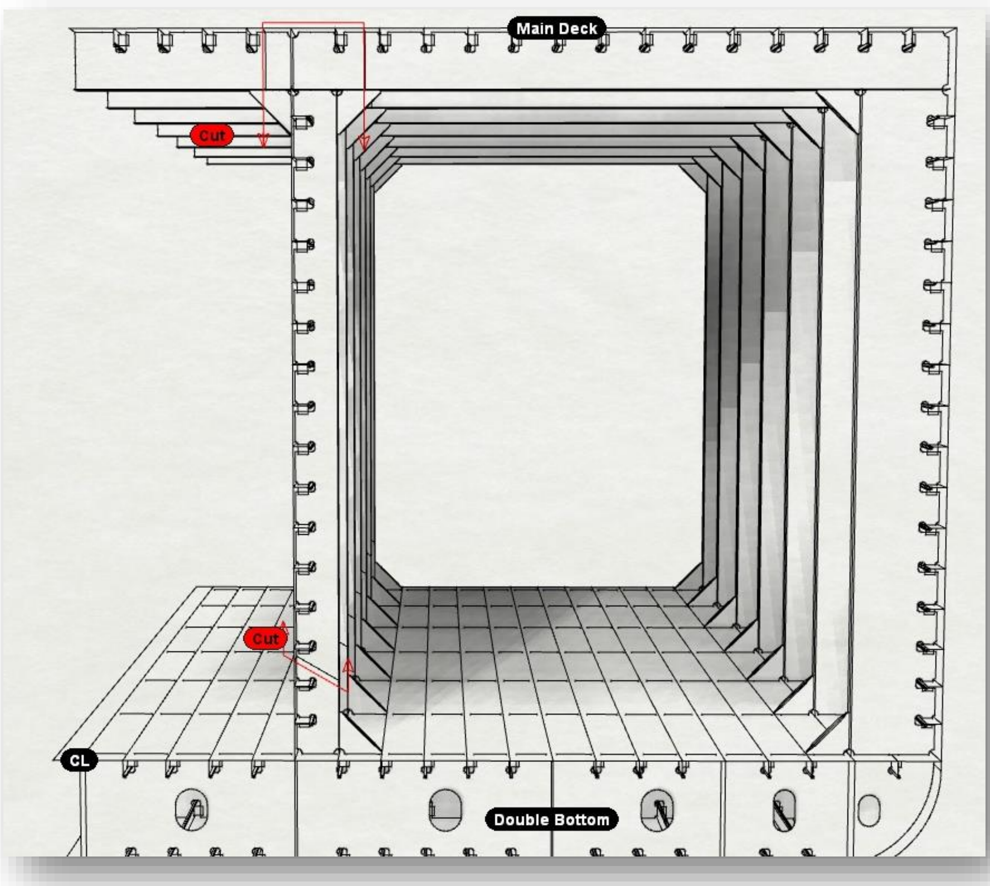


Figure 5-9, Cut points on bulkhead for relocation 1 (Koros, 2014)

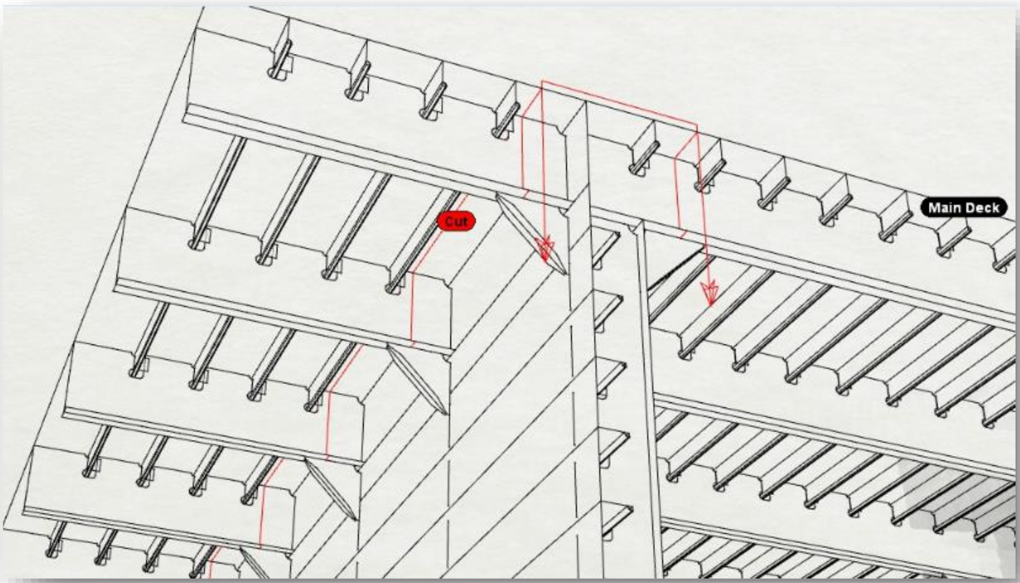


Figure 5-10, Cut points for bulkhead relocation 2 (Koros, 2014)

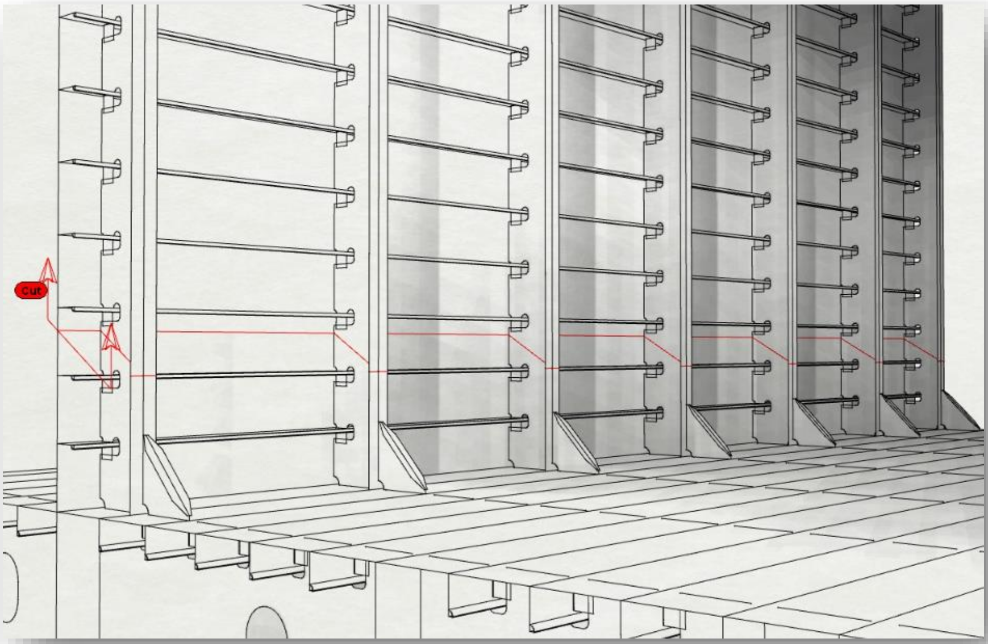


Figure 5-11, Cut points for bulkhead relocation 3

(Koros, 2014)

- STAGE 2 – Hoisting the bulkhead

Now that the bulkhead has been almost freed from top and bottom, it is important to determine the points of its hoisting, and identify the forces acting on it for its relocation. Figure 5-14 shows 4 forces acting on the bulkhead. It can also be seen that technical openings have been created on the deck to aid the bulkhead's relocation and that the webs have been cut where the bulkhead will be relocated to permit fitting in figures 5-13 and 5-12 respectively.

F1 is the upward force acting on the bulkhead through the pier's crane. F2 is the upward force acting on the bulkhead through two chain blocks which will aid keeping it in place at a later stage. F3 is the downward force acting on the bulkhead through two chain blocks and is the force that is required to pivot the bulkhead and aid place it on the intermediate position before fitting it in the right place, as will be demonstrated in the next stage. F4 is the upward force acting on the bulkhead through two chain blocks which will aid the bulkhead to be placed on its intermediate position before fitting it finally in place.

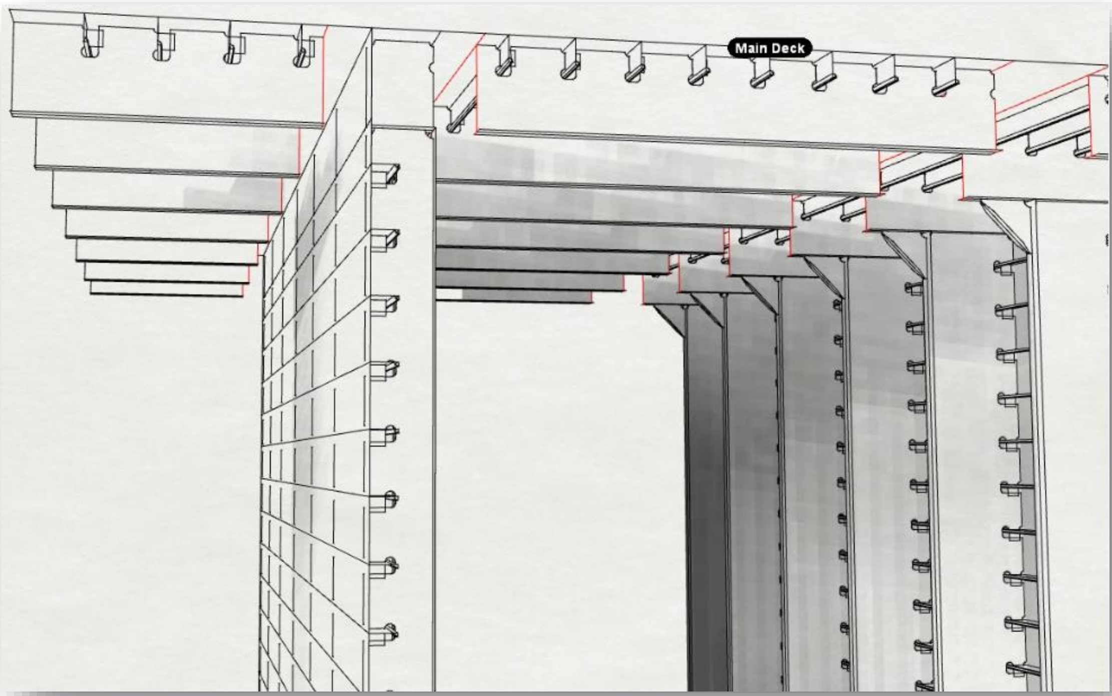


Figure 5-12, Freed bulkhead and cut webs where bulkhead will be relocated
(Koros, 2014)

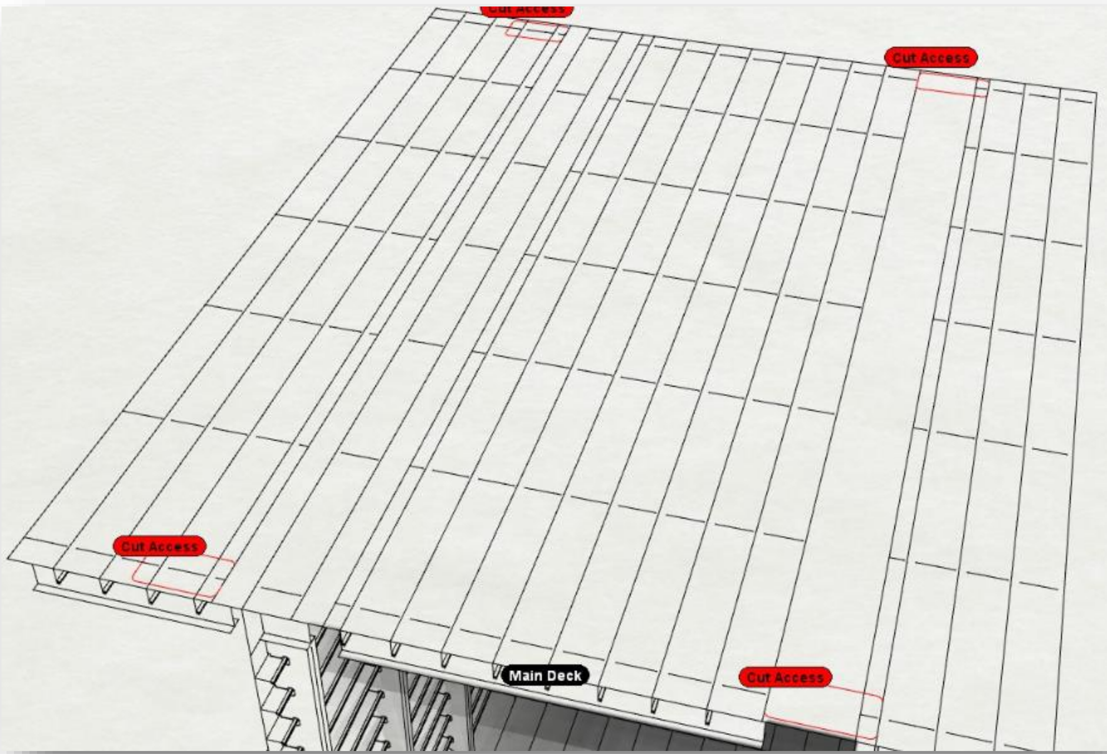


Figure 5-13, Cut access points on deck for bulkhead relocation
(Koros, 2014)

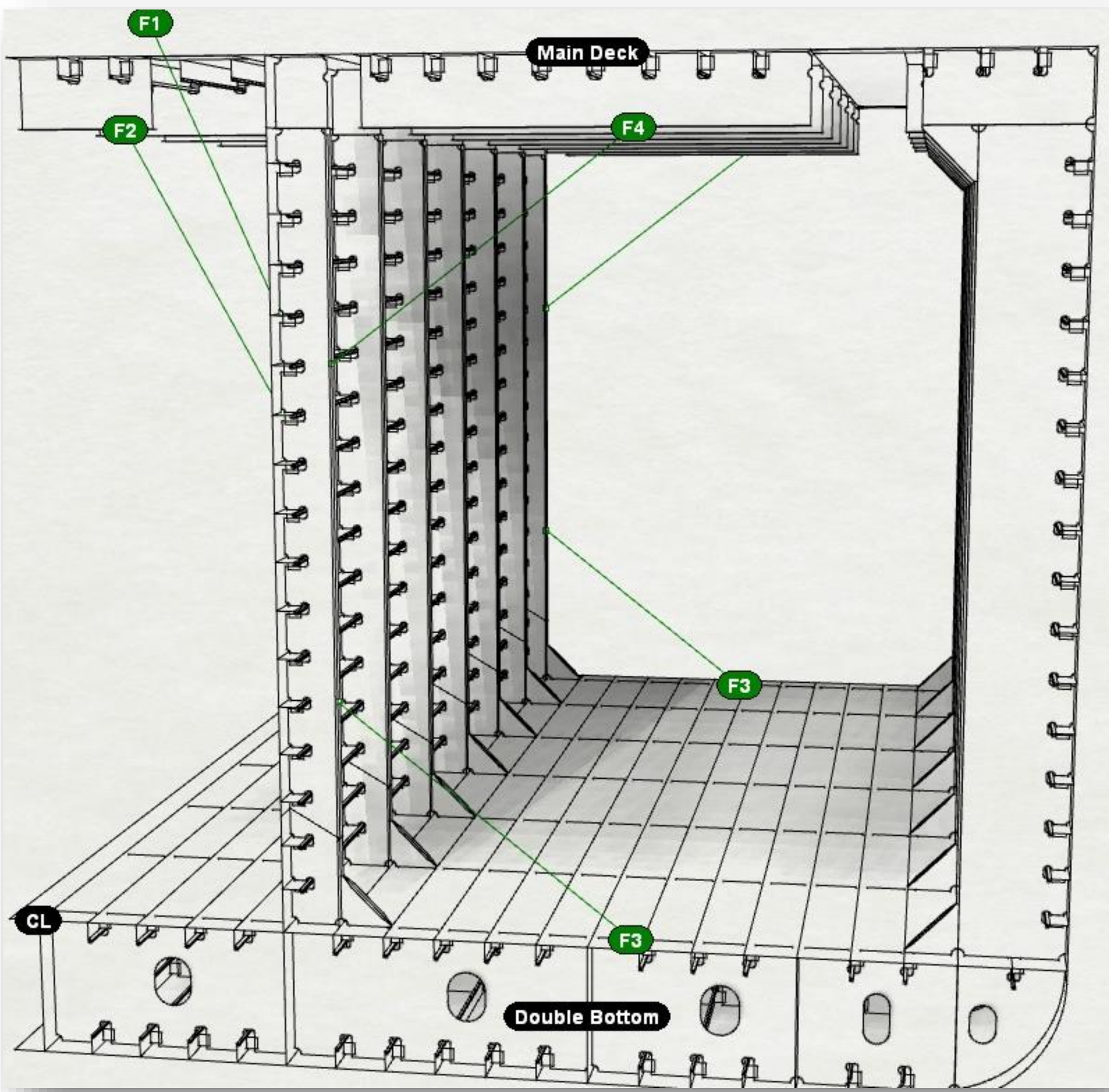


Figure 5-14, Forces acting on bulkhead
(Koros, 2014)

STAGE 3 – Moving the bulkhead to its intermediate position

As soon as the final holding points of the bulkhead have been cut, F3 is the first force that must come into effect. This will help the bulkhead to pivot about its central axis. As soon as the bulkhead has taken its first inclination, F1 and F2 must start releasing. At the same time F3 and F4 must be pulling. After some time the result will be that the bulkhead has moved to its intermediate position, as shown in figure 5-15.

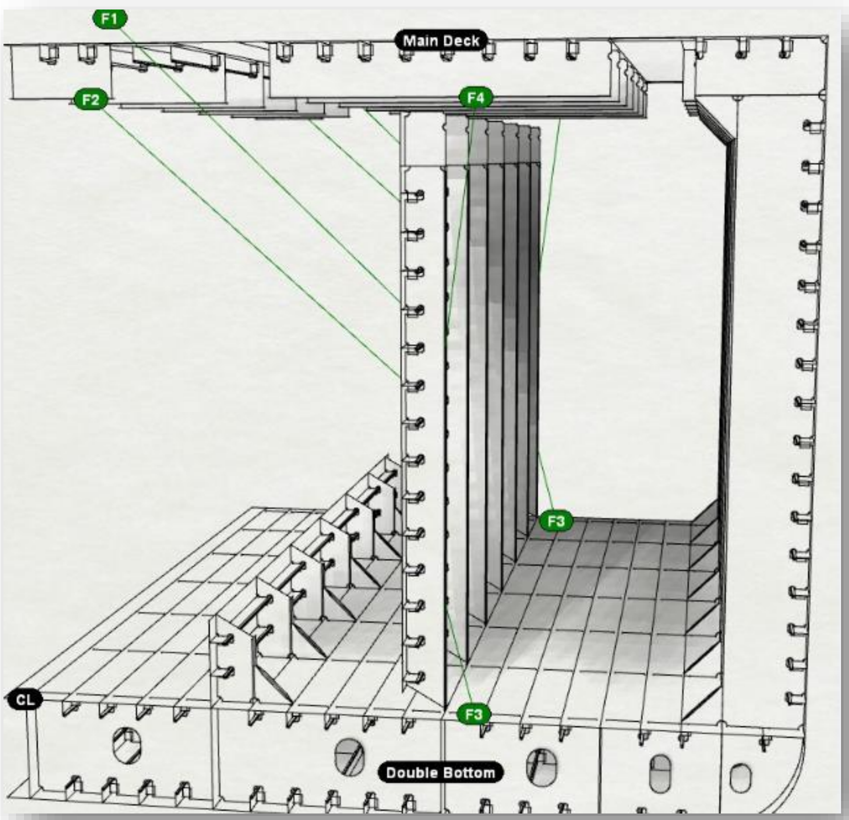


Figure 5-15, Intermediate position of bulkhead
(Koros, 2014)

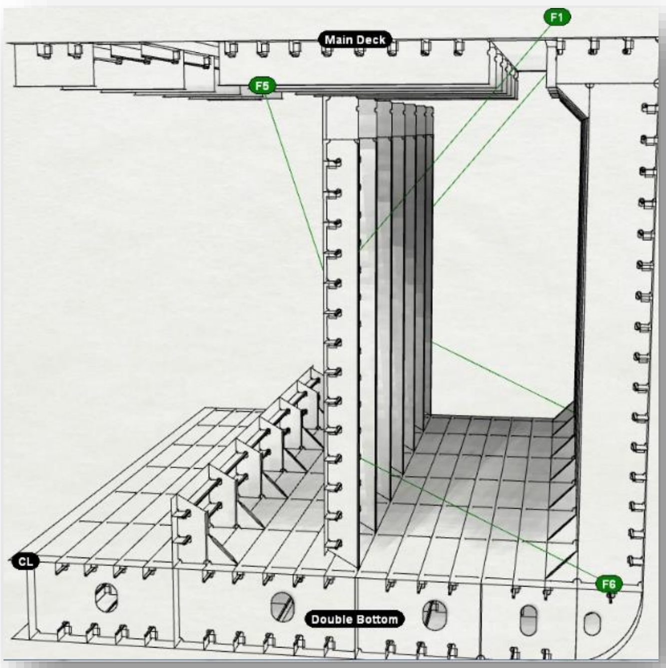


Figure 5-16, Forces acting on bulkhead
(Koros, 2014)

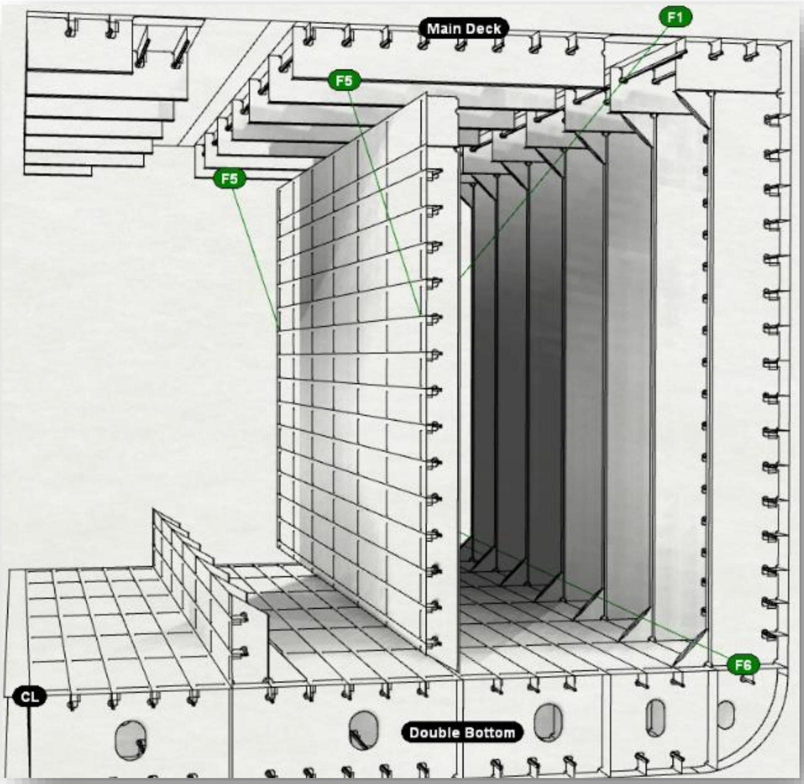


Figure 5-17 Forces acting on bulkhead
(Koros, 2014)

STAGE 4 – Moving the bulkhead to its final position

After the bulkhead has been placed in its intermediate position, F1 must change position. Also, 2 chain blocks must be fitted, acting upwards and towards the opposite direction of the movement (F5), and two more acting downwards and towards the side, in the direction of the move (F6), as shown in figures 5-16 and 5-17. F5 must start releasing, and at the same time F1 must be pulling. This will lift the bulkhead up, and because of the direction of F1, also to the side. F6 is there to aid the lower bottom positioning with safety, as shown in figures 5-18 and 5-19.

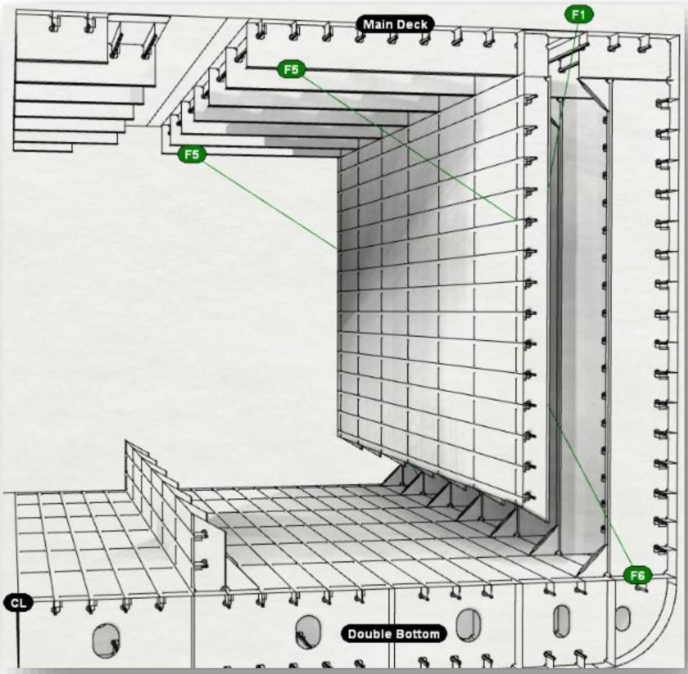


Figure 5-18, Forces acting on bulkhead
(Koros, 2014)

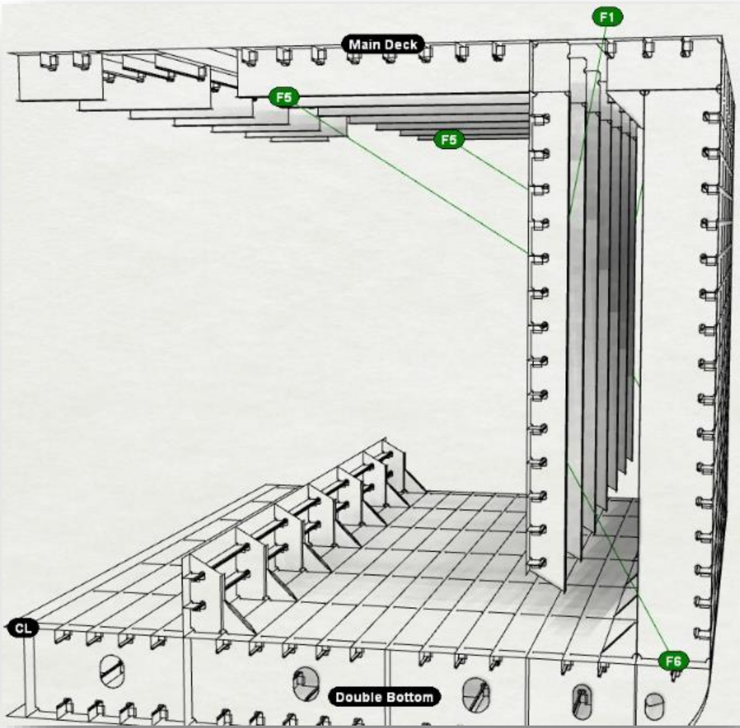


Figure 5-19, Forces acting on bulkhead
(Koros, 2014)

STAGE 5 – Final fitting

When the bulkhead has been moved to its final position, the final fitting remains, which is a simple job done with the aid of chain blocks to pull it to the side, and fitting the last remaining bottom part in place, which is again a simple job because of its light weight and easy maneuverability.

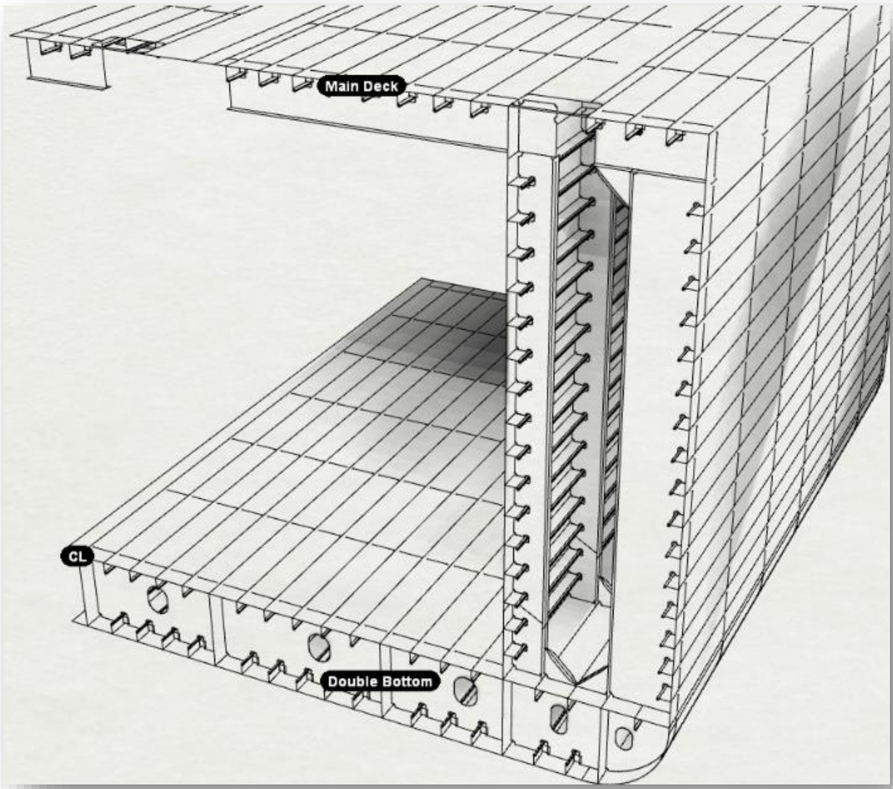


Figure 5-20, Bulkhead relocation completed
(Koros, 2014)

The actions required for the whole procedure are listed below and the network connecting them together to perform the task successfully is given in figure 5-21 below:

1. Staging in side tank
2. Cutting off the tie beams
3. Preparing the web frames
4. Fitting the longitudinal stringer
5. Cutting the web that holds the bulkhead at the top
6. Cutting the bulkhead at the bottom
7. Welding ear plates on the bulkhead
8. Attaching chain blocks and crane for forces F1, F2, F3, F4
9. Releasing the bulkheads holding points

10. Pivoting the bulkhead and relocating it to intermediate position
11. Releasing F1
12. Reattaching F1 from starboard side
13. Attaching chain blocks for forces F5 and F6
14. Releasing forces F2, F3, F4
15. Relocating bulkhead to final position
16. Attaching new chain blocks to pull it towards the side shell so that the longitudinal stiffeners can be housed inside the slots created on the side shell webs
17. Spot welding the bulkhead on the webs while pulling forces to the side are in action
18. Releasing F1
19. Releasing chain blocks that hold it to the side
20. Welding the bulkhead in place
21. Relocating bottom part of bulkhead
22. Welding bottom part of bulkhead

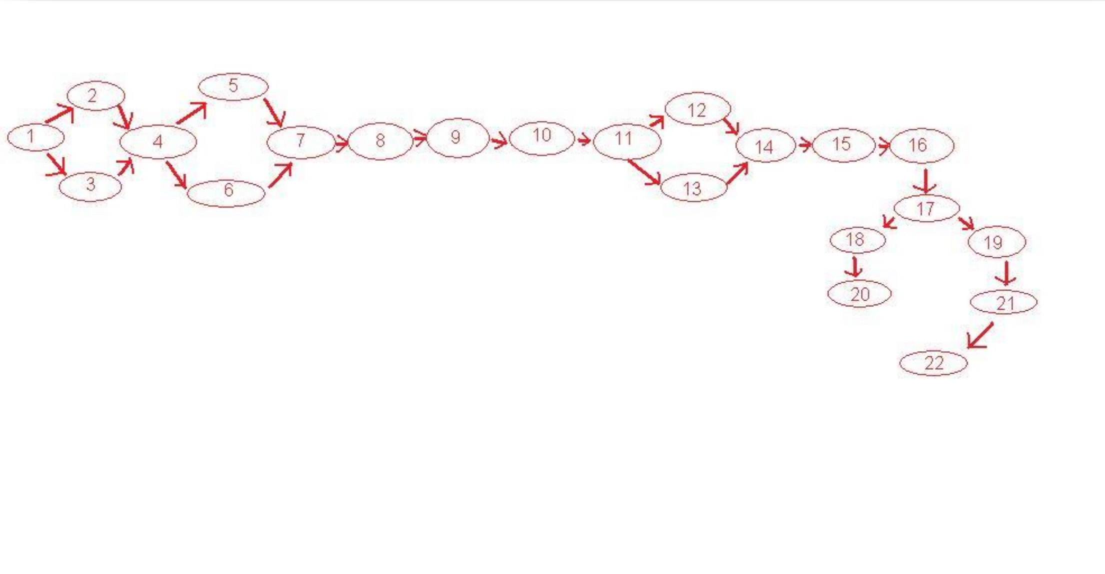


Figure 5-21 Series of actions for method 1

(Author's diagram)

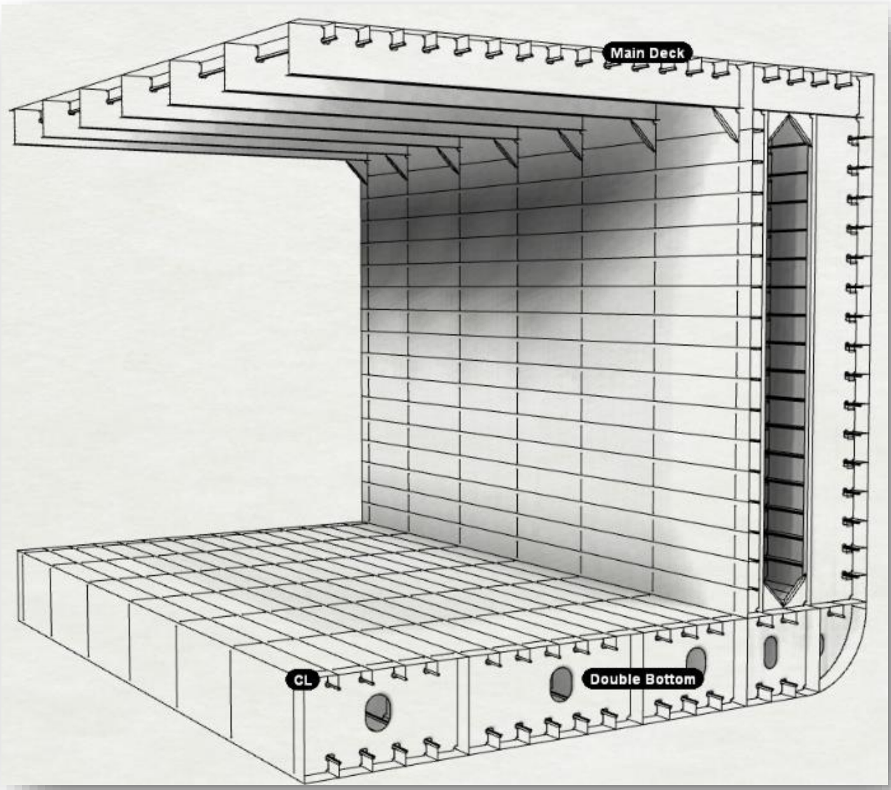


Figure 5-22 Fully completed bulkhead relocation and webs fitted in place
(Koros, 2014)

Picture 18 Deck reinforcement for the avoidance of deformation
(Koros, 2010)

As explained before, in order to relocate the bulkheads, the webs have to be cut at certain points in order to release the bulkhead from its original position, pivot it, and fit it to its new location, where again the webs have to be cut to house it. By cutting the main stiffening members of the deck, and even by creating large technical openings, local deformations may appear on the deck, in the form of buckling. This happens because the deck, especially around its cut edges, cannot support the stresses it is receiving and therefore the material around the cut edges exceeds its Yield point, resulting to plastic distortion.

For this reason, the deck around its cut edges has to be stiffened. This can be performed by creating above deck a web of temporary stiffeners which will absorb and also direct the stresses acting on these areas to other areas of the deck which are intact. The easiest way of doing this, is to temporarily stiffen the deck with transverse and longitudinal I beams, as shown in picture 18.

5.5 Fitting New Bulkheads and Removing The Existing Bulkheads

Fitting new longitudinal bulkheads in a tanker is a conversion that was common in the decade of 2001-2010, due to the fact that single side and single hull vessels were not allowed to operate in many areas of the world after 2010 due to new IMO regulations. It had therefore become common practice, among many yards in the world, to fit new longitudinal bulkheads, thus creating a new double side section in single skin vessels.

Picture 19 Prefabricated bulkhead piece lifted for fitting
(Koros, 2009b)

It is a conversion that benefits from design for production. The bulkheads are prefabricated as panels, which if designed for production can reduce the cost of conversion drastically. By designing for production, the bulkheads' stiffening structure is made of simple repetitive components which can be prefabricated in workstations allowing for man-hour consumption reduction through simplification and perhaps automation of the construction processes. If the prefabricated pieces' size is maximized to enable the full use of the fabrication facilities' capabilities (as large as possible), as design for production dictates, then man-hour consumption can be optimized. However, one major difference exists between a conversion of a single side tanker to a double sided tanker and that to a double hull bulk carrier. The tanker will also make use of its existing longitudinal bulkheads, whilst the bulk carrier will not. This fact adds the procedure of removing the old bulkheads to the conversion.

5.5.1 Problems that have to be overcome

In order for the bulkheads to be fitted efficiently, they would have to be prefabricated. The question of how much prefabrication is the optimum arises, since fitting uncontrollably large pieces will create problems, as explained below. Therefore size of the panels is one of the major concerns.

In order for the panels to be fitted, technical openings would have to be created exactly above the point where the bulkheads would be fitted. As the size of the technical opening increases, so does the risk of permanent deformations and in this case, deck buckling. It would be very productive if the deck could be "sliced" continuously from both sides of the vessel, from the start until the end of the cargo area, so that bulkheads could be fitted throughout the whole cargo length simultaneously. This method would in theory have been very productive, but it would most likely create buckling and alignment problems which would be visible when the time came to close the technical openings. The most probable scenario is that the left and right side of the opening would have a difference in height, which would be visible at the end in the form of a small "step" on the deck.

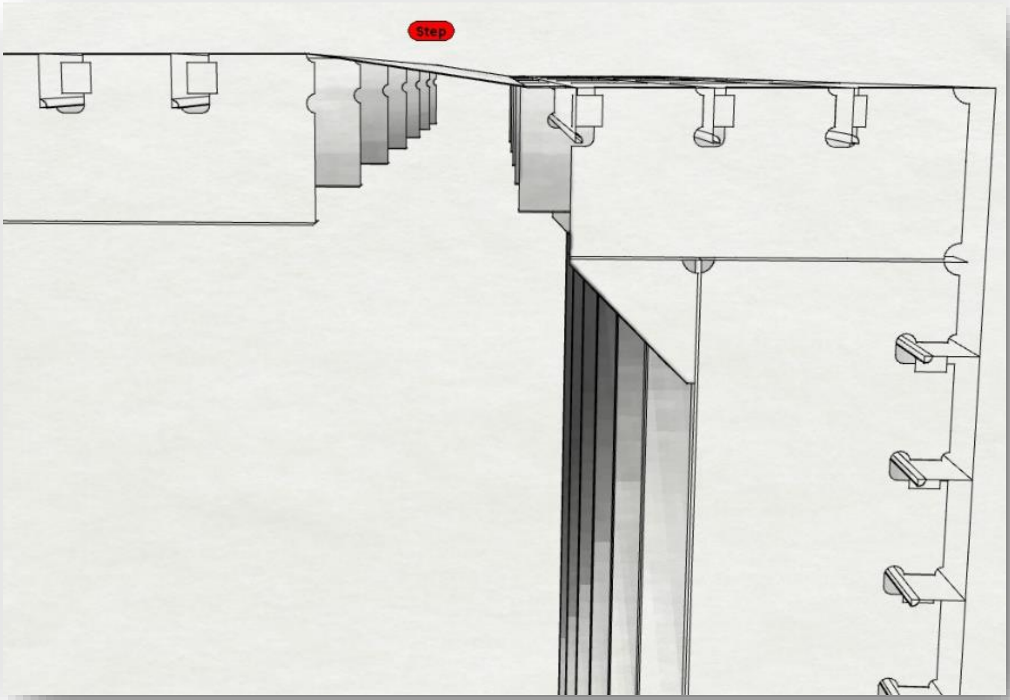


Figure 5-23 Step deformation
(Koros, 2009b)

The other most probable deformation would be that the openings would undergo a deformation in the form of ovality. This would occur because the weight of the sides would be pulling the deck outwards, and since there would be no reinforcement to keep the openings from losing their shape, they would eventually have an oval shape.

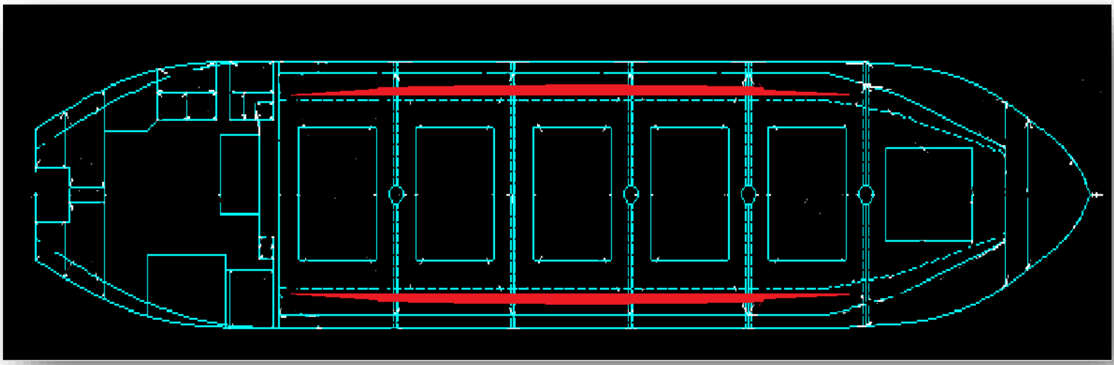


Figure 5-24 Ovality deformation
(Koros, 2009b)

Another problem which would be very likely to occur is misalignment of the vertical webs of the new bulkheads in relation to the ones on the existing side shell. There are always defects in the alignment and spacing of the members on existing ships. One can never predict all of them and it is not economical and practical to allow that many tolerances in the prefabrication to compensate for every mistake in the already constructed structure. Such a case would defeat the point of prefabrication all together because there would be need for excessive in situ repairs and modifications which would increase the man-hours required dramatically.

It is of course very important for the conversion to be completed quickly and therefore many technical openings would have to be in place simultaneously. In this respect, it would be best to divide the openings on the deck in groups. For example the openings can be done in groups of 2 or 3 always leaving a hold intact between them so it would be able to withstand the forces and avoid deformation as much as possible. In that way ovality can be avoided. In order to avoid the “step” formation on the deck, two longitudinal I-beams can be welded on the deck temporarily, along the length of the opening and until the next under-deck transverse frame. In this way, the rigidity of the I-beam would help support the weight of the deck edge so that it should not drop and create the “step”.

In order to avoid the misalignment issues described above, the vertical webs of the new bulkheads would have to be fitted in place separately from the bulkhead panels, and then the fitting of the panels would be performed with greater ease, as their longitudinal members would slide in their place in the vertical webs. If the bulkhead panels were to be fitted with their vertical webs during the prefabrication stage, it is certain, from experience, that there would be cases of misalignment in the webs and therefore some of the new webs would have to be cropped and moved slightly in order for the fitting to be acceptable by the classification society. That would mean that all the man-hours spent to fit and weld that web on the panel would be completely lost and new would be added to correct it.

5.5.2 Procedure

The first procedure would be to create the technical openings. As said previously the openings must be in groups of 2 or 3 in order for the whole deck structure to hold its composure better. It is also advisable that since this procedure will be performed simultaneously at both sides of the deck, that port side and starboard side patterns (groups) are not symmetrical, i.e. different patterns (groups) must be created from either side as shown in figure 5-26.

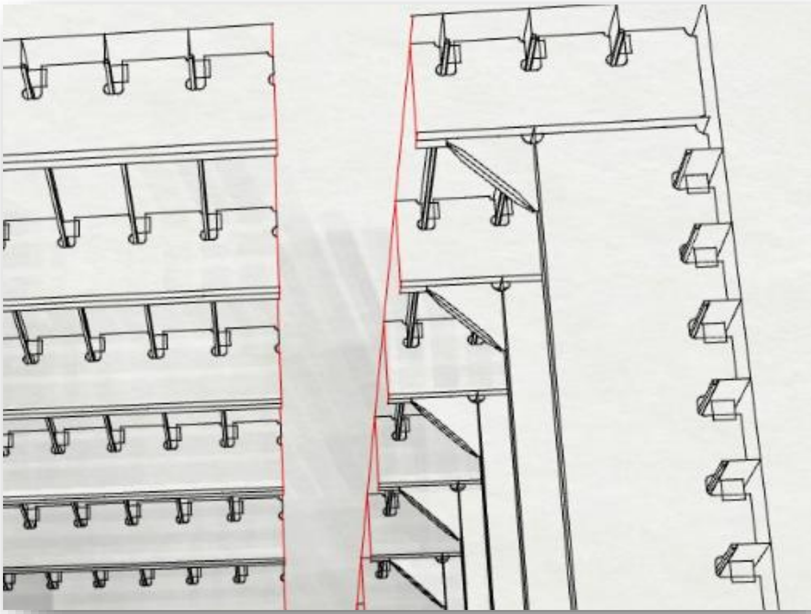


Figure 5-25 Technical opening for fitting new bulkhead

(Koros, 2009b)

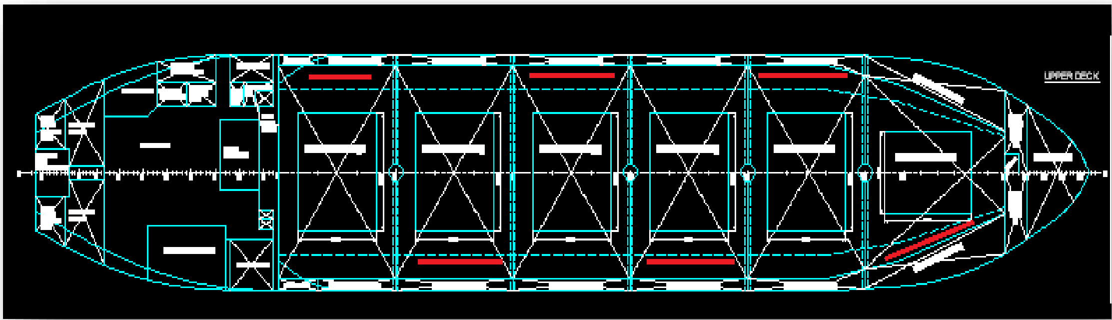
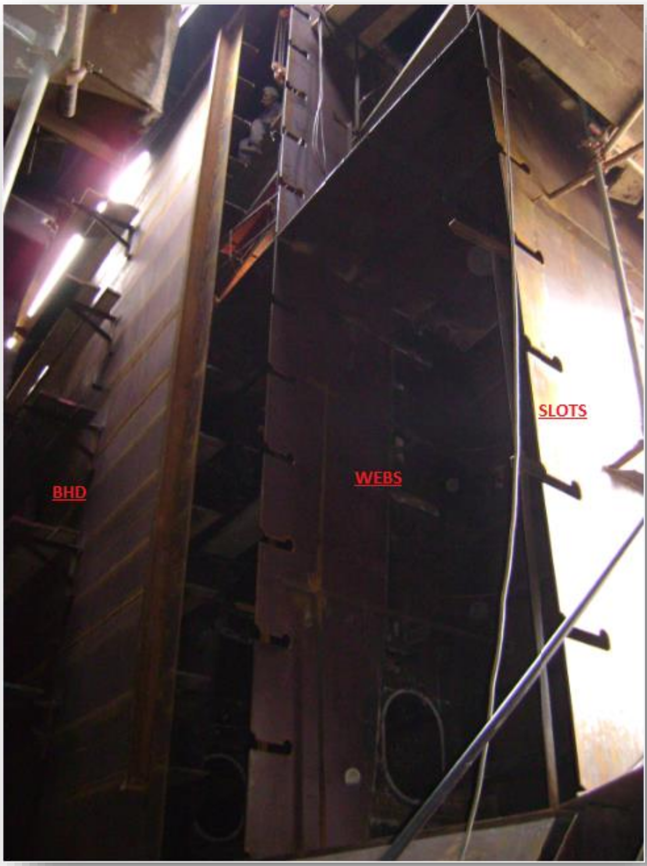


Figure 5-26 Technical openings series

(Koros, 2009b)

Staging would be the next procedure to take place. Staging should be erected, rising from the tank top until the under-deck area, along the length of the technical opening, which would normally be the length of a cargo tank and an additional number of frames further required for new bulkhead penetration. The staging's width should not exceed the distance between the outer shell and where the edge of the new bulkhead's longitudinal stiffeners will be. The reason for this is that the staging in this way will not block or interfere in any way with the new bulkhead's longitudinal stiffeners sliding in the slots of the vertical webs when it will be fitted. Details of the slots and the bulkhead fitting are shown in picture 20.

Once the staging has been raised, it is time to fit the new vertical webs and stringers. The webs and the stringers are the members which at a later stage will hold the bulkhead in its place and aid in fitting in the right place, avoiding misalignments. After the fitting of the above, it is best to complete the welding on the side shell at this time as it will save man-hours, since at this stage the ventilation is better because the new bulkhead has not been fitted yet.



Picture 20 Fitting new bulkhead detail
(Koros, 2009b)

After the welding of the fitted structures has been completed, it would be time to fit the new bulkhead panels. The panels should be lowered by crane through the technical openings on the deck slightly further than the position that they will be finally fitted, and then pulled to their final position with the use of chain blocks. Bulkhead securing, final fitting and welding must be performed at this stage.

After the internal welding is completed, it is time for the staging to be disassembled and new staging to be erected externally so that the bulkhead panels be welded together externally and also welded to the rest of the structure externally, i.e. tank top, under-deck structure etc. At this point also the parts of the under-deck girders which were cut would be refitted in place and welded.

The same staging can be expanded to reach the existing longitudinal bulkhead from top to bottom so that its removal procedure could begin at this stage.

5.6 Fitting Top Side Tanks

The top side tanks would have to be prefabricated as complete panels at a size and weight which would aid maneuverability while being lifted in place. It is generally considered a straight forward task that follows the philosophy of Design for Production and hence production is not anticipated to present any difficulty. The panels are to be prefabricated, transported to the dock, lifted and then lowered on the tank top through the hatch openings. The only thing that has to be performed beforehand is for technical openings to be opened on deck exactly above the point of the final fitting. Through these technical openings the top side tanks are to be lifted for their fitting with the aid of the crane. Once the panel has been lifted, it will be pulled towards the longitudinal bulkhead with the aid of chain blocks and be spot welded in place. After adequate spot welding has been performed the team can move on to the next panel. One significant characteristic of this procedure is that, since this is a main longitudinal member, there must be no discontinuity in its structure. It must therefore pass through the existing transverse bulkheads. The procedure for this is exactly the same as described above, but with the only difference that the panel will have to be pulled through the transverse bulkhead with again the aid of chain blocks and then be pulled towards the side longitudinal bulkhead. More details of this method are given in the case study section.

5.7 Avoiding Longitudinal Deformation, Hogging Monitoring

As explained before, when the deck and the longitudinal bulkhead of a ship are cut, the longitudinal strength they provide is discontinued, making the ship more vulnerable to its bending moments and shear stresses. If these exceed the permissible limits of the hull, it could result to permanent hogging of the vessel.

From a technical perspective, the easiest way to avoid such problems would be to convert the vessel in a dry dock, preferably a graving dock as they are by nature more solid and resistant to shear forces and bending moments. The conversion could be performed on a floating dock as well, where its ballast system would be used to counteract all shear forces, so that the vessel would be fully aligned at any point of the conversion in order to avoid major permanent deformations.

Performing major conversion in dry docks usually presents problems as far as material flow is concerned. The reason for this is the lack (not always) of high capacity cranes on the dock, making lifting and fitting large prefabricated pieces impossible via the dock's means. Having to work with smaller prefabricated structures inevitably will result in more restricted material flow, higher consumption of man-hours per ton fitted and therefore higher cost and slower progress. This theoretically can be avoided with the use of a floating crane which can feed prefabricated pieces to the vessel for fitting. In this case an argument could be made, stating that there is a possibility that the benefits provided by the dry dock, coupled to the lifting power of a floating crane, could reduce the duration of the conversion project.

A different argument however, that the extra cost of dry dock stay, dock relevant services, and the cost of the floating crane (if used) may defeat the purpose, as the increased costs cannot be compensated for by the technical benefits and possible reduced time of converting in dry dock, is plausible.

However, this only means that a different approach can be studied to address the longitudinal deformation problem. If the vessel were on a floating dock, the dock's ballast system would have to be used to counteract for all the forces the ship would be imposing on the dock. By assuming that the vessel's double bottom is a floating dock, exactly the same result can be achieved.

Therefore, exactly the same thing can be performed with the vessel's ballast system in order to overcome the dry dock problem and counterbalance the moments and shear forces. This can be done easily if the system is not disconnected, and can be managed accordingly based on calculations through the vessel's load indicator and by taking draught measurements.

External separate readings of the vessel's hogging could also be useful.

This can be performed by putting markings/ targets on the vessel in the bow and stern and measuring their height difference with every major movement of a bulkhead or extraction of a deck piece, using laser beams.

By knowing the ship's laden condition at any time in terms of loads, ballast, fuel etc, measuring the hogging and consulting with the vessel's load indicator, it is possible to calculate if the hogging is within the permissible limits.

However, it is understandable that the ship at that time is not the same structure as the one input in the load indicator since building. This is because some steel has been taken away, and some has been added, therefore affecting the vessel's section modulus. However again, by adding steel on a vessel, hardly any harm can be done. By removing steel, the vessel is weakened at that point, affecting both its longitudinal strength (and thus the hogging) and its local strength. Since the longitudinal strength can be managed with the aid of the ballasting system, and local strength with temporary local stiffening as explained above, the ship is in no immediate danger. This however of course is true if the vessel is not weakened in all the points of interest at once, or in an uncontrollable fashion. As explained before, cutting and removing the deck, and cutting the longitudinal bulkheads for relocation, are actions that should be taken one at a time, with logic, thus giving the time to check and control all the changing parameters of the vessel in terms of strength and strength management.

Hiring a Naval Architecture office to measure the stresses created by these actions, and also calculating the new section modulus of every major stage of the conversion, along with the aid of all mentioned above, make the use of dry dock not necessary – technically speaking.

5.8 Summary

The main design issues and planning issues present when having to convert tankers to double hull bulk carriers have been discussed in detail in this section of the Thesis. The main conversion strategy issues have been discussed and the four main conversion steps have been presented, including the technical challenges associated with each step of the conversion.

Chapter 6. Case Study – Application of the Design and Strategy Created for the Tanker to Bulk Carrier Conversion

6.1 Introduction

The two conversions described in this section were performed taking the four steps as outlined in the strategy discussed in the previous section. Some of these steps were performed with success, within budget and time frame, whilst others presented challenges which made the shipyard re-examine the conversion design and strategy.

This section examines the most important parts of the conversions, analyses the success or failure of the specific conversion processes and presents improved alternatives to the failed processes through lessons learnt.

6.2 The Vessels Under Conversion

In this study the conversions of two sister ships that took place between 2007 and 2009 are examined. The conversion work was completed in 2009 at Salamis Shipyards, Greece. The vessels were both Croatia built double bottom single side tankers, built 1988 and 1990, the ADMIRAL T, and the SALVOR T respectively. Both ships were product carriers of 39,600 tons DWT. As Segregated Ballast Tanks (SBT) tankers they had seven (7) watertight transverse bulkheads in the cargo space. Five (5) of them were horizontally corrugated. The cargo space was divided in two (2) wing tanks and a centre one by two (2) longitudinal bulkheads running along the whole length of the cargo space.

Picture 21 Motor Tanker Salvor T before conversion
(Koros, 2010)

The ships had a total cubic capacity (excluding the slop tanks, 98% full) of 43,580 cubic meters. Their slop tanks had a capacity (98% full) of 1,128 cubic meters.

Both ships were equipped with four (4) centrifugal cargo pumps driven by steam turbines, with a capacity of 1,200 Cubic Metres per Hour and two (2) with submerged hydraulically driven pumps for slops with a capacity of 150 Cubic Metres per Hour.

The propelling machinery was a 2-stroke, single acting, reversible, turbo charged, five cylinder engine, type 5L60 MC, delivering 10400 BHP at 111 RPM. It drives directly a fixed pitch, 4-bladed propeller.

The ships were converted to Double Hull Bulk carriers with top side tanks. After the conversion, they then had six (6) cargo holds with a total carrying capacity of abt. 43,700 cubic meters and a DWT of approximately 39,000 tonnes. Both ships were equipped with three (3) cranes each.

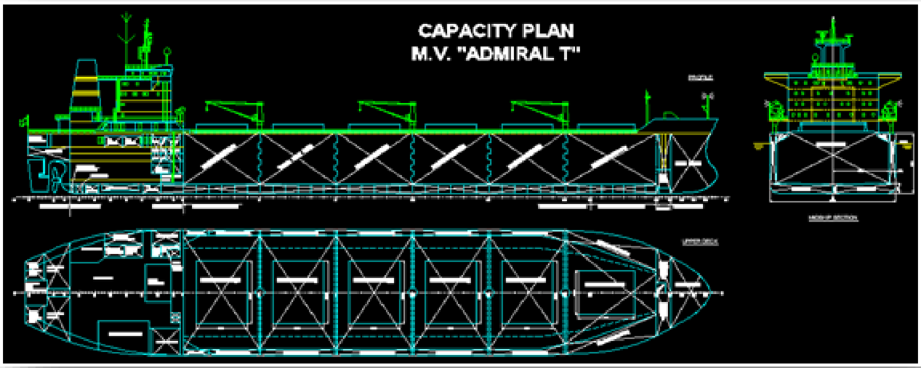


Figure 6-1 Capacity plan of converted ships

(Salamis Shipyards, 2007)

PRINCIPAL DIMENSIONS	BEFORE CONVERSION	AFTER CONVERSION
LOA	176.00m	176.00m
LBP	169.00m	169.00m
BREADTH	32.00m	32.00m
DEPTH	15.10m	15.10m
DRAFT	10.00m	10.00m
CAPACITIES		
NO. OF CARGO TANKS/ HOLDS	18	6
NO. OF SLOP TANKS	2	0
NO. OF BALLAST TANKS	7	13
CARGO TANKS/HOLDS (cubic metres)	43,580.00	43,700.00
DEADWEIGHT	39,600 T	38,000 T
NO. OF HATCH COVERS&COAMINGS	0	6
NO.OF CRANES	1	3

Figure 6-2 Comparison table of vessels before and after conversion
(Salamis Shipyards, 2007)

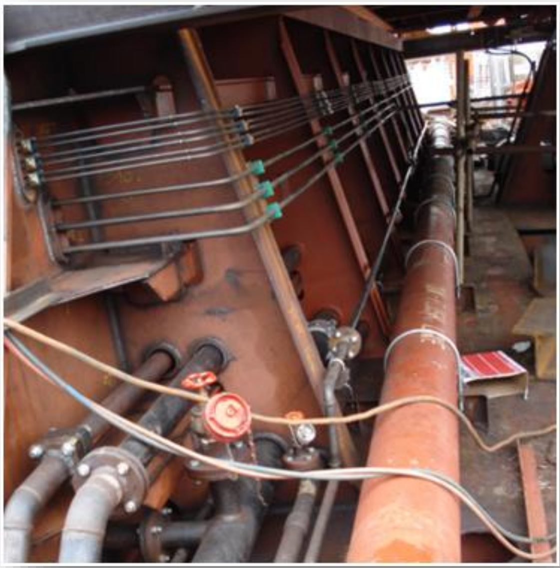
6.3 New Cargo Handling Systems

The vessels were fitted with new hatch covers, designed and built by Salamis Shipyards. The hatch covers were of Side Rolling type. The hatch covers would rest on a compression bar fitted on the hatch coamings. To open, the hatch covers would be raised, by means of a hydraulic power pack driving hydraulic rams, and then be pulled to the sides via tensioned chains driven by a hydraulic motor. The hatch covers would roll, through steel rolling wheels, on side track-ways fitted on the deck.

Picture 22 Hatch cover hydraulic motor and chains
(Koros, 2010)

Picture 23 Hatch cover track and roller wheels
(Koros, 2010)

The hatch coamings were two metres high so to increase the carrying capacity of the vessel while still presenting as little problems possible for crew access and inspection of cargo holds due to height. The coamings carried all the hydraulic piping required for the hatch cover movement, the fire line and the CO2 lines fitted for cargo fire extinguishing. Next to the coamings a large diameter pipe (12 inch) was fitted that contained all the electrical cables needed to be passed and junctioned on the deck for lighting, crane power supply and other applications.



Picture 24 Piping on hatch coamings
(Koros, 2010)

Picture 25 Electric junction box on deck
(Koros, 2010)

The vessels were fitted with three cranes each of safe working load of 25 tons (SWL 25tons). The cranes were bought used but were fully refurbished.

The construction and fitting of the cargo handling systems posed no problems to the shipyard. Hatch covers and hatch coamings were designed for production, allowing the yard to produce them efficiently and at the budgeted cost and time.

Picture-26 below shows the structure of the hatch covers. As it can be seen it is essentially a flat panel consisting of welded plates, on which longitudinal and transverse T beams are welded. Also angle bars are fitted between the main longitudinal T beams.

Since the members of this stiffening structure were of a repetitive nature, they were prefabricated in work stations which allowed for specialisation and man-hour consumption reduction. The plates for the panel were joined and welded in a separate workstation, which again reduced man-hour consumption because of the standardised work content. Once the stiffening members were fabricated they were transported to a final workstation where they were fitted on the welded plates, thus forming the panel. The panel was then welded and later transported to the ship for final fitting onboard.

Picture 26 Hatch cover stiffener structure
(Koros, 2010)

The same procedure was followed with the hatch coamings since they were also designed for production. The stays and the longitudinal angle bars were prefabricated in workstations and the fact that they were all exactly identical made their production very easily manageable thus saving man-hours. Once they were fabricated they were transported to a final workstation where they were fitted on the coaming plates to form the panel. After welding they were transported onboard.

Fitting on board posed no problem as all tanker equipment had been removed, leaving the empty deck free of obstacles.

Picture 27 Completed deck of M/V Admiral T
(Koros, 2010)

6.4 Topside Tank and Under-Deck Longitudinal Girders

The main longitudinal strength members used in these conversions were Top Side Tanks. The design office that performed the calculations, along with Salamis Shipyards, decided that this would be the most efficient strength member as it aided production, because of its repetitive and standardised construction and presented the best result as a single strength member in terms of strength.

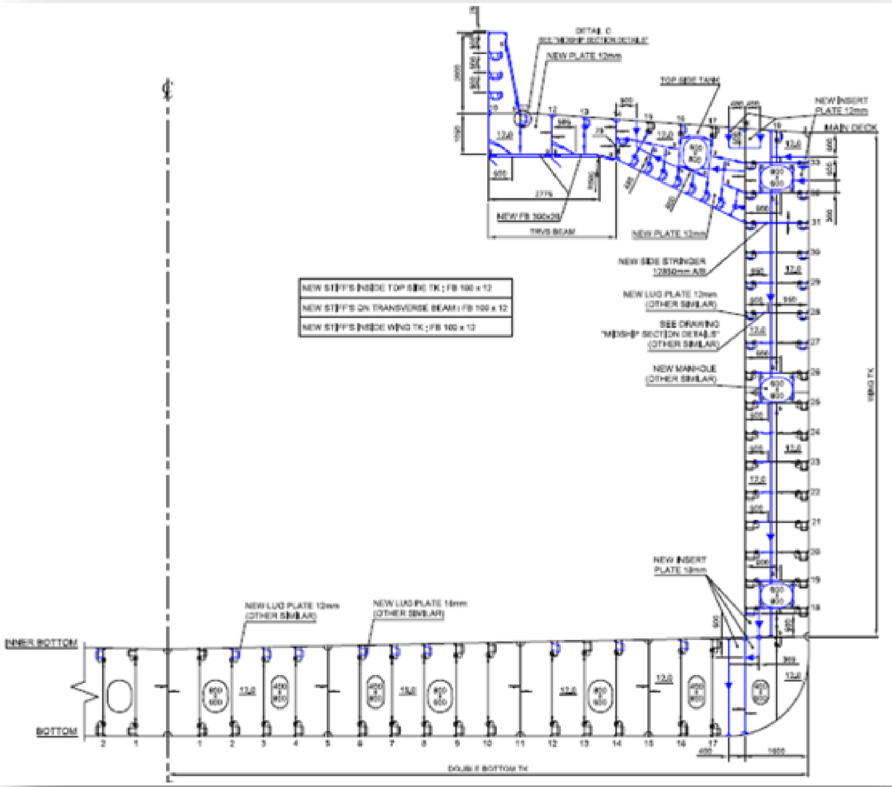


Figure 6-3 Mid-ship section of the topside tank initial concept design

(Salamis Shipyards, 2007)

The other option available at the time was enhancing the existing strength member structure of the vessel, which in the particular case are beneath the main deck. In the evaluation of this option it was noted that achieving the required strength by enhancing the existing structure would require too many man-hours and time as too much work would have to be performed in situ, thus eliminating the advantages of standardised production of work in the workshops.

However, in order to obtain the required longitudinal strength for the vessels, the Top Side tanks would have to be of a size that would reduce the loading capacity of the vessels, due to their volume, significantly according to the owners and therefore a combination of top side tanks and under-deck longitudinal girders was used. By using under-deck girders, cargo is allowed to be stored between the longitudinal girders, whereas top side tanks create void spaces in which cargo cannot be stored.

Picture 28 Prefabricated topside tank
(Koros, 2010)

Since normal T girders would be prone to cargo retention they had to be replaced with re-designed girders which, along with the Top Side tanks, would give the converted vessels the required strength. The re-designed girders featured a slanted flat bar as a flange, instead of a normal T flange, and a slanted stiffening flat bar in the half-height of the girder's main body, as shown in figure 6-4.

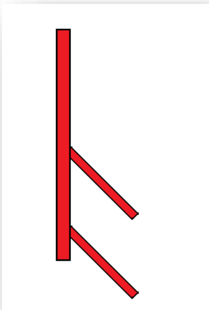


Figure 6-4 Cross section of longitudinal girder

(Author's figure)

The design featured two such longitudinal girders per ship side along with the top side tank. One of the girders was to be placed beneath the location where the hatch coaming was to be placed and therefore also provide support for it and protection to the other members from grabs during loading and discharging operations, and the other was to be fitted next to it.

The girders where fitted prior to fitting the hatch coamings and cutting the deck, in accordance with the conversion strategy plan.

Picture 29 Prefabricated longitudinal girders awaiting fitting
(Koros, 2010)

The girders passed through access cut out points created specially on the deck and where fitted in place using chain blocks, operated by workers on staging which was erected beforehand.

Picture 30 Cut-out access point on deck for girder fitting
(Koros, 2010)

This was a procedure that the shipyard had miscalculated as it resulted in excessive man-hour and time consumption. This was because of the difficulty presented in manoeuvring the girders through the access points on deck, lifting them in place and fitting them through the existing transverse web matrix, and working on staging. Fitting the girders and connecting them to the existing web matrix proved particularly difficult and out of budget as many factors were not thought of during the strategy planning. In order to fit the girders, large pieces of the existing webs had to be cut, as shown in picture 31, thus "intruding" into the vessel's existing structure, leaving parts of the deck unsupported and prone to deformation. For deformations to be avoided, the shipyard had to strengthen the deck transversely (above deck) where the webs were cut (below deck) by welding I beams on deck, as shown in picture 32.

Picture 31 New girder fitted, cut web and bulb-flats under-deck
(Koros, 2010)

Picture 32 Cut out access on deck for topside tank fitting and deck reinforcement
(Koros, 2010)

Working on staging whilst trying to lift long heavy girder sections without the use of the yard's crane, proved to be more difficult than anticipated. The working space created between the staging planks and the deck, whilst having to work between existing stiffening members, was so "confined-like" that designing the girders for production and prefabricating them in as large a size possible to reduce man-hours, in reality actually made the task of fitting them in place more difficult and man-hour consuming. The fact also that the workers had to perform tasks over-head, with gravity working against them also increased the difficulty of performing the required tasks. Had the girders been smaller, they would have been easier to fit in place. At this point suspicions of a mistake in design for the conversion were a reality, and these suspicions were confirmed again when the top side tanks had to be fitted.

When fabricating the Top Side Tanks, saving material was an issue of value to save cost and thus pieces of the cut deck were used to fabricate the top sides.

However, reusing the deck material to create this particular structure meant that the transverse webs should be cut as they bared little resemblance to the transverse stiffening required for the tanks. Due to the continuous heating of the plates during the web cutting process, the parts were deformed / bent. Reusing them to create the panel meant that they would have to be straightened again, which required applying loads on it and keeping it straight so that the new members could be fitted. It was found that the man-hours required to perform this task cost more than buying new material and creating the panel from scratch. Therefore after two panels were fabricated by reusing material, the idea was scrapped in favour of using new material and saving cost and time.

Top side tanks were thought to be a clever idea since they were designed for production (as were hatch covers and coamings), thus prefabricated in large sections, and would minimise work in situ as the case would have been with just enhancing the existing stiffener matrix.

After the longitudinal bulkhead had been fitted it was time to fit the top side tank. The top side tanks were prefabricated and left on the tank top awaiting their fitting time. Before lifting them in place, access points were created on the deck, similar to those created for the longitudinal girders. Staging was erected and pad-eyes were welded beneath the deck which would later help fitting the tanks in place.

The top side tanks, in order to be fitted required the transverse webs under the deck to be cut, again “intruding” to the vessel’s structure and creating deformation issues and therefore, once again, the deck had to be temporarily stiffened by means of I beams welded on the deck, as shown in picture 33 below.

Picture 33 Deck reinforcements
(Koros, 2010)

Once the I beams had been welded, the staging was disassembled and the top side tanks were lifted in place by the yard’s crane, via steel wires which had passed through the access points on the deck. When they were lifted as close to the deck as possible using the crane, they were brought to “kiss” the deck in their final fitting position using chain blocks which were left in the tanks beforehand, that were attached to the pad-eyes fitted. Spot welding was performed and the tanks were fitted in place. Internal welding took place using the access points and external welding required staging to be erected.

Picture 34 Cut out webs for new topside tank fitting
(Koros, 2010)

This had so far been a time and man-hour consuming process due to its complexity and the amount of residual sub-procedures it required, such as staging, web cropping, chain block lifting etc. It was however calculated in the planning stage and had then been considered the best possible solution to the longitudinal strength problem.

The difficult part of the Top Side tank fitting procedure was fitting the tanks through the transverse bulkheads. It was at this stage that the suspicions of a mistake in the design and planning of this conversion was confirmed once more, after the longitudinal girder fitting process.

The top side tanks, having been designed for production and thus prefabricated in as large sections possible presented a big problem when having to pass through existing vessel structures.

Since they were to be fitted to play the role of main longitudinal stiffening, their continuity as a structure should remain throughout the ship’s length. Otherwise they could not be regarded as participants in the longitudinal strength of the vessel. For this reason, all transverse bulkheads between the tanks of the vessel had to be partially cut in order for the top side tanks to pass through and then refitted accordingly.

Picture 35 Piece of transverse bulkhead to be cut so that top side tank passes through
(Koros, 2010)

As in the case of the deck webs, the now unsupported piece of the deck had to be temporarily strengthened via I beams. The top side tanks were lifted, again using the crane, as close to the deck as possible but were left hanging now from the chain blocks left inside the tank, instead of being lifted to “kiss” the deck. A part of the staging erected for web cutting had been left standing at one side of the bulkhead and new staging was erected on the other side of the transverse bulkhead and so a piece of the bulkhead was cut. Using the erected staging, pad-eyes were welded on the bottom part of the deck plating on the side to which the tank was to be passed. Chain blocks were attached to the top side tank and the pad-eyes and pulling commenced. As the new chain blocks pulled, the previously attached to the tank chain blocks, keeping it in the air, had to release. Eventually the tanks passed through the transverse bulkhead and were fitted in place.

Once again, having to work on staging, over-head, and having to maneuver such large structures between existing vessel’s structures, and having to “intrude” to the vessels existing structure so much, by way of web and bulkhead cutting in order to fit the tanks, caused delays and excessive man-hour consumption. This problem was even greater when having to pull and fit the structures outside the parallel middle body area, especially in cargo hold 1. The hull in that hold created an even worse confined space situation as it “closed in” making pulling through, but also avoiding misalignment when fitting, even more difficult.

Before the end of the conversions, the shipyard had decided that the Top Side Tank and Girder method was not a success as it had gone over budget due to the unforeseen complexity of the method.

Since the owners of the vessels wished at the time to convert two more sister-ships, an improved method should be considered.

6.5 Fitting Box Girders on Deck

The Author proposed the idea of fitting box girders on deck to replace the top side tanks.

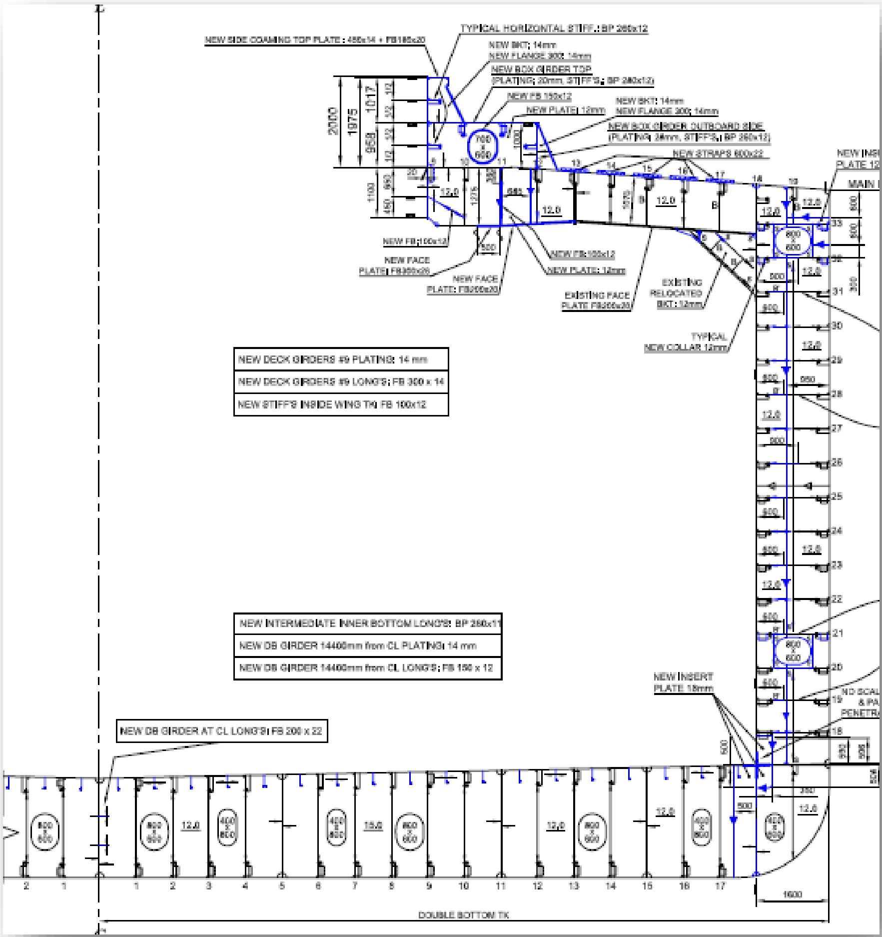


Figure 6-5 Box girder concept mid-ship section
(Salamis Shipyards, 2008a)

The box girder would provide all the advantages of the top side tanks method, whilst avoiding the disadvantages mentioned. Fitting structures on deck, especially in this case where the deck was free of any obstacles was proven to be, when fitting the cargo handling systems, very efficient and predictable. It requires no work on staging, and therefore no man-hours to erect staging, it does not require work in confined spaces, over-head, temporary strengthening, use of chain blocks etc. Moreover, the pier crane can be utilised to its full extent.

As in the case of the top side tanks, the box girders were to be designed for production and prefabricated extensively. This time however, their size would not hinder the fitting stage as work could be conducted freely on deck.

Because the box girders would be fitted on deck, free of any obstructions and making full use of the crane, their assembly on board would resemble much a shipbuilding approach of joining blocks on the building berth. In shipbuilding, blocks, which have been built/prefabricated to be as large as possible in order to be lifted by the crane facilities and pre-outfitted to the maximum extent possible to reduce work on the berth, are joined on the building berth; the berth presents no obstacles for the joining of the blocks. (Lamb, 1986)

The box girders would also not be fitted in an area with curvature, as the deck presents no curvature in or outside the parallel middle body area, thus the repetitive nature of their components provided for maximum standardization and simplification in their fabrication.

The box girder method also, is a far less intrusive procedure to the vessel's hull. As it requires minimum or no alteration to the vessel's existing strengthening members, compared to the need to crop out under-deck webs, girders and bulkheads to fit top-side tanks, it requires less man-hours and time; hence its advantage over that method regarding intrusion is clear.

Box girders would also eliminate the need for under deck longitudinal stiffeners. As all the required strength could be built into the girder's stiffeners, this would reduce the number of components this method required compared to the top side tank and under-deck girder method. This therefore could be characterized a suitable design for production (Larkins, 2007). It would also have the benefit of not reducing the cargo hold's capacity as the girders would be fitted outside the cargo hold area.

All these also meant that the shipyard could accurately schedule and budget the whole procedure.

There are however some disadvantages to the box girder method, the most obvious being its appearance. It must be said that having box girders on deck may look out of place on a vessel and in this respect the idea is radical. However, there appear to be no problems caused in the vessel's operation. The girders in fact may actually make cargo hold inspection easier, as the coamings are relatively high. The crew can step on the girders to inspect the holds and can be fitted with railing to protect the crew when walking on them, as shown in figure 6-6.

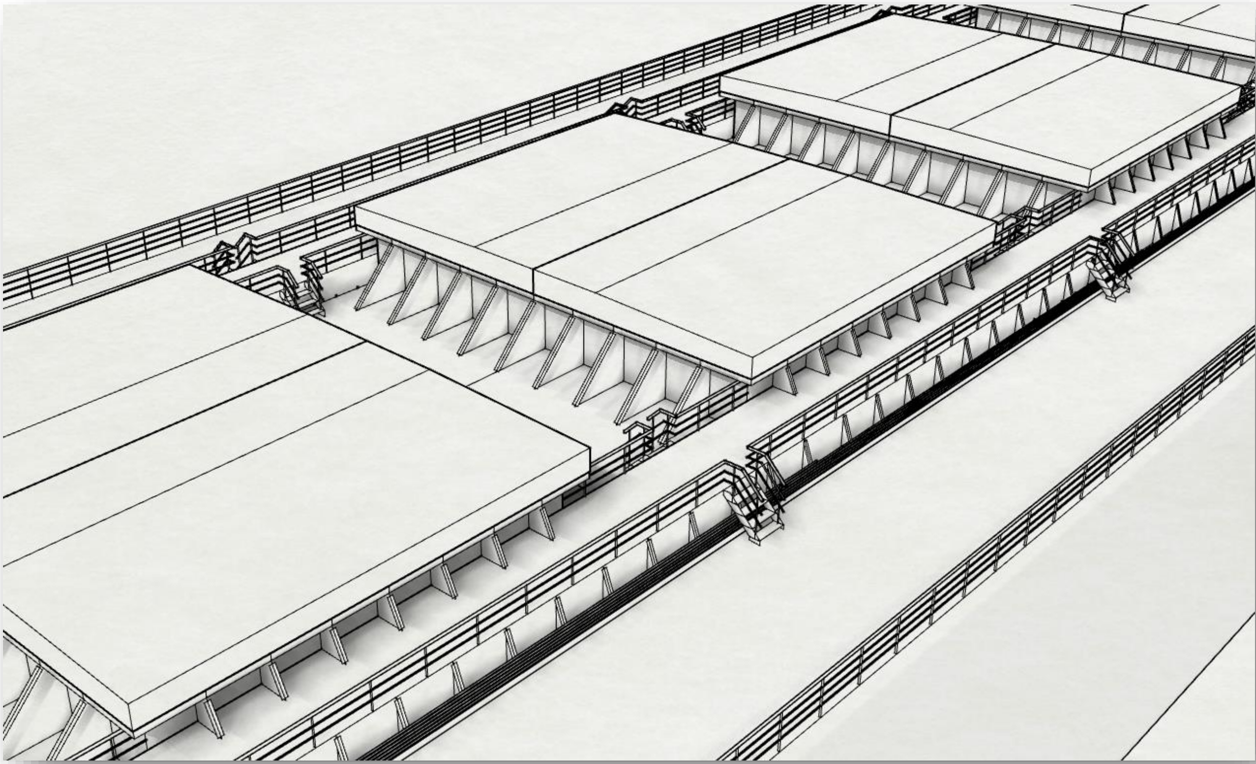


Figure 6-6 Box girder indicative layout with side safety rails
(Koros, 2015)

Figure 6-6 above shows an indicative layout of the box girders fitted on deck, with rails fitted on either side, to-and-from the cross-deck area, which allows for easy crew access to all the cargo area on deck for inspection with safety.

Also all the piping can be neatly fitted on the box girder instead of the hatch coamings and can perhaps be inspected and repaired more easily as it will not have to pass through the coaming stay brackets, but rather be fitted directly on the stay brackets of the box girder as shown in figure 6-7.

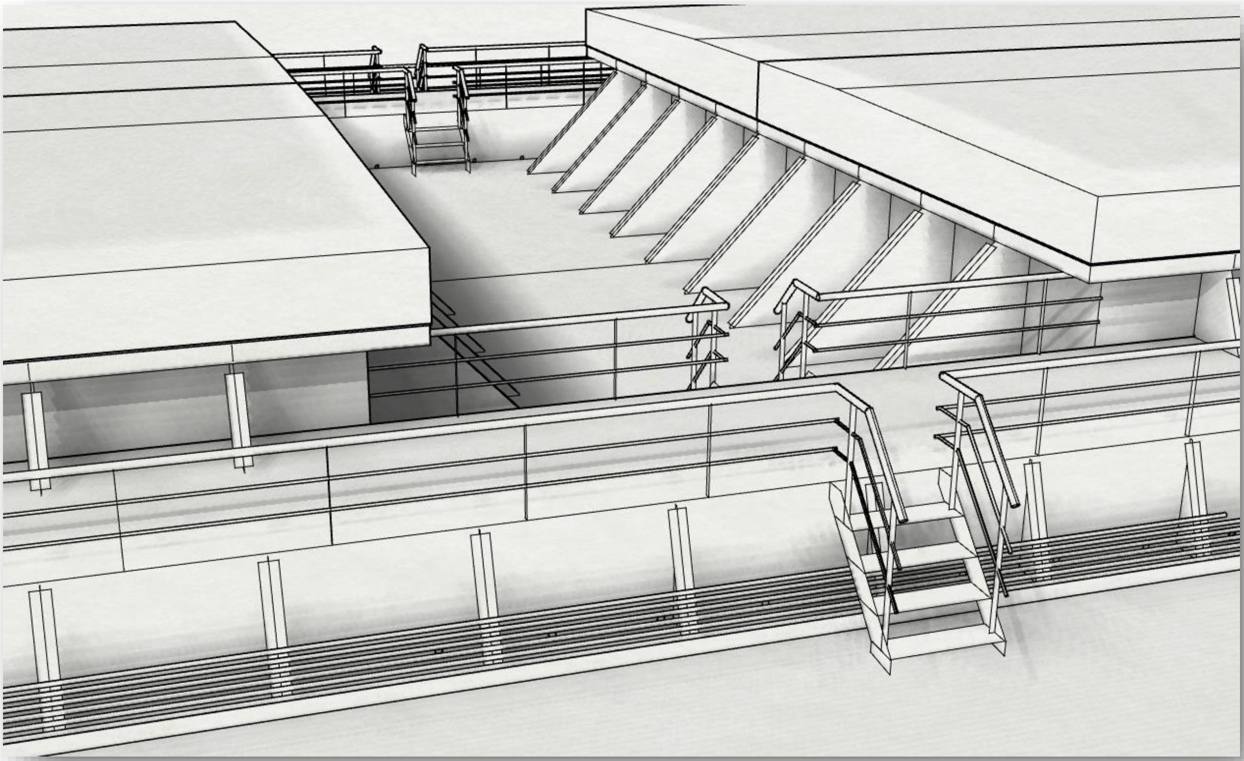


Figure 6-7 Piping on box girder stay brackets
(Koros, 2015)

A point of interest in the girders method is that in the cross deck area water accumulation may occur due to rain or heavy weather. This however can be resolved by incorporating drains in the box girders, passing from the cross-deck area straight to the deck area, thus allowing accumulated water to pass through.

The figure below illustrates such drains fitted on the box girder, just for demonstration purposes. The requirements for the number and diameter of the drains have not been calculated.

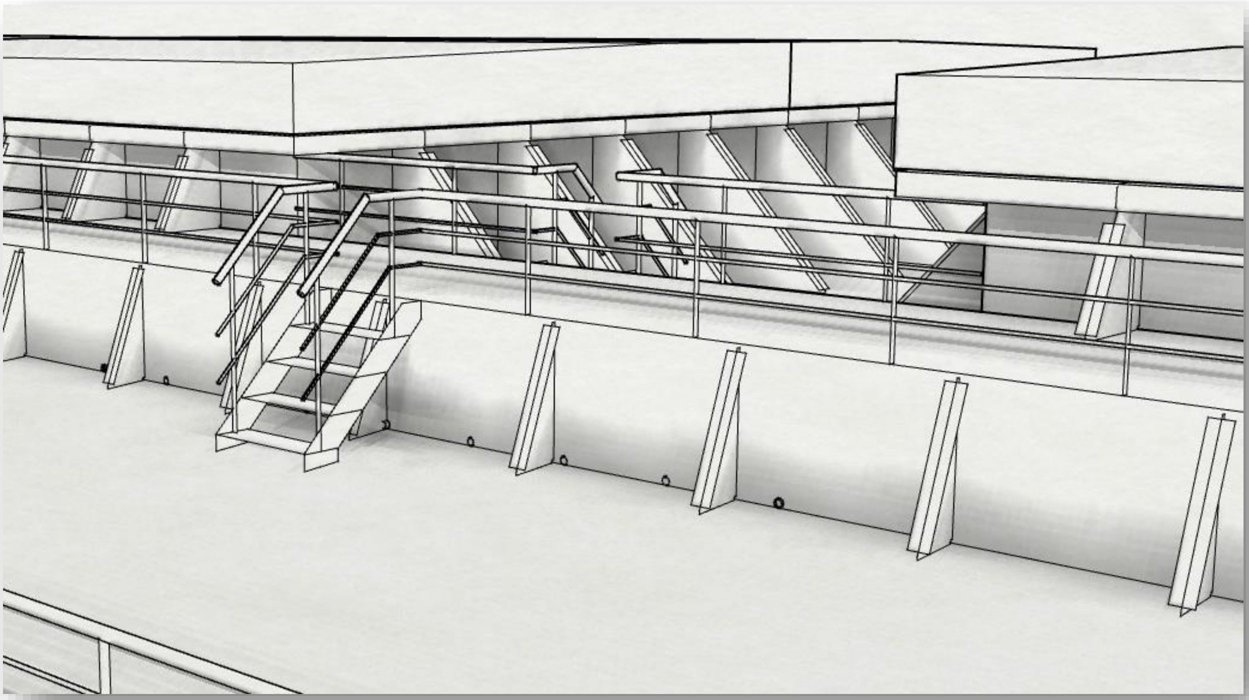


Figure 6-8 Indicative drains on box girders for cross deck area
(Koros, 2015)

Unfortunately, the dire economic environment in the shipping industry, not to mention the global economy, in late 2008, which made owning and operating bulk carriers commercially unattractive, forced owners to cancel the conversion of the further two sister ships, for pure commercial reasons, and therefore the yard could not implement the innovative idea of the box girders.

6.6 Double Hull Structure

The yard decided to use the bulkhead relocation method in order to create the double hull structure in the vessels. Bulkhead relocation is a procedure that was appealing due to the fact that it saves material and man-hours, compared to constructing new bulkheads, fitting them in the vessel and scrapping the existing bulkheads. However it is a procedure that requires its techniques and since it was never before performed by the shipyard, it was a trial and error effort.

Initially the yard used the procedure described in the strategy for conversion and the bulkheads were cut to six pieces as it was considered easier to be moved due to the compact size and light weight of the panels. As time passed confidence grew and the six pieces became four. This reduced man-hours required for the task. It was later on noticed that it was still possible to relocate the bulkhead in four panels with even reduced man-hours further.

The new way required no intermediate position, as described below:

- STAGE 1 – Releasing the longitudinal bulkhead from the surrounding structure

This stage of the new procedure is exactly the same as the one in the first procedure.

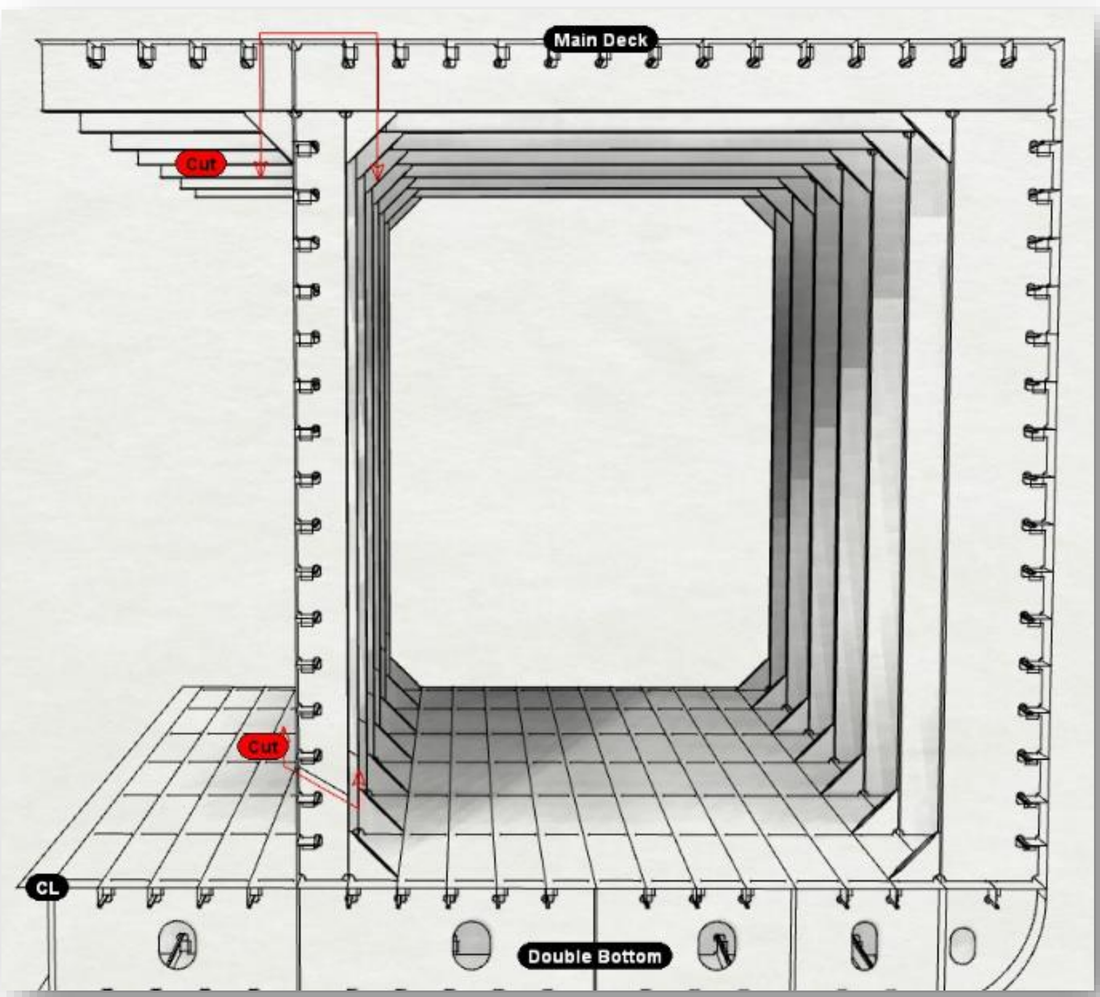


Figure 6-9 Cut points for bulkhead

(Koros, 2014)

- STAGE 2 – Hoisting the bulkhead and moving it to the side

Now that the bulkhead has been almost freed from top and bottom, it is important to determine the points of its hoisting, and identify the forces acting on it for its relocation, as done in the first procedure. Figure 6-10 shows 4 forces acting on the bulkhead. It can also be seen that technical openings have been created on the deck to aid the bulkhead's relocation.

F1 is the upward force acting on the bulkhead the dock's crane. F2 is the upward and towards the left side force acting on the bulkhead through two chain blocks which will aid in keeping the bulkhead from falling to the right hand side as the other forces are acting on the bulkhead and F1 is released from its original position. F3 is the force acting on the bulkhead through two chain blocks and is the force that is required to move the bulkhead towards the side shell in one move. F4 is the downward force acting on the bulkhead through two chain blocks which will aid the bulkhead to be placed on its final position.

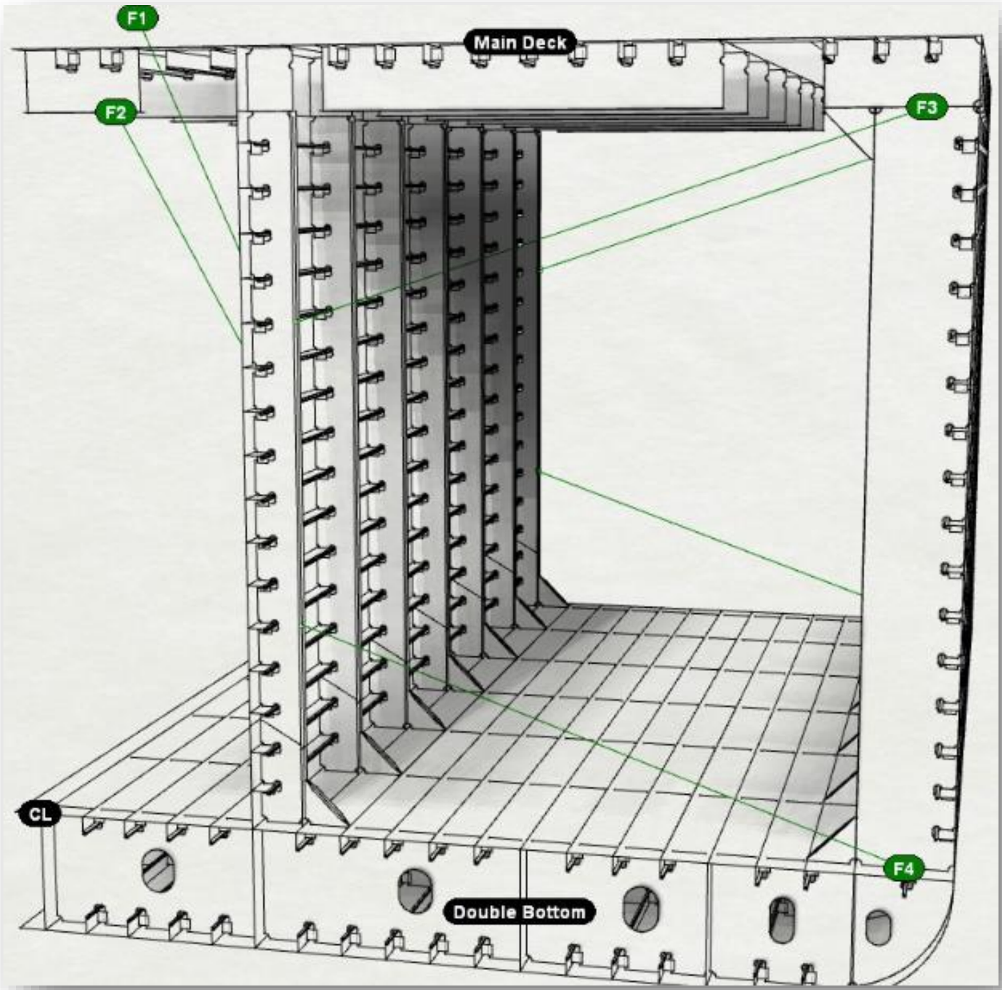


Figure 6-10 Forces acting on bulkhead, method 2

(Koros, 2014)

Picture 36 Forces acting on bulkhead
(Koros, 2010)

The bulkhead will pivot to the left via F4, be slightly lowered via F1 and F2, and pulled towards the side shell via F3 and F4, and rest in its final position before being lifted while F2, F3 and F4 are acting on it.

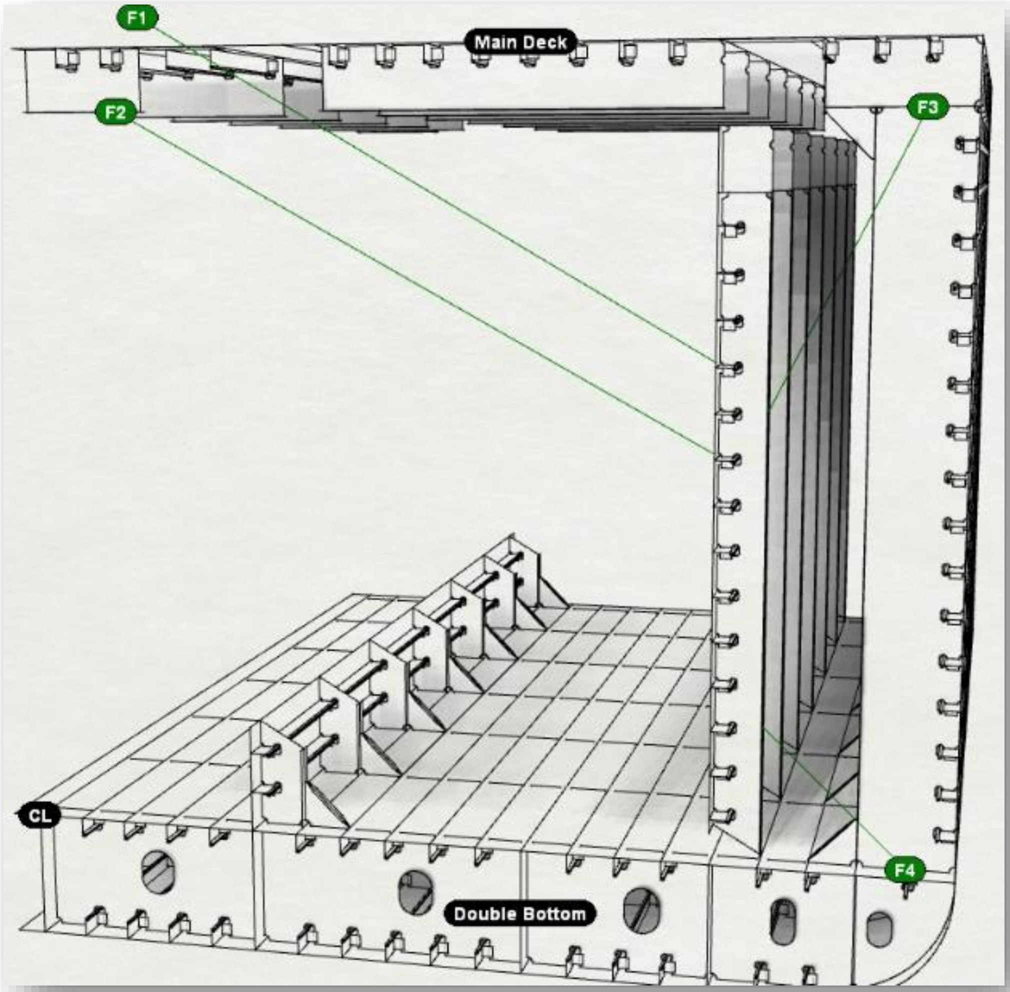


Figure 6-11 Forces acting on bulkhead

(Koros, 2014)

- STAGE 3 – Lifting the bulkhead

When the bulkhead has been moved to its final position, F1 will change place and now will be acting through the technical opening above the final position of the bulkhead. F1 will raise the bulkhead, F3 and F4 will pull it to the side in order for its longitudinal to be housed in the slots created on the shell's webs, and F2 will provide a counter balance so that the whole maneuver is performed in a safe manner.

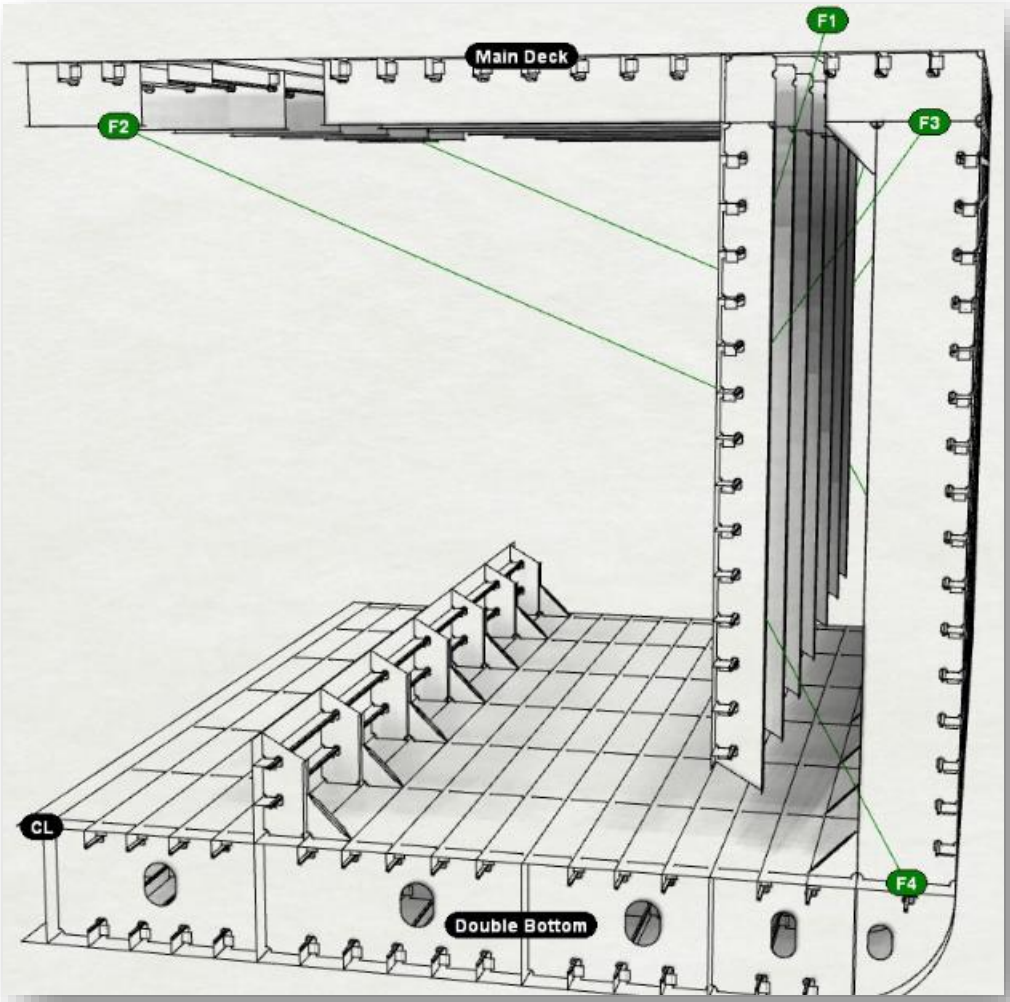


Figure 6-12 Forces acting on bulkhead for lifting

(Koros, 2014)

- STAGE 4 – Relocating the lower part of the bulkhead

Again the last action that remains to be taken after the top part of the bulkhead has been fitted in its final position, is to relocate the bottom part of the bulkhead, which as explained previously is a straightforward task, and therefore it is the author’s view that no further analysis is required.

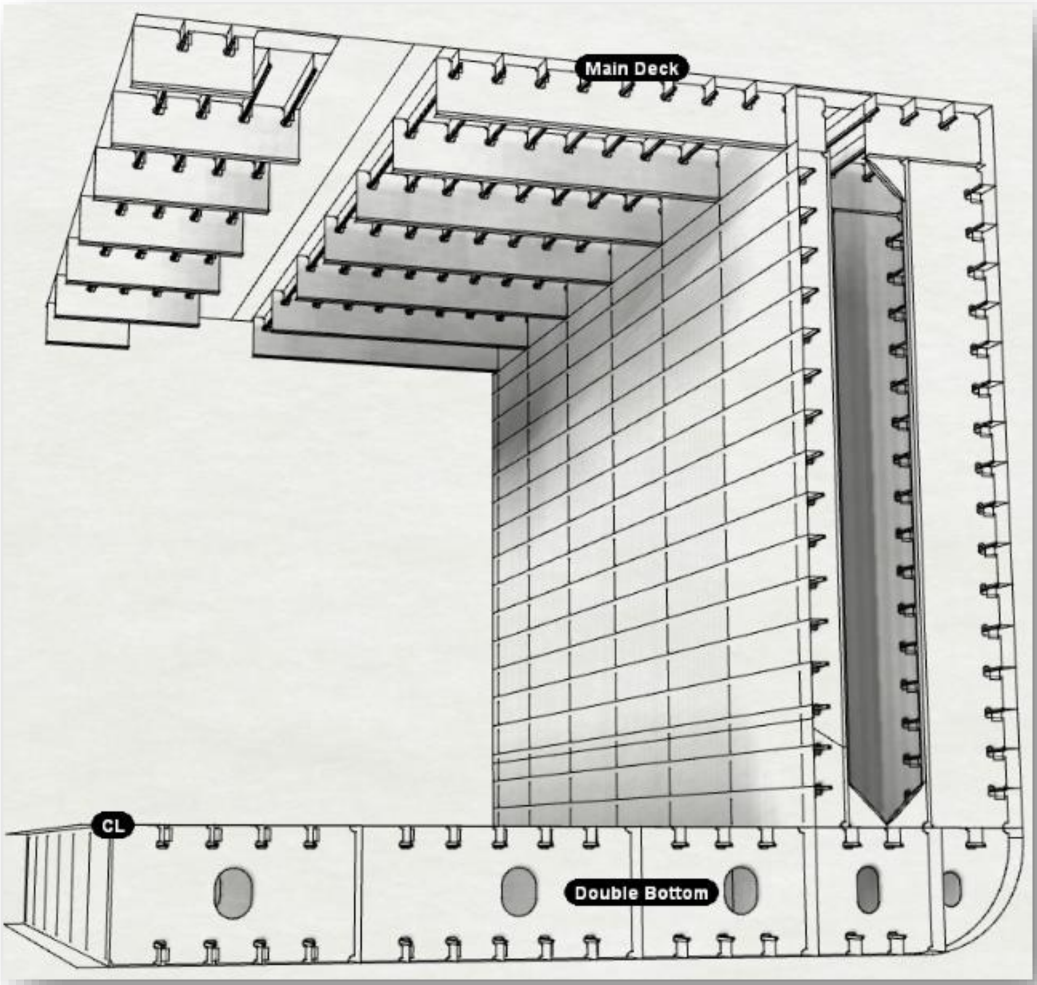


Figure 6-13 Bulkhead in final position and lower part relocated

(Koros, 2014)

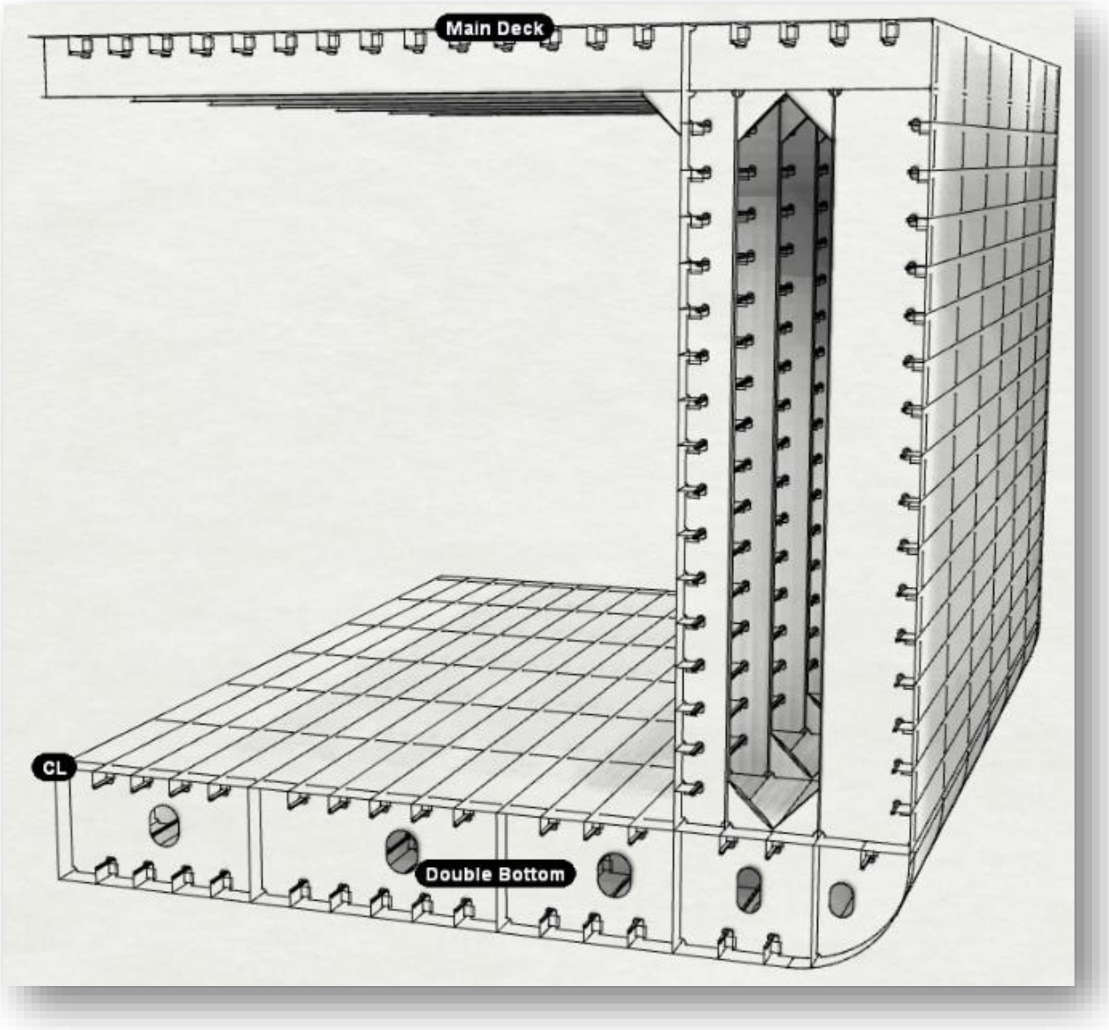


Figure 6-14 Bulkhead fully relocated and webs fitted in place
(Koros, 2014)

The actions required for the whole procedure are listed below and the network connecting them together to perform the task successfully is given in figure 6-15 below:

1. Staging in side tank
2. Cutting off the tie beams
3. Preparing the web frames
4. Fitting the longitudinal stringer
5. Cutting the web that holds the bulkhead at the top
6. Cutting the bulkhead at the bottom
7. Welding pad-eyes on the bulkhead
8. Attaching chain blocks and crane for forces F1, F2, F3, F4
9. Releasing the bulkheads holding points
10. Pivoting the bulkhead and relocating it to final position
11. Releasing F1

12. Reattaching F1 from starboard side through the technical opening above the bulkhead's final position
13. Lifting the bulkhead and housing it on the webs
14. Spot welding the bulkhead on the webs while pulling forces to the side are in action
15. Releasing F1
16. Releasing chain blocks that hold it to the side
17. Welding the bulkhead in place
18. Relocating bottom part of bulkhead
19. Welding bottom part of bulkhead

As it can be seen by comparing the number of the steps and logic of each bulkhead relocation method, the second one is simpler. Making the procedure simpler has an immediate effect in man-hours required for the task. The man-hours are reduced and time is saved.

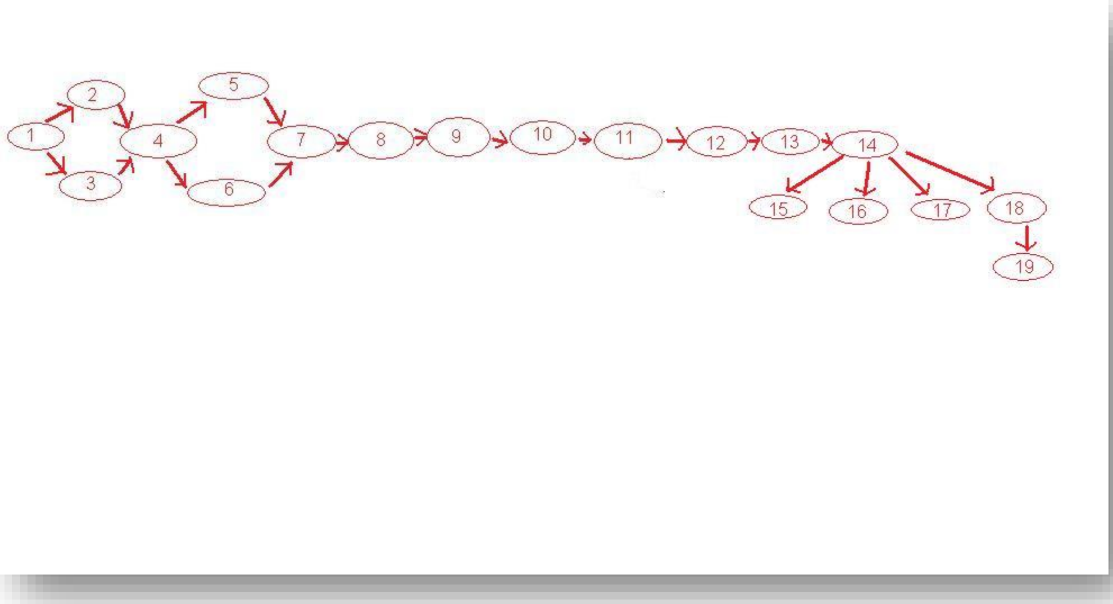


Figure 6-15 Actions required for method 2

(Author's diagram)

6.6.1 *What can go wrong*

When relocating bulkheads the height issue is the most important. Figure 6-16 illustrates the bulkhead before its relocation and pays special attention to two heights, H1 and H2. H1 is the distance between the bottom end of the under-deck web and the tank top. H2 is the distance between the upper and lower cutting points of the bulkhead to be relocated. Always H1 must be greater than H2.

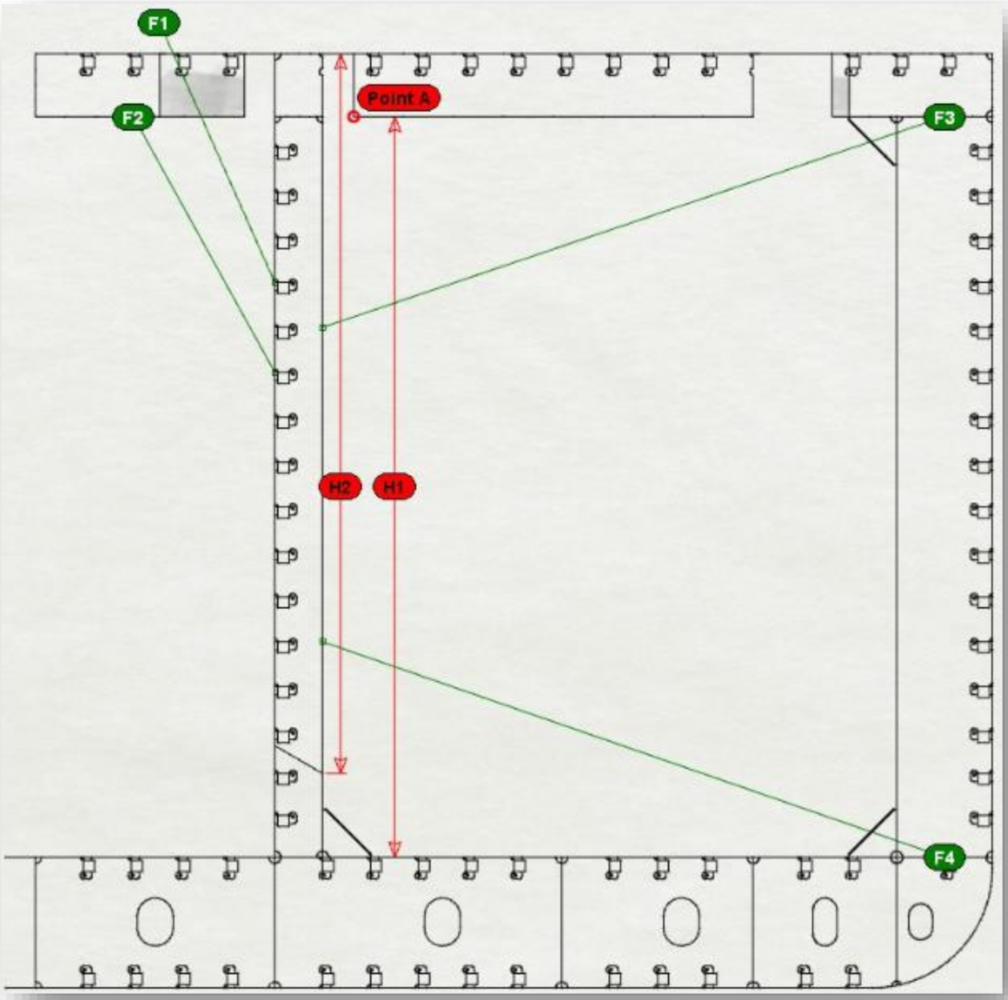


Figure 6-16 H1 must be greater than H2

(Koros, 2014)

Point A represents the bottom edge of the cut web. In bulkhead relocation it is very common that the bulkhead while it is being pivoted and relocated to get stuck at point A, as shown in picture 37 below.

Picture 37 Obstacle in bulkhead relocation

(Koros, 2010)

The height of the cut bulkhead will have to be less than the distance between point A and the tank top, so that the bulkhead can be lowered more in order to pass below point A. If this is not the case the only option is to lower a worker in a basket and cut a small piece off the bulkhead, but this is going to create problems later in the final fitting stage, as that piece will have to be added, thus increasing man-hours and time required for the procedure, which is what happened in the first relocation.

It is not advised to pull the bulkhead harder in order to allow the bulkheads elasticity to take place so that point A can be overcome without lowering the bulkhead or cutting a piece.

Picture 38 Obstacle overcome

(Koros, 2010)

6.7 Staging Improvements

Initial staging sequence:

- Staging No.1, as shown in figure 6-17, was raised on the left hand side of the bulkhead to be relocated, in order for the pad-eyes to be fitted, on which the chain blocks will be attached, the technical opening to be created and the bulkhead to be cut for relocation.

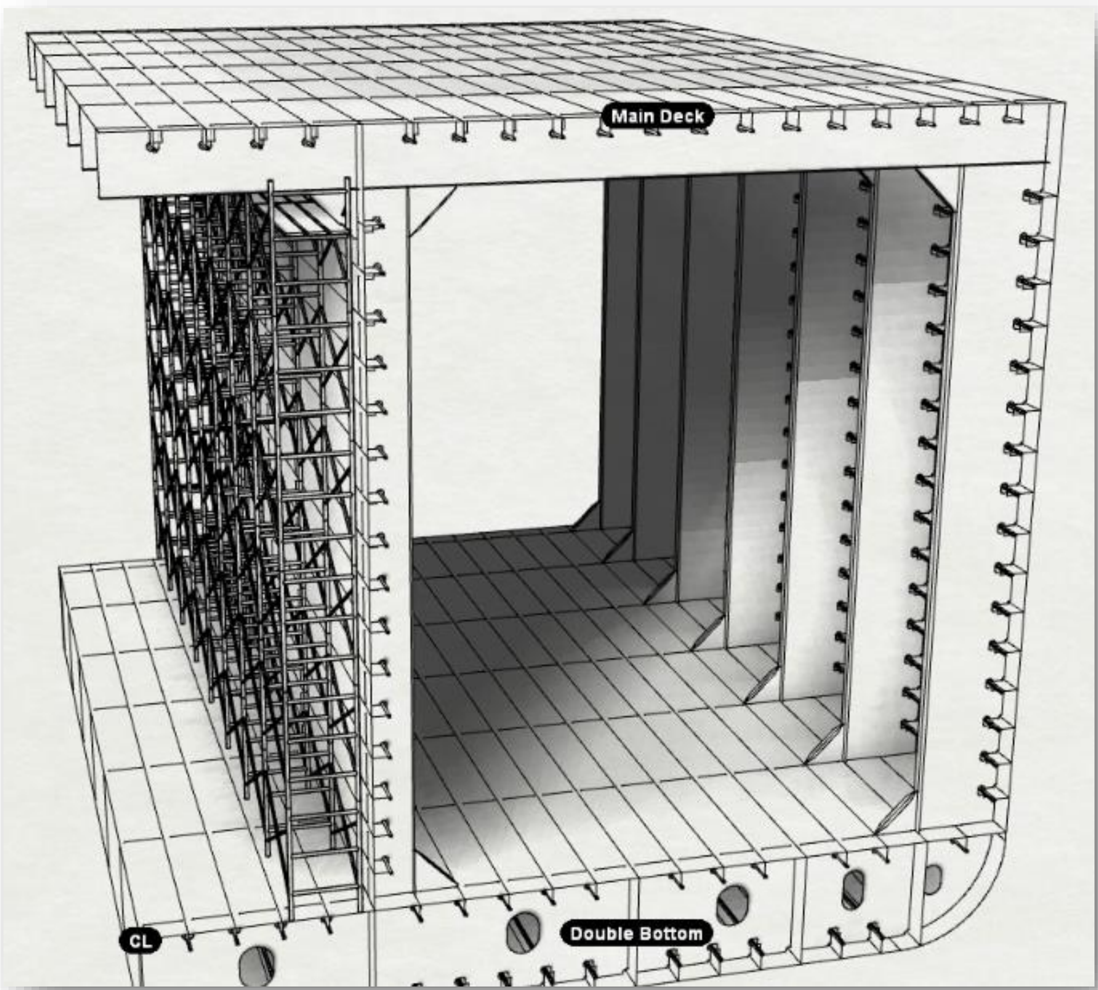


Figure 6-17 Staging No. 1
(Koros, 2014)

- Staging No.2, as shown in figure 6-18, was raised all across the side tank, in order for workers to prepare the webs and the stringer for the relocation and also fit the pad-eyes on the other side of the bulkhead. After that it was disassembled to relocate the bulkhead.

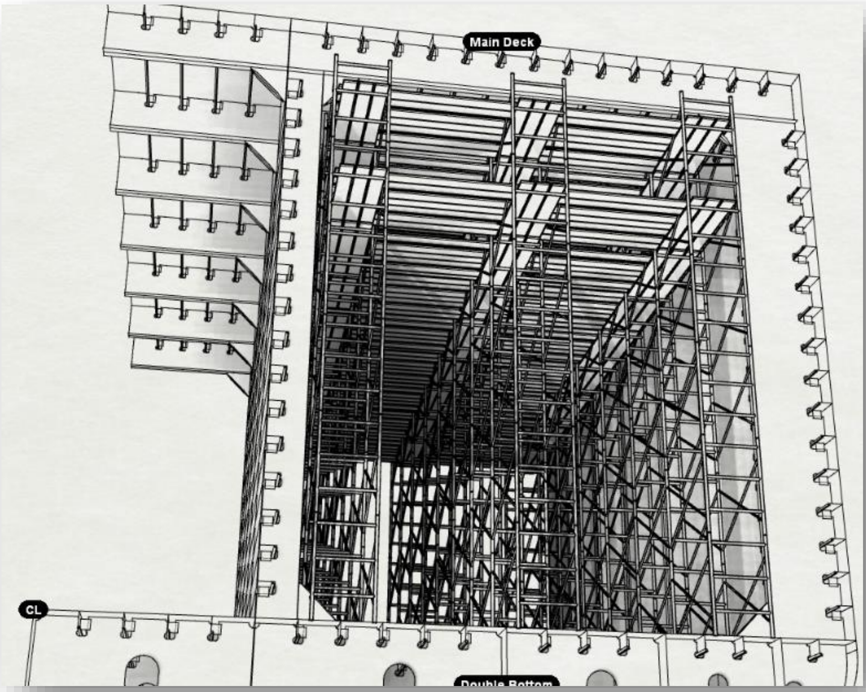


Figure 6-18 Staging No. 2
(Koros, 2014)

- After the bulkhead was relocated, staging No.3 was raised in order to fit the bulkhead in place, as shown in figure 6-19.

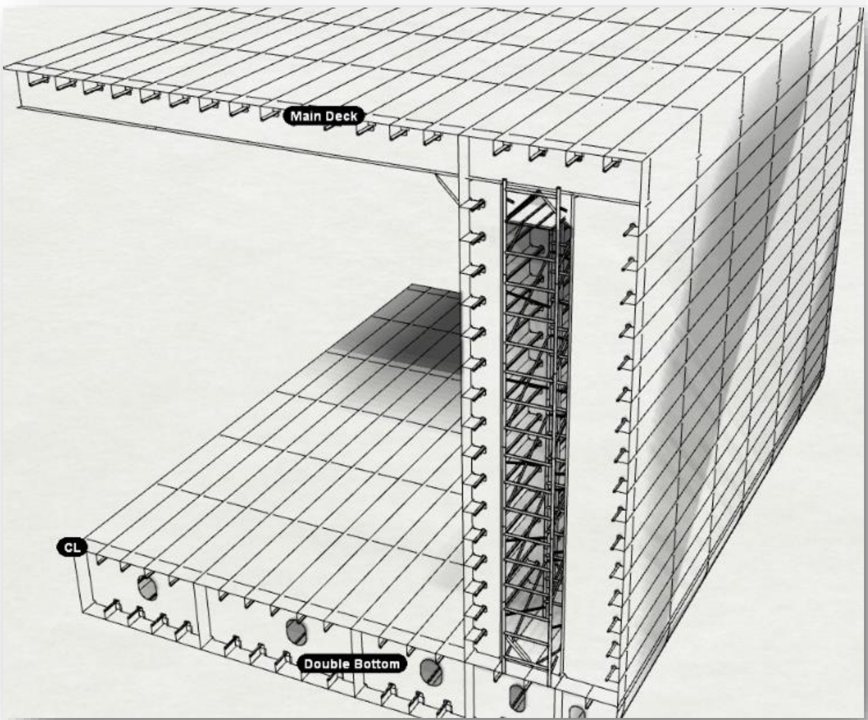


Figure 6-19 Staging No. 3
(Koros, 2014)

- Staging No.4 was fitted on the left hand side of the relocated bulkhead to complete all the remaining welding in place, as shown in figure 6-20.

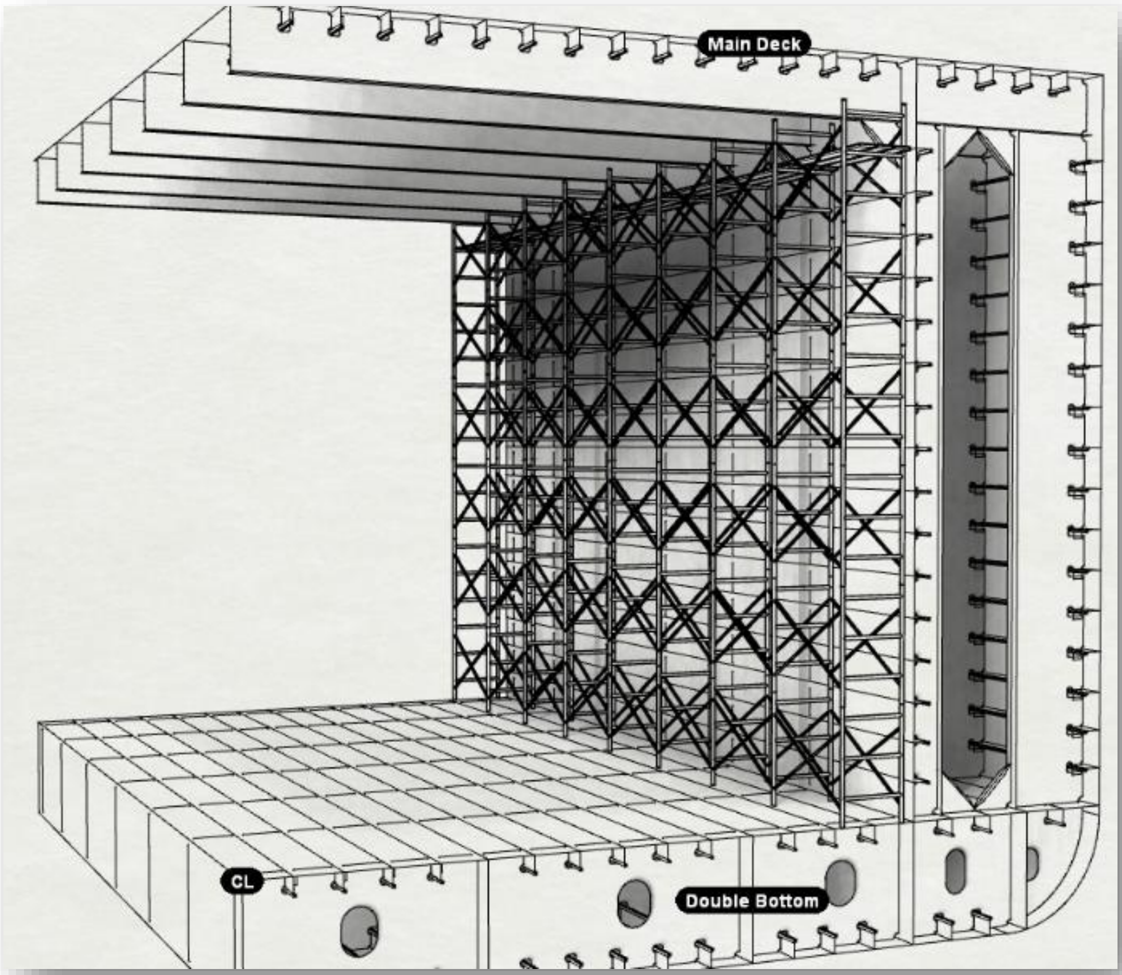


Figure 6-20 Staging No. 4
(Koros, 2014)

Improved procedure:

After trial and error, it was concluded that only one stage of staging is required, which contains 2 parts.

Staging No.2 is the only necessary staging and it is divided in parts A and B, as shown in figure 6-21 and picture 39. Although the whole side tank will be staged, it is possible to do it by only using rectangular frame staging on the side shell and the side of the bulkhead and connecting them with pipes, as shown in figure 6-21.

In this way, it is possible to remove staging on the side of the bulkhead, along with the interconnecting pipes and planks, without removing the staging on the side shell (part B).

Staging No.1 must be raised anyway in order to fit and weld the under-deck girders that go beneath the hatch coamings.

Welding the bulkhead in place externally can be performed in by using ceramic strips on the external side of the seams, which can be fitted by a cherry picker or a scissor lift. Any remaining welding that cannot be performed with the aid of ceramic strips can again be performed by the means of lifting mentioned just now. Therefore staging No.4 is not required.

This improvement was again another example of how trial and error in conversions is inevitable but in the end produces satisfactory results.

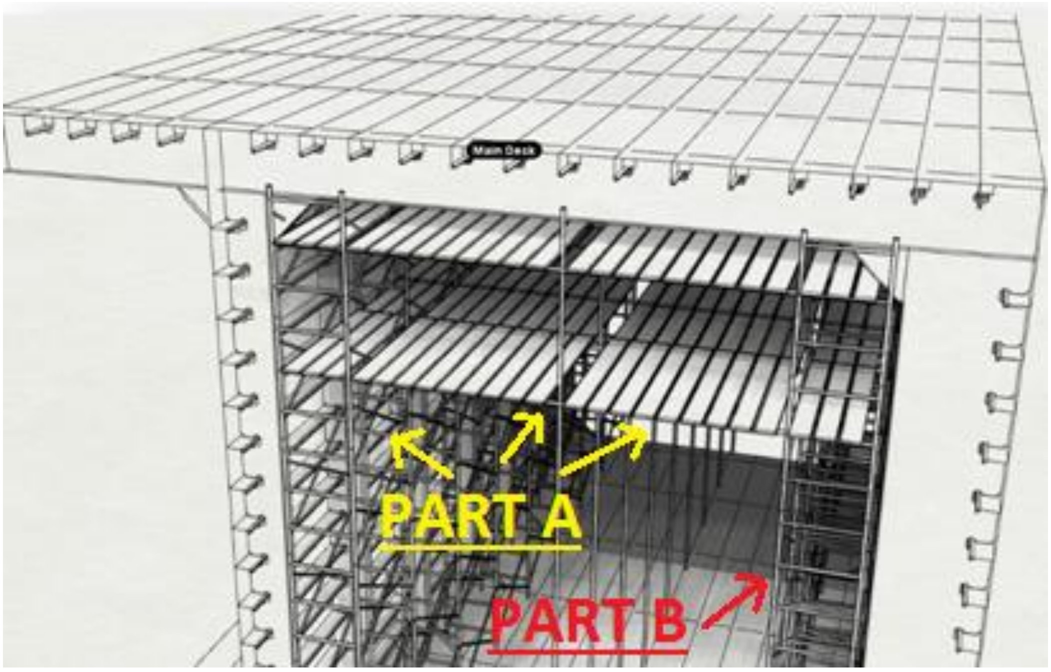


Figure 6-21 Improved staging No. 2
(Koros, 2014)

Picture 39 Improved staging, detailed
(Koros, 2010)

6.8 Tank Top Strengthening Issues

Because these two vessels were originally tankers, the cargoes they were carrying had small specific gravities and were loaded into the ships with ease and with small impact force, through a pumping and piping system. Now that the ships would be turned to bulk carriers, they would be carrying much more aggressive cargoes in terms of specific gravity.

Because these ships were tankers they have a “thin” tank top plating (14mm) and a large web frame spacing (3.26m). The preliminary design study showed that this tank top was not suitable for carrying cargos of specific gravity more than 1, and was therefore necessarily in need of reinforcement, as owners required a minimum cargo density of 2. The design office, in coordination with the classification society at the time, chose to reinforce the tank top by adding intermediate transverse floors in the double bottom, and also longitudinal flat bars between the existing longitudinal strength members (previous spacing 800mm, and now 400mm).

Picture 40 Tank-top cut out access and floor
(Koros, 2010)

Fitting floors in the double bottom created many problems. Working in confined spaces, such as the double bottom, creates many logistics as well as final steel product fitting problems. Fitting the floors in the double bottom meant that many access points had to be cut on the tank top so that the floors could pass through, as shown in picture 40. As floors are large structures as they have a length equal to the distance between the main longitudinal girders and height equal to the height of the double bottom, are very difficult to maneuver. Fitting them in place requires cutting an access point right above the location of fitting as it is impossible to fit them through the existing manholes in the double bottom. Therefore the amount of cut points on the tank top increases with the amount of floors to be fitted, a fact that increases excessively the "complementary indirect work" of fitting floors as those access points will eventually have to be re-fitted and re-welded. Fitting floors in the double bottom was made even more difficult when there were secondary system structures obstructing the fitting, such as ballast pipes and valves. The floors, which were prefabricated, had to be cut in pieces so that the pipes in those areas could fit through, as shown in picture 41. In essence the prefabricated floors were being cut and being re-built around the pipes, rendering the man-hours and consumables used to prefabricate them useless.

Picture 41 Prefabricated floor cut and re-built around ballast pipe
(Koros, 2010)

Working in confined spaces may sometimes create confusion in material logistics, as was the case in these conversions too. Many prefabricated items which were meant for fitting elsewhere, were fitted randomly as there was pressure to complete the work as soon as possible. This resulted in floor repairs and alterations so that they would fit in the space they were fed to, rather than be taken back out of the double bottom and see where they were meant for fitting, as shown in picture 42.

Picture 42 Floor re-built to correct mistake in material allocation
(Koros, 2010)

The owners of the vessels at some point during the conversions decided to change classification society to RINA, the Italian Classification Society (Registro Italiano Navale). RINA has a vessel condition assessment scheme which estimates the “conventional age” of the vessel and can issue “conventional age reduction certificates”(www.rina.org) based on the amount of major work performed on a vessel. Whilst this is not actual age reduction certification, the certificates indicate that the condition of the vessel is such as if it were built a specifically estimated amount of years later than the actual build date. This certification can prove useful to owners for chartering reasons.

RINA had also another advantage compared to the previous classification society, relating to the maximum allowable distance between double bottom transverse floors. The previous class required a maximum distance of 2.5 metres from floor to floor, whilst RINA had no such requirements as long as structural integrity was proven to be adequate. RINA, after performing the tank top strength calculations decided that they could accept less stiffening for a cargo density of 2. Instead of the double bottom floors and flat bars, they would accept just the flat bars welded between the bulb flats at the bottom end of the tank top plating (double bottom ceiling), as shown in picture 43.

Picture 43 Flat bar fitted below tank top
(Koros, 2010)

This reduced man-hours required to complete the task drastically. Flat bars were easy to maneuver in the double bottom as they would fit easily through the manholes, they were light and thus could be lifted more easily by hand and hence less work was required using chain blocks, and required less access points, thus also reducing the indirect work required to fit them.

Since RINA now did not require any major stiffening in the double bottom, and focused purely on the strength of the plating, thus only require stiffening for the tank top plating, applying SPS could be a solution to the problem. The shipyard did not have the opportunity to examine this scenario in the next two conversions, as the financial crisis of 2008 reduced the values of bulk carriers dramatically, making owners not proceed with the further two conversions.

.

6.9 Permanent Deformation

One of the initial considerations that brought skepticism was how the vessel would perform under the concentrated stresses that resulted due to the removal of the vessels' strengthening members to perform the conversion. The decision to complete the work afloat was the main reason for this concern, as the yard did not own a dry dock. The fear was that the vessels would suffer extreme hogging which could result in permanent deformation. The initial solution that was considered was performing the conversion in a graving dock as it would support the weight of the vessels evenly without allowing any concentrated stresses to affect the hulls' integrity. The cost of such an experiment would most likely mean that the conversion would not be possible financially, as a large portion of the conversions would have to be performed at a third party's dry dock, increasing cost excessively. It was then thought that the conversion can be performed afloat and the stresses resulting due to the cropping of main longitudinal members could be "evened out" with the aid of the vessels' own ballasting systems. To ensure that this procedure would be performed correctly the vessels' existing load indicator programs were used, which allowed to monitor maximum allowable hogging in port conditions, under different ballast conditions and laser beam equipment was used to measure the hogging of the hull at any given time, so that it could be cross checked with the results from the load indicator software and correct the ballasting procedure where necessary.

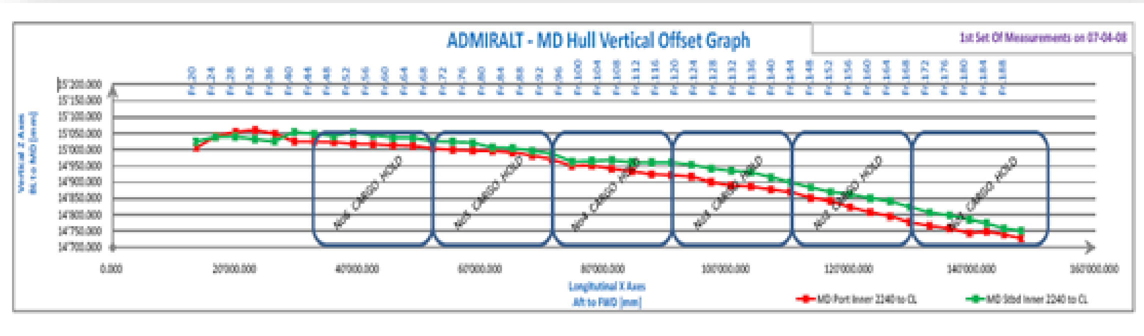


Figure 6-22 Vertical offset / hogging measurement graph

(SALAMIS SHIPYARDS, 2008b)

These conversions proved that conversions in general which affect the longitudinal strength of the vessels can be performed afloat without any danger to the vessels, as long as a careful ballasting strategy is followed.

6.10 Summary

This chapter has presented the vessels on which the conversions took place and continued by analysing the results of the application of the designs and the procedures as defined in the previous section of the Thesis.

The application of these designs and procedures was performed in some cases with success, within budget and time frame, whilst in other cases it presented challenges which made the shipyard re-examine the conversion strategy and design it had originally created. In this respect new ideas were presented and discussed addressing processes for dealing with the main design and planning issues pertaining to the conversions. This section makes the fact that conversions present a “learning ground” for improvement, even if a careful design and strategy are in place, apparent.

Chapter 7. Evaluation of Procedures Used to Address Design and Planning Issues in the Case Study

7.1 Introduction

Having discussed in the Case Study the difficulties associated with each procedure used to address design and planning issues in the conversions, whilst having presented replacement procedures and improvements in the same procedures, as the case may be, and having given explanations for the reasons that made the initial procedures inefficient and inadequate to cover the needs for low cost and low cycle time, it must be determined quantitatively if indeed these reasons were the cause of the problem, and if so, how effective were the new procedures in eliminating the said reasons.

By analyzing the man-hour consumption of each procedure and the time needed for its application, it can be safely determined if the replacement procedures were in fact improvements.

By breaking down the man-hour consumption of each procedure to man-hours consumed per task, the man-hours consumed for the reasons said to be the cause of the initial method’s ineffectiveness, can be determined.

By comparing the man-hours consumed for these reasons in the initial and the revised procedures, it can be determined if they were eliminated, and if so, it can be concluded that they were indeed the cause of ineffectiveness.

By identifying common causes of procedure ineffectiveness, conclusions can be drawn which will aid in the generation of a set of global principles which when applied may reduce the cost of conversion projects.

7.2 Solving the Longitudinal Strength Problem

The case study discusses the use of two methods to address the longitudinal strength problem created in these conversions:

- The addition of Top Side Tanks and under-deck girders, and
- The addition of Box Girders on deck

The addition of Top Side Tanks and under-deck girders being the method used to solve the problem in the conversions in the case study, allows for actual data availability of man-hours consumed and allocated in the different sub-procedures, as well as an accurate Gantt chart showing how this method was applied to the project.

As far as the Box Girder method is concerned, despite the fact that it did not actually take place, the shipyard were able to estimate man-hour consumptions as well as create an equivalent Gantt chart, based on their experience of producing the cargo handling systems. The systems, basically hatch covers and coamings, have many similarities to the Box girders:

- They have similar structures, being panels containing longitudinal and transverse stiffeners and brackets, with no curvature
- They are designed for production and therefore their production is repetitive, simple and makes maximum use of the shipyard’s facilities
- There are no obstacles that will impede final fitting in place as all are fitted on a free and cleared deck
- No staging and no work in confined spaces are required; apart from internal box girder welding when fitted in place onboard the vessel.

The Author and the shipyard therefore felt confident with the estimate of man-hours consumption and allocations and the Gantt chart for this method, given in this comparison.

7.2.1 The top side tank strengthening method

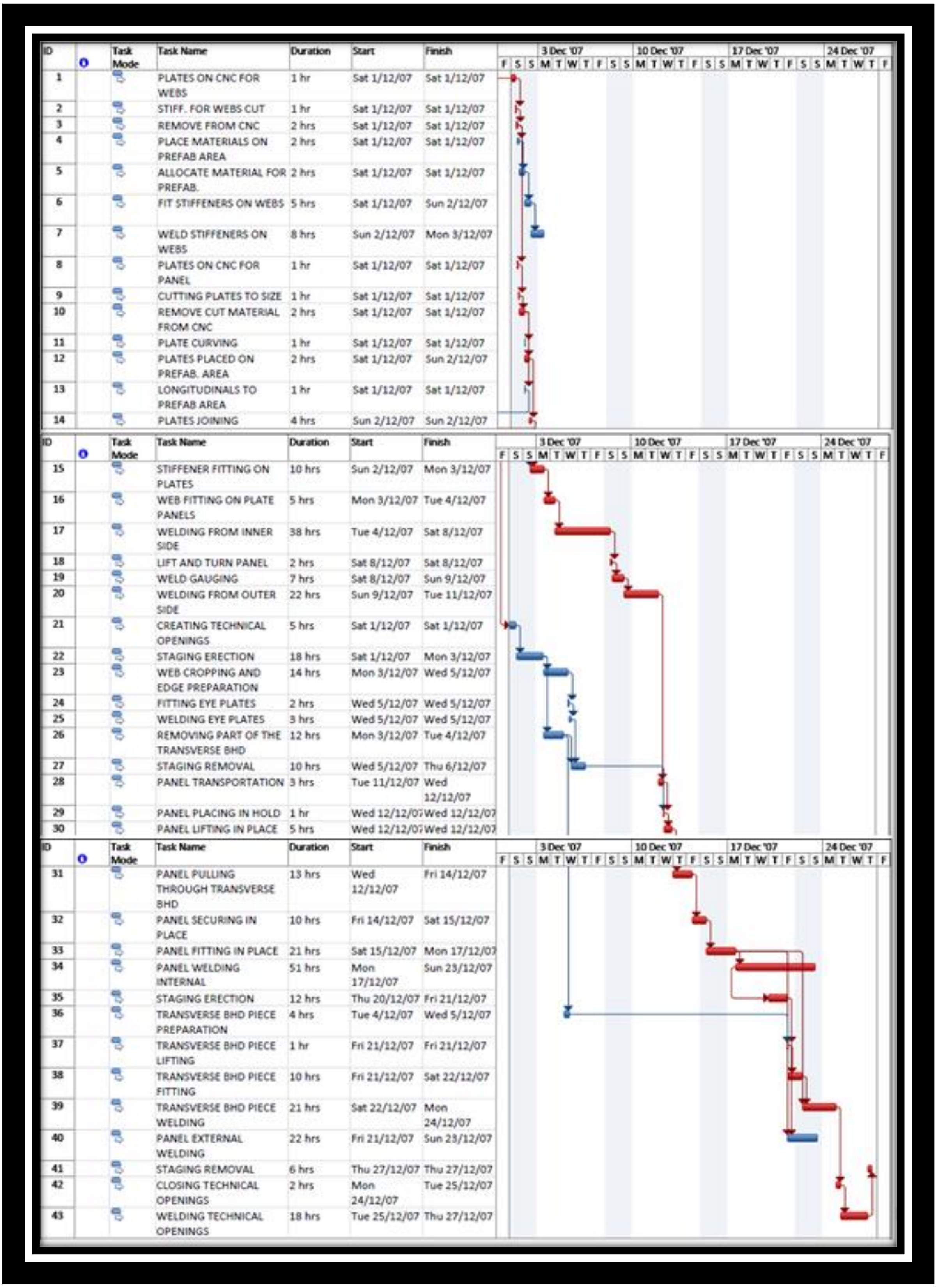
Man-Hour Consumption and Allocation

TOP SIDE TANK METHOD (MANHOUR CONSUMPTION)			
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	WEB PREFABRICATION		80
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
2	CUTTING THE WEBS	6	
3	CUTTING THE STIFFENERS FOR THE WEBS	3	
4	REMOVING CUT MATERIAL FROM CUTTING MACHINE	10	
5	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	8	
6	ALLOCATING THE MATERIAL FOR PREFAB.	9	
7	FITTING THE STIFFENERS ON THE WEBS	16	
8	WELDING THE STIFFENERS ON THE WEBS	25	
	PLATE JOINING AND PREFAB		
9	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	67
10	CUTTING THE PLATES TO SIZE	3	
11	REMOVING CUT MATERIAL FROM CUTTING MACHINE	4	
12	PLATE CURVING	2	
13	PLACING PLATES IN PREFAB. AREA	8	
14	BRINGING LONGITUDINALS FROM STOCK TO PREFAB AREA	1	
15	JOINING THE PLATES	8	
16	FITTING THE STIFFENERS ON THE PLATES	38	
	TOP SIDE PANEL FABRICATION		194
17	FITTING WEBS ON THE PLATE PANNELS	20	
18	WELDING FROM INNER SIDE	112	
19	LIFTING PANEL AND TURNING	10	
20	WELD GAUGING	7	
21	WELDING FROM OUTER SIDE	45	
	PREPARATION IN SITU FOR TOP SIDE PANEL FITTING		292
22	FITTING AND WELDING OF TEMPORARY REINFORCEMENTS	35	
23	CREATING THE TECHNICAL OPENING	20	
24	ERECTING STAGING FOR WEB CROPPING ETC	106	
25	EXISTING WEB CROPPING AND EDGE PREPARATION	28	
26	FITTING EYE PLATES ON THE BULKHEAD FOR THE FINAL FIT	3	
27	WELDING EYE PLATES	9	
28	REMOVING PART OF THE TRANSVERSE BULKHEAD	28	
29	REMOVING STAGING	63	
	FITTING THE PANEL		587
30	PANEL TRANSPORTATION	12	
31	PANEL LIFTING AND PLACING IN HOLD	4	
32	PANEL LIFTING FROM HOLD IN PLACE	35	
33	PANEL PULLING THROUGH TRANSVERSE BHD	54	
34	PANEL SECURING IN PLACE	38	
35	PANEL FITTED IN PLACE	84	
36	PANEL WELDED INTERNALY	102	
37	STAGING ERECTION	76	
38	TRANSVERSE BHD PIECE PREPARATION	9	
39	TRANSVERSE BHD PIECE LIFTED	2	
40	TRANSVERSE BHD PIECE FITTED IN PLACE	20	
41	TRANSVERSE BHD PIECE WELDED IN PLACE	21	
42	PANEL WELDING EXTERNALLY	45	
43	DISASSEMBLING STAGING	36	
44	CLOSING TECHNICAL OPENINGS	4	
45	WELDING TECHNICAL OPENINGS	35	
46	REMOVING TEMPORARY REINFORCEMENTS	10	
	TOTAL MANHOURS REQUIRED FOR 1 PANEL		1220
	TOTAL MANHOURS REQUIRED FOR 2 PANELS (1 CARGO HOLD SIDE)		2440

Table 7-1 Man-hour Consumption of Topside Tank Method
(Koros, 2008a)

It can be seen from the table above that the total man-hours required for a whole cargo hold side are 2440. This includes the man-hours required for cargo hold to cargo hold penetration.

Gantt chart



ID	Task Name	Duration	Start	Finish
1	PLATES ON CNC FOR WEBS	1 hr	Sat 1/12/07	Sat 1/12/07
2	STIFF. FOR WEBS CUT	1 hr	Sat 1/12/07	Sat 1/12/07
3	REMOVE FROM CNC	2 hrs	Sat 1/12/07	Sat 1/12/07
4	PLACE MATERIALS ON PREFAB AREA	2 hrs	Sat 1/12/07	Sat 1/12/07
5	ALLOCATE MATERIAL FOR PREFAB.	2 hrs	Sat 1/12/07	Sat 1/12/07
6	FIT STIFFENERS ON WEBS	5 hrs	Sat 1/12/07	Sun 2/12/07
7	WELD STIFFENERS ON WEBS	8 hrs	Sun 2/12/07	Mon 3/12/07
8	PLATES ON CNC FOR PANEL	1 hr	Sat 1/12/07	Sat 1/12/07
9	CUTTING PLATES TO SIZE	1 hr	Sat 1/12/07	Sat 1/12/07
10	REMOVE CUT MATERIAL FROM CNC	2 hrs	Sat 1/12/07	Sat 1/12/07
11	PLATE CURVING	1 hr	Sat 1/12/07	Sat 1/12/07
12	PLATES PLACED ON PREFAB. AREA	2 hrs	Sat 1/12/07	Sun 2/12/07
13	LONGITUDINALS TO PREFAB AREA	1 hr	Sat 1/12/07	Sat 1/12/07
14	PLATES JOINING	4 hrs	Sun 2/12/07	Sun 2/12/07
15	STIFFENER FITTING ON PLATES	10 hrs	Sun 2/12/07	Mon 3/12/07
16	WEB FITTING ON PLATE PANELS	5 hrs	Mon 3/12/07	Tue 4/12/07
17	WELDING FROM INNER SIDE	38 hrs	Tue 4/12/07	Sat 8/12/07
18	LIFT AND TURN PANEL	2 hrs	Sat 8/12/07	Sat 8/12/07
19	WELD GAUGING	7 hrs	Sat 8/12/07	Sun 9/12/07
20	WELDING FROM OUTER SIDE	22 hrs	Sun 9/12/07	Tue 11/12/07
21	CREATING TECHNICAL OPENINGS	5 hrs	Sat 1/12/07	Sat 1/12/07
22	STAGING ERECTION	18 hrs	Sat 1/12/07	Mon 3/12/07
23	WEB CROPPING AND EDGE PREPARATION	14 hrs	Mon 3/12/07	Wed 5/12/07
24	FITTING EYE PLATES	2 hrs	Wed 5/12/07	Wed 5/12/07
25	WELDING EYE PLATES	3 hrs	Wed 5/12/07	Wed 5/12/07
26	REMOVING PART OF THE TRANSVERSE BHD	12 hrs	Mon 3/12/07	Tue 4/12/07
27	STAGING REMOVAL	10 hrs	Wed 5/12/07	Thu 6/12/07
28	PANEL TRANSPORTATION	3 hrs	Tue 11/12/07	Wed 12/12/07
29	PANEL PLACING IN HOLD	1 hr	Wed 12/12/07	Wed 12/12/07
30	PANEL LIFTING IN PLACE	5 hrs	Wed 12/12/07	Wed 12/12/07
31	PANEL PULLING THROUGH TRANSVERSE BHD	13 hrs	Wed 12/12/07	Fri 14/12/07
32	PANEL SECURING IN PLACE	10 hrs	Fri 14/12/07	Sat 15/12/07
33	PANEL FITTING IN PLACE	21 hrs	Sat 15/12/07	Mon 17/12/07
34	PANEL WELDING INTERNAL	51 hrs	Mon 17/12/07	Sun 23/12/07
35	STAGING ERECTION	12 hrs	Thu 20/12/07	Fri 21/12/07
36	TRANSVERSE BHD PIECE PREPARATION	4 hrs	Tue 4/12/07	Wed 5/12/07
37	TRANSVERSE BHD PIECE LIFTING	1 hr	Fri 21/12/07	Fri 21/12/07
38	TRANSVERSE BHD PIECE FITTING	10 hrs	Fri 21/12/07	Sat 22/12/07
39	TRANSVERSE BHD PIECE WELDING	21 hrs	Sat 22/12/07	Mon 24/12/07
40	PANEL EXTERNAL WELDING	22 hrs	Fri 21/12/07	Sun 23/12/07
41	STAGING REMOVAL	6 hrs	Thu 27/12/07	Thu 27/12/07
42	CLOSING TECHNICAL OPENINGS	2 hrs	Mon 24/12/07	Tue 25/12/07
43	WELDING TECHNICAL OPENINGS	18 hrs	Tue 25/12/07	Thu 27/12/07

Figure 7-1 Gantt Chart for Topside Tank Method
(Koros, 2008b)

It can be seen from the Gantt chart shown above that in order to complete one full cargo hold side at the parallel middle body, the amount of time required is 27 days. Both sides can be completed within 27 days as two teams may work in parallel.

7.2.2 Box Girder Strengthening Method

Man-Hour Consumption

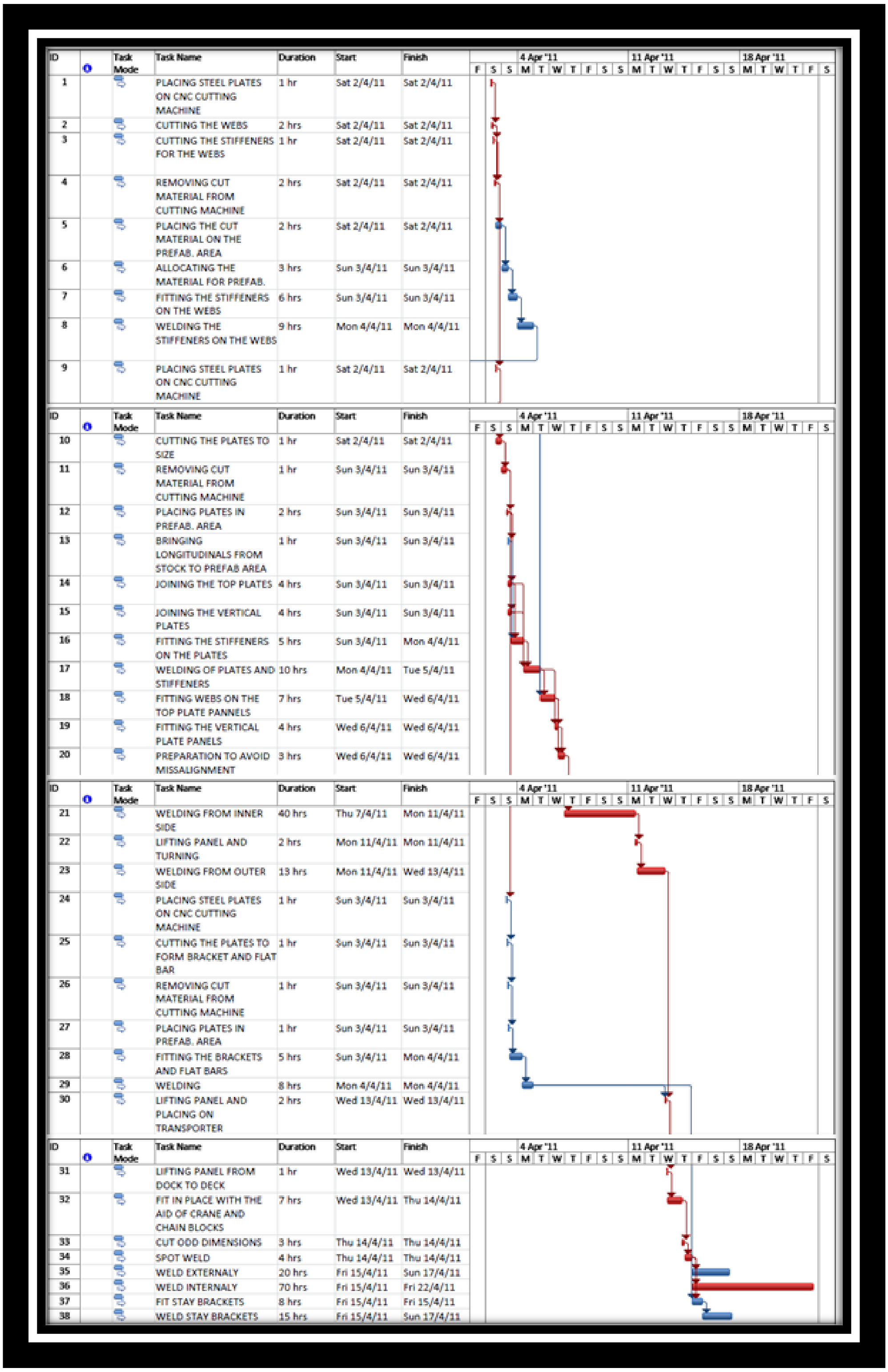
	BOX GIRDER METHOD (MANHOUR CONSUMPTION)		
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	WEB PREFABRICATION		79
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
2	CUTTING THE WEBS	6	
3	CUTTING THE STIFFENERS FOR THE WEBS	3	
4	REMOVING CUT MATERIAL FROM CUTTING MACHINE	9	
5	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	8	
6	ALLOCATING THE MATERIAL FOR PREFAB.	9	
7	FITTING THE STIFFENERS ON THE WEBS	16	
8	WELDING THE STIFFENERS ON THE WEBS	25	
	PLATE JOINING AND PREFAB		84
9	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
10	CUTTING THE PLATES TO SIZE	3	
11	REMOVING CUT MATERIAL FROM CUTTING MACHINE	4	
12	PLACING PLATES IN PREFAB. AREA	8	
13	BRINGING LONGITUDINALS FROM STOCK TO PREFAB AREA	1	
14	JOINING THE TOP PLATES	9	
15	JOINING THE VERTICAL PLATES	8	
16	FITTING THE STIFFENERS ON THE PLATES	18	
17	WELDING OF PLATES AND STIFFENERS	30	
	BOX GIRDER PANEL FABRICATION		247
18	FITTING WEBS ON THE TOP PLATE PANNELS	25	
19	FITTING THE VERTICAL PLATE PANELS	15	
20	PREPARATION TO AVOID MISSALIGNMENT	12	
21	WELDING FROM INNER SIDE	160	
22	LIFTING PANEL AND TURNING	10	
23	WELDING FROM OUTER SIDE	25	
	STAY BRACKET PREFABRICATION		24
24	PLACING STEEL PLATES ON CNC CUTTING MACHINE	2	
25	CUTTING THE PLATES TO FORM BRACKET AND FLAT BAR	2	
26	REMOVING CUT MATERIAL FROM CUTTING MACHINE	1	
27	PLACING PLATES IN PREFAB. AREA	1	
28	FITTING THE BRACKETS AND FLAT BARS	10	
29	WELDING	8	
	PANEL AND STAYS TRANSPORTATION		20
30	LIFTING PANEL AND PLACING ON TRANSPORTER	10	
31	LIFTING PANEL FROM DOCK TO DECK	10	
	FITTING THE PANEL		402
32	FIT IN PLACE WITH THE AID OF PIER CRANE	34	
33	CUT ODD DIMENSIONS	12	
34	SPOT WELD	11	
35	WELD EXTERNALY	75	
36	WELD INTERNALY	210	
37	FIT STAY BRACKETS	15	
38	WELD STAY BRACKETS	45	
	TOTAL MANHOURS REQUIRED FOR 1 PANEL		856
	TOTAL MANHOURS REQUIRED FOR 2 PANELS (1 CARGO HOLD SIDE)		1712

Table 7-2 Box girder method man-hour consumption

(Koros, 2008a)

It can be seen from the analysis (estimate) given above that this method requires 1712 man-hours to complete one full cargo hold side.

<u>Gantt chart</u>



ID	Task Mode	Task Name	Duration	Start	Finish
1		PLACING STEEL PLATES ON CNC CUTTING MACHINE	1 hr	Sat 2/4/11	Sat 2/4/11
2		CUTTING THE WEBS	2 hrs	Sat 2/4/11	Sat 2/4/11
3		CUTTING THE STIFFENERS FOR THE WEBS	1 hr	Sat 2/4/11	Sat 2/4/11
4		REMOVING CUT MATERIAL FROM CUTTING MACHINE	2 hrs	Sat 2/4/11	Sat 2/4/11
5		PLACING THE CUT MATERIAL ON THE PREFAB. AREA	2 hrs	Sat 2/4/11	Sat 2/4/11
6		ALLOCATING THE MATERIAL FOR PREFAB.	3 hrs	Sun 3/4/11	Sun 3/4/11
7		FITTING THE STIFFENERS ON THE WEBS	6 hrs	Sun 3/4/11	Sun 3/4/11
8		WELDING THE STIFFENERS ON THE WEBS	9 hrs	Mon 4/4/11	Mon 4/4/11
9		PLACING STEEL PLATES ON CNC CUTTING MACHINE	1 hr	Sat 2/4/11	Sat 2/4/11
10		CUTTING THE PLATES TO SIZE	1 hr	Sat 2/4/11	Sat 2/4/11
11		REMOVING CUT MATERIAL FROM CUTTING MACHINE	1 hr	Sun 3/4/11	Sun 3/4/11
12		PLACING PLATES IN PREFAB. AREA	2 hrs	Sun 3/4/11	Sun 3/4/11
13		BRINGING LONGITUDINALS FROM STOCK TO PREFAB AREA	1 hr	Sun 3/4/11	Sun 3/4/11
14		JOINING THE TOP PLATES	4 hrs	Sun 3/4/11	Sun 3/4/11
15		JOINING THE VERTICAL PLATES	4 hrs	Sun 3/4/11	Sun 3/4/11
16		FITTING THE STIFFENERS ON THE PLATES	5 hrs	Sun 3/4/11	Mon 4/4/11
17		WELDING OF PLATES AND STIFFENERS	10 hrs	Mon 4/4/11	Tue 5/4/11
18		FITTING WEBS ON THE TOP PLATE PANNELS	7 hrs	Tue 5/4/11	Wed 6/4/11
19		FITTING THE VERTICAL PLATE PANELS	4 hrs	Wed 6/4/11	Wed 6/4/11
20		PREPARATION TO AVOID MISSALIGNMENT	3 hrs	Wed 6/4/11	Wed 6/4/11
21		WELDING FROM INNER SIDE	40 hrs	Thu 7/4/11	Mon 11/4/11
22		LIFTING PANEL AND TURNING	2 hrs	Mon 11/4/11	Mon 11/4/11
23		WELDING FROM OUTER SIDE	13 hrs	Mon 11/4/11	Wed 13/4/11
24		PLACING STEEL PLATES ON CNC CUTTING MACHINE	1 hr	Sun 3/4/11	Sun 3/4/11
25		CUTTING THE PLATES TO FORM BRACKET AND FLAT BAR	1 hr	Sun 3/4/11	Sun 3/4/11
26		REMOVING CUT MATERIAL FROM CUTTING MACHINE	1 hr	Sun 3/4/11	Sun 3/4/11
27		PLACING PLATES IN PREFAB. AREA	1 hr	Sun 3/4/11	Sun 3/4/11
28		FITTING THE BRACKETS AND FLAT BARS	5 hrs	Sun 3/4/11	Mon 4/4/11
29		WELDING	8 hrs	Mon 4/4/11	Mon 4/4/11
30		LIFTING PANEL AND PLACING ON TRANSPORTER	2 hrs	Wed 13/4/11	Wed 13/4/11
31		LIFTING PANEL FROM DOCK TO DECK	1 hr	Wed 13/4/11	Wed 13/4/11
32		FIT IN PLACE WITH THE AID OF CRANE AND CHAIN BLOCKS	7 hrs	Wed 13/4/11	Thu 14/4/11
33		CUT ODD DIMENSIONS	3 hrs	Thu 14/4/11	Thu 14/4/11
34		SPOT WELD	4 hrs	Thu 14/4/11	Thu 14/4/11
35		WELD EXTERNALY	20 hrs	Fri 15/4/11	Sun 17/4/11
36		WELD INTERNALY	70 hrs	Fri 15/4/11	Fri 22/4/11
37		FIT STAY BRACKETS	8 hrs	Fri 15/4/11	Fri 15/4/11
38		WELD STAY BRACKETS	15 hrs	Fri 15/4/11	Sun 17/4/11

Figure 7-2 Gantt chart for box girder method

(Koros, 2008b)

It can be seen from the Gantt chart shown above that in order to complete one full cargo hold side, the amount of time required is 20 days. Both sides can be completed within 20 days as two teams may work in parallel.

7.2.3 Comparison of the methods

Having produced man-hour consumption tables and Gantt charts for the two methods, it is evident by comparing them that the Box Girder method required less man-hours per cargo hold side, and also less time to be completed. It is therefore a better method. However, the reasons that led to the above must be analyzed so that general and usable conclusions can be drawn.

During the conversions described in the case study, it was evident that the yard was not satisfied with the performance of the Top Side Tank method, as it presented "hidden", non budgeted tasks which were man-hour and time consuming, despite the fact that it was designed for production. These tasks have been referred to as "bottlenecks", and they were:

- Work on staging
- Work in confined-like spaces
- Work for temporary reinforcements
- "Intrusion" to the existing ship structure
- Limited use of crane/use of chain blocks instead
- Some work required in situ

The table and graph below compare man-hour consumption from both Methods, for the above mentioned bottlenecks, taken out of the man-hour consumption tables of each respective method. The table indicates the numbered sub-processes, as taken from the respective man-hour consumption tables, of each method in which the relevant bottlenecks were present. The graph was generated using the data from the table to produce an illustrated comparison between the two methods, so that the differences between them are more distinguishable.

COMPARISON OF MAN-HOUR CONSUMPTIONS PER CARGO HOLD SIDE FOR BOX-GIRDER AND TOP SIDE TANK METHODS				
	BOX GIRDER METHOD	Sub-Procedures Included	TOP SIDE TANK METHOD	Sub-Procedures Included
Total Man-Hours	1712	ALL	2440	ALL
Production/Prefabrication Man-Hours	868	1 TO 29	682	1 TO 21
Man-Hours Onboard	804	30 TO 38	1758	22 TO 46
Man-Hours On Staging	0	NOT APPLICABLE	982	24 TO 29, 33, 37, 39 TO 43
Man-Hours In Confined Spaces	420	36	692	25 TO 28, 33 TO 36
Man-Hours "Intrusive" To Existing Structure	0	NOT APPLICABLE	256	23, 25, 28, 38 to 41
Man-Hours for Temporary Reinforcements	0	NOT APPLICABLE	90	22, 46
Man-Hours Using Chain Blocks	0	NOT APPLICABLE	452	28, 33 TO 35, 39, 40
Man-Hours for Fabrication In Situ	0	NOT APPLICABLE	160	28, 38 TO 41
Note: Man-hours in Sub-procedures in the respective Man-hour consumption tables are for half a Cargo Hold side and have therefore been multiplied by two (X2) in this table to account for one full cargo hold side				

Table 7-3 Comparison of man-hour consumption for Box-girder and Topside tank method (Author's table)

The table and the graph clearly show the positive result of using the Box Girder Method as it produced the same structural result as the Top Side tank method but with much less man-hours consumed. The fact also that it required far less man-hours to be consumed on board indicates that as a method designed for production, it is far more efficient than the Top-Side Tank method.

It is also evident that the bottlenecks:

- Work on staging
- Work for temporary reinforcements
- "Intrusion" to the existing ship structure
- Limited use of crane/use of chain blocks instead
- Some work required in situ

Were completely absent in the Box-Girder method, whilst work in confined spaces was far less than that of the Top-Side Tank method.

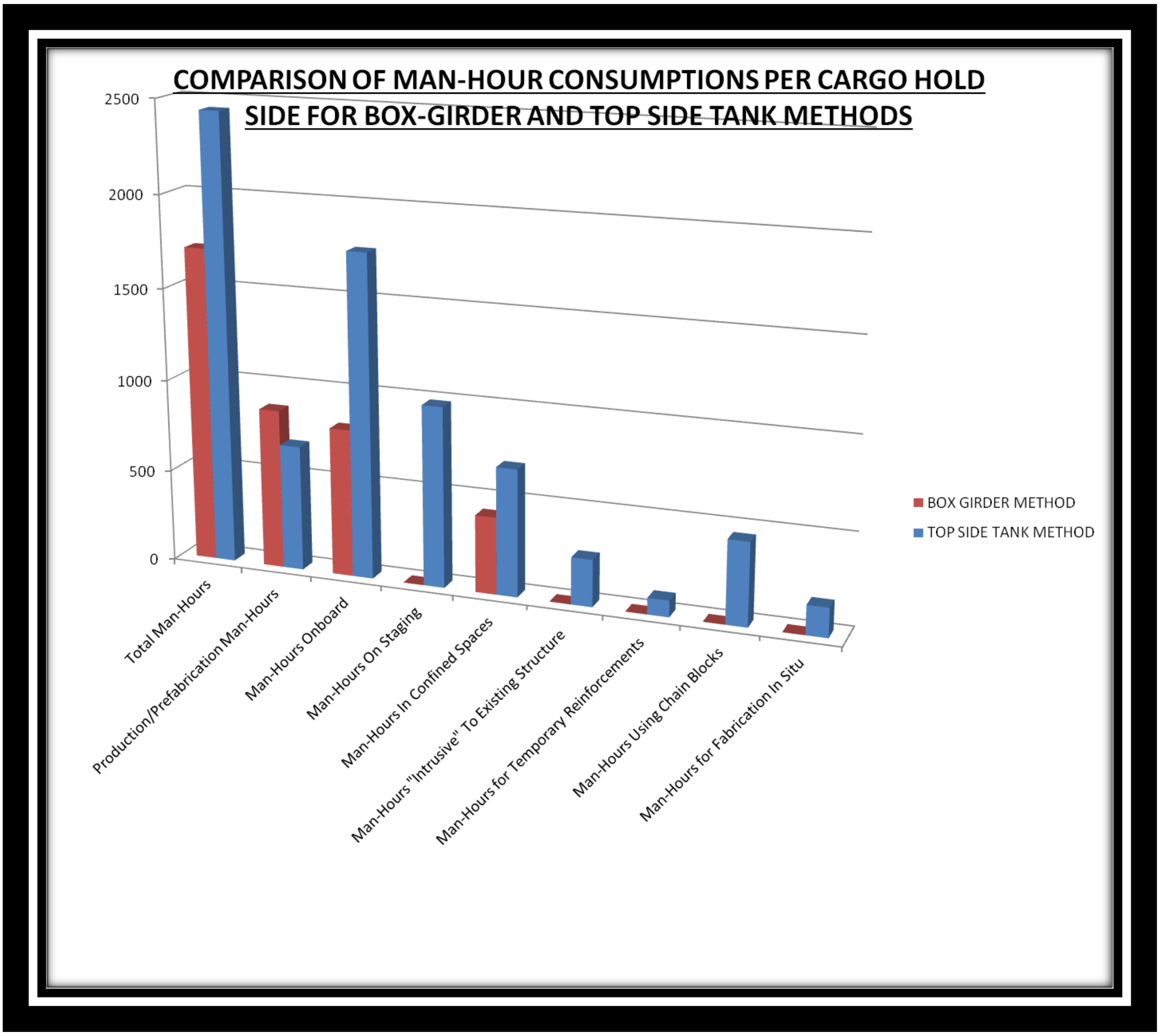


Figure 7-3 Comparison of man-hour consumption for Box-girder and Topside tank method (Author's figure)

The simplicity of the box girder method is evident when comparing the man-hours of the two methods required onboard the vessel, where it requires less than half of the Top Side Tank method. It is also a far less intrusive method, as it requires no change to the vessel's existing structures, whereas the top side tanks method requires under-deck web, girder and bulkhead modifications to be applied to the existing ship structure.

The Box Girder method requires virtually no use of chain-blocks as the newly fitted structures are easily accessible to the pier cranes and thus fitting and general prefabricated section maneuverability is aided significantly, in contrast to the Top-Side Tank method, where final fitting and bulkhead penetration require the use of chain blocks.

The Box Girder also requires no work on staging, as all work onboard is performed on deck, no temporary stiffening works as it is a non intrusive procedure, and finally no re-work in situ as it is easily fitted onboard without having to be modified, or having to modify nearby structures to be fitted.

When comparing the Gantt charts of the two methods, the simplicity of the Box Girder method, achieved through avoiding the aforementioned conversion bottlenecks, is evident as it is 7 days, or approximately 26% faster than the Top Side Tank method per cargo hold.

It is therefore evident that, despite the fact that both methods were designed for production, using an innovative method, such as the Box-Girder method, to solve a conversion problem, in this case the longitudinal strength problem, conversion bottlenecks can be reduced and in some cases eliminated, thus providing a far more efficient result in terms of man-hours consumption and cycle time compared to a conventional solution to that problem.

7.3 Bulkheads Relocation Versus Fitting New Bulkheads

In the case study, the yard decided to proceed with the bulkhead relocation method, instead of scraping the existing longitudinal bulkheads, and fitting new ones, to create the double hull section required for the conversion. The idea behind this venture was that material, along with man-hours required to fabricate new bulkheads would be saved, which would thus decrease the cost of the conversion.

The yard, after the conversions discussed in this case study, performed a single to double hull tanker conversion on one of the sister ships of the vessels presented in the case study, by adding new bulkheads in order for the tanker to comply with the IMO double hull regulations. The author can thus present exact data for man-hours consumed and an actual Gantt chart of performing the said conversion to an identical vessel, for which conversion the author had exactly the same authorities as in the bulk carrier conversions in the case study.

The case that bulkheads relocation was favoured to fitting new bulkheads was made in this thesis, based on an assumption. By comparing the two methods, using actual data obtained from two different conversions but of identical vessels, will help determine if that assumption was correct. The two methods must be examined in terms of man-hours consumed, material saving, but also in terms of bottleneck avoidance. Given that both methods take place inside the hull of the vessel, it is unlikely that bottlenecks will be avoided in any method, but it is the author’s opinion that both should be studied and compared by the same means as the Top Side tank and Box Girder methods, to identify any reduction of man-hours consumption for bottlenecks.

7.3.1 Bulkhead Relocation Method

Man-Hours Consumption Table

	BULKHEAD RELOCATION		
	ACTIVITY AND SUB-ACTIVITY	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	DECK RE-INFORCEMENT AND PREPARATION		299
1	MARKING OF POSITIONS WHERE I BEAMS WILL BE FITTED	12	
2	BURNING AND SCRAPING THE PAINT FROM THE DECK	12	
3	MOVING I BEAMS FROM DOCK TO DECK	20	
4	PLACING I BEAMS IN PLACE	20	
5	WELDING I BEAMS	25	
6	CREATING TECHNICAL OPENINGS	30	
7	STAGING (RELOCATION METHOD 2)	180	
	PREFABRICATION		206
8	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
9	CUTTING THE STRINGERS AND WEBS	11	
10	CUTTING THE STIFFENERS FOR THE WEBS AND STRINGERS	3	
11	REMOVING CUT MATERIAL FROM CUTTING MACHINE	8	
12	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	9	
13	ALLOCATING THE MATERIAL FOR PREFAB.	14	
14	FITTING THE STIFFENERS ON THE WEBS AND STRINGERS	78	
15	WELDING THE STIFFENERS ON THE WEBS AND STRINGERS	70	
16	MOVING PREFABRICATED MATERIAL TO DOCK	10	
	BULKHEAD RELOCATION		1082
17	FITTING WEBS AND STRINGERS	180	
18	WELDING WEBS AND STRINGERS	160	
19	FITTING EYE PLATES	25	
20	FITTING CHAIN BLOCKS	17	
21	CUTTING THE BULKHEAD IN PIECES	12	
22	CUTTING THE UNDERDECK WEBS	8	
23	CUTTING THE LOWER PART OF THE BULKHEAD PIECE	6	
24	SETTING UP THE CHAIN BLOCKS AND CRANE	10	
25	FINAL CUT OFF	3	
26	STAGING REMOVAL	45	
27	RELOCATION (METHOD 2) OF UPPER PART	40	
28	SECURING IN PLACE	78	
29	FITTING IN PLACE	87	
30	WELDING	110	
31	RELOCATION OF LOWER PART	34	
32	FINAL FITTING	27	
33	FINAL WELDING	28	
34	REMOVAL OF EYE PLATES	4	
35	CLOSING OF TECHNICAL OPENINGS	65	
36	REMOVAL OF I BEAMS	15	
37	REMOVAL OF STAGING	128	
	TOTAL MANHOURS REQUIRED FOR 1 PANEL		1587
	TOTAL MANHOURS REQUIRED FOR 2 PANELS (1 HOLD SIDE)		3174

Table 7-4 Man-hour consumption for bulkhead relocation method

(Koros, 2008a)

The table above shows that a total of 3174 Man-Hours are required for one complete bulkhead relocation for one cargo hold side.

Gantt chart

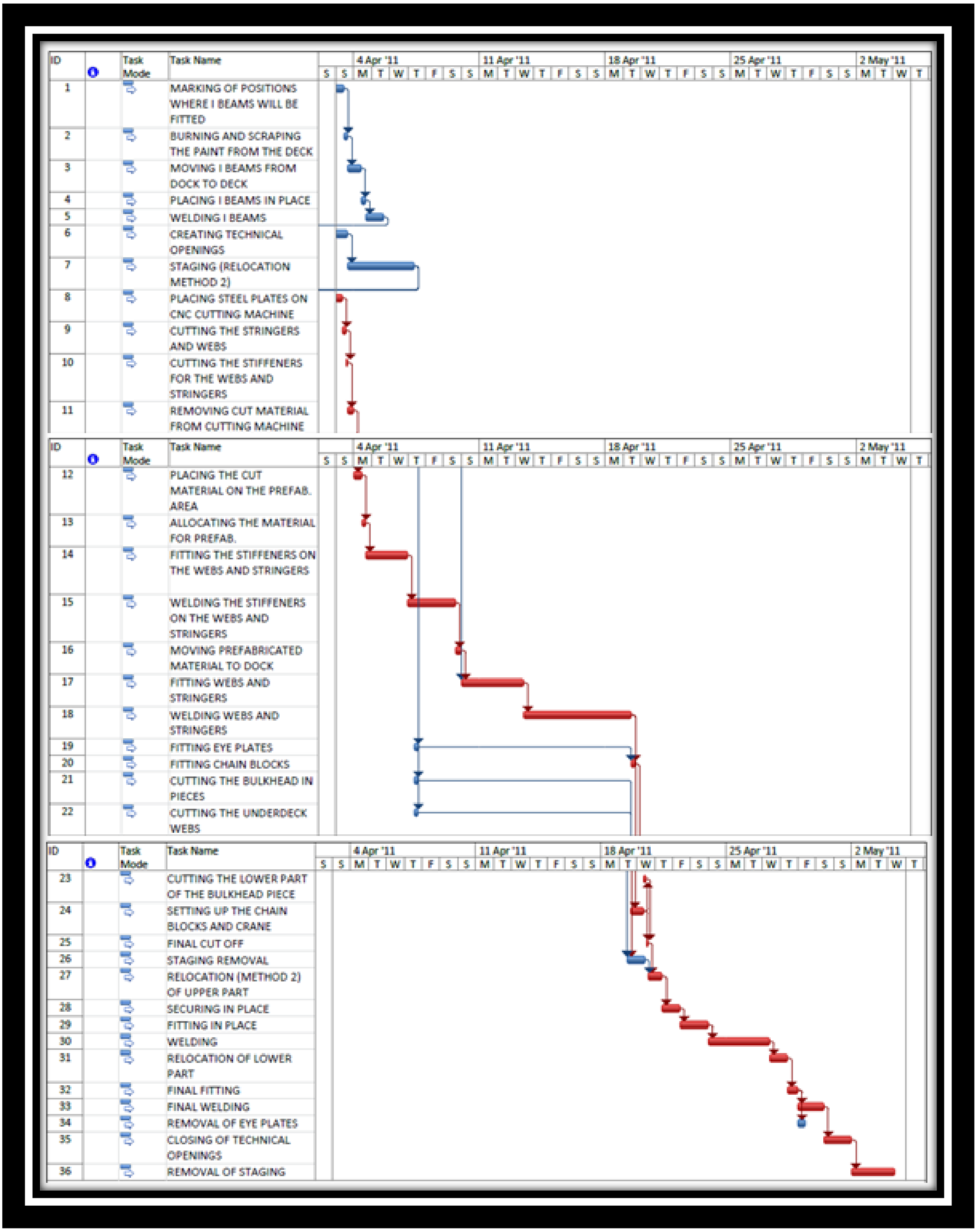


Figure 7-4 Gantt chart for bulkhead relocation method

(Koros, 2008b)

The Gantt chart shows that the procedure for one cargo hold side requires 32 days to be completed.

7.3.2 New Bulkheads Method

Man-Hours Consumption Table

FITTING NEW BULKHEADS			
	ACTIVITY AND SUB-ACTIVITY	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	PANEL PREFABRICATION		417
1	PLACING THE STEEL PLATES ON THE CNC CUTTING MACHINE	5	
2	CUTTING THE PLATES TO SIZE AND PREPARING THE EDGES	4	
3	REMOVING CUT MATERIAL FROM CUTTING MACHINE	7	
4	PLACING CUT MATERIAL ON THE PREFAB. AREA	15	
5	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
6	CUTTING THE STIFFENERS FOR THE PANEL	17	
7	REMOVING CUT MATERIAL FROM CUTTING MACHINE	7	
8	PLACING CUT MATERIAL ON THE PREFAB. AREA	13	
9	ALLOCATING THE MATERIAL FOR PREFAB.	34	
10	JOINING THE PLATES TOGETHER	28	
11	FITTING THE STIFFENERS ON THE PLATES	45	
12	WELDING THE PANEL FROM ONE SIDE	162	
13	PANEL FLIP ROTATION	7	
14	PANEL WELDING FROM THE OTHER SIDE	45	
15	TRANSPORTATION OF PANEL TO DOCK	25	
	MAIN VERTICAL AND LONG. MEMBER PREFAB.		221
16	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
17	CUTTING THE STRINGERS AND WEBS	11	
18	CUTTING THE STIFFENERS FOR THE WEBS AND STRINGERS	3	
19	REMOVING CUT MATERIAL FROM CUTTING MACHINE	8	
20	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	9	
21	ALLOCATING THE MATERIAL FOR PREFAB.	14	
22	FITTING THE STIFFENERS ON THE WEBS AND STRINGERS	78	
23	WELDING THE STIFFENERS ON THE WEBS AND STRINGERS	76	
24	MOVING PREFABRICATED MATERIAL TO DOCK	19	
	BULKHEAD FITTING		1974
25	MARKING OF POSITIONS WHERE I BEAMS WILL BE FITTED	14	
26	BURNING AND SCRAPING THE PAINT FROM THE DECK	14	
27	MOVING I BEAMS FROM DOCK TO DECK	19	
28	PLACING I BEAMS IN PLACE	29	
29	WELDING I BEAMS	34	
30	CREATING TECHNICAL OPENINGS	30	
31	STAGING	160	
32	PREPARING THE EXISTING WEBS	67	
33	FITTING WEBS AND STRINGERS	180	
34	WELDING WEBS AND STRINGERS	160	
35	LOWERING THE NEW BULKHEAD PANEL	67	
36	FITTING CHAIN BLOCKS	34	
37	PULLING THE NEW BHD IN POSITION	83	
38	SPOT WELDING THE NEW BHD IN POSITION	65	
39	REMOVING THE CHAIN BLOCKS	12	
40	WELDING THE BHD IN PLACE INTERNALLY	178	
41	CLOSING TECHNICAL OPENINGS	80	
42	REMOVING I BEAMS	15	
43	STAGING REMOVAL	74	
44	STAGING EXTERNALLY	120	
45	WELDING EXTERNALLY	60	
46	STAGING ON EXISTING BHD	98	
47	CUTTING EXISTING BHD	149	
48	REMOVING EXISTING BHD	87	
49	REMOVING STAGING	145	
	TOTAL MANHOURS REQUIRED FOR 1 PANEL		2612
	TOTAL MANHOURS REQUIRED FOR 2 PANELS (1 HOLD SIDE)		5224

Table 7-5 Man-hour consumption for fitting new bulkhead
(Koros, 2009a)

The table above shows that a total of 5224 Man-Hours are required for one complete cargo hold side.

<u>Gantt chart</u>

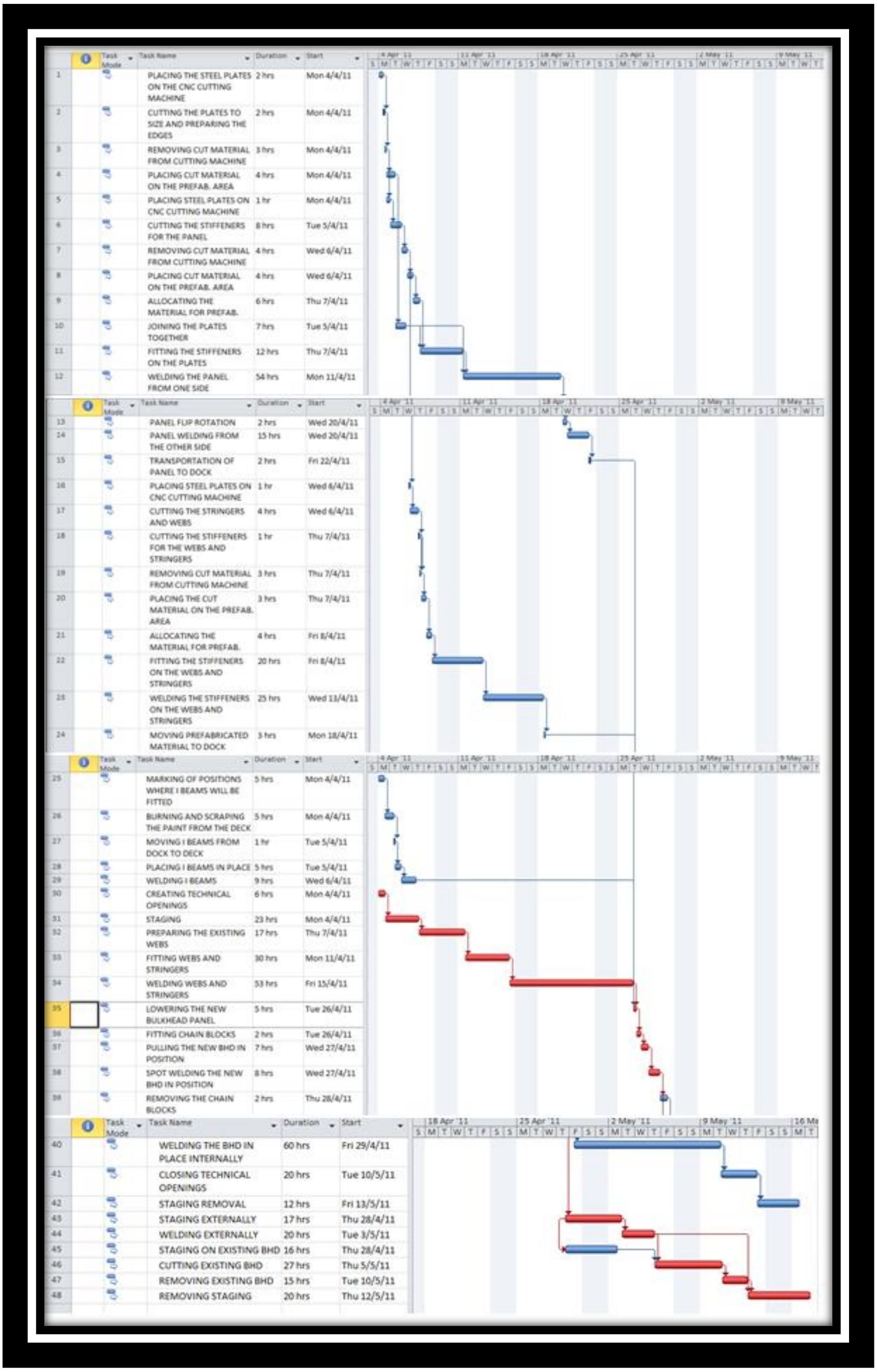


Figure 7-5 Gantt chart for fitting new bulkhead method

(Koros, 2009a)

The Gantt chart shows that the procedure for one cargo hold side requires 44 days to be completed.

7.3.3 Comparison of the methods

Having produced man-hour consumption tables and Gantt charts for the two methods, it is evident by comparing them that the Bulkheads Relocation method required less man-hours per cargo hold side, and also less time to be completed, whilst saving the material required to fabricate the new bulkheads. It is therefore a better method. However, it is important to analyse the saving of man-hours and determine their nature. It is certain that many man-hours have been saved by avoiding the fabrication of bulkheads, but it is also important to see how this method fairs in terms of bottleneck avoidance.

COMPARISON OF MAN-HOUR CONSUMPTIONS PER CARGO HOLD SIDE FOR BULKHEADS RELOCATION AND FITTING NEW BULKHEADS METHODS				
	BULKHEADS RELOCATION	**Sub-Procedures Included**	**NEW BULKHEADS**	**Sub-Procedures Included**
Total Man-Hours	3174	ALL	5224	ALL
Production/Prefabrication Man-Hours	412	8 TO 16	1276	1 TO 15, 16 TO 24
Man-Hours Onboard	2762	1 TO 7, 17 TO 37	3948	25 TO 49
Man-Hours On Staging	2094	7, 17 TO 22, 24 TO 26, 28 TO 30, 34, 37	3276	31 TO 34, 37 TO 40, 43 TO 49
Man-Hours In Confined Spaces	0	NOT APPLICABLE	0	NOT APPLICABLE
Man-Hours "Intrusive" To Existing Structure	248	6, 21 TO 23, 25, 35	826	30, 32, 41, 47, 48
Man-Hours for Temporary Reinforcements	208	1 TO 5, 36	250	25 TO 29, 42
Man-Hours Using Chain Blocks	946	17, 21, 24, 27 TO 29,	748	33, 36 TO 39
Man-Hours for Fabrication In Situ	0	NOT APPLICABLE	0	NOT APPLICABLE
Note: Man-hours in Sub-procedures in the respective Man-hour consumption tables are for half a Cargo Hold side and have therefore been multiplied by two (X2) in this table to account for one full cargo hold side				

Table 7-6 Comparison between bulkhead methods
(Author’s table)

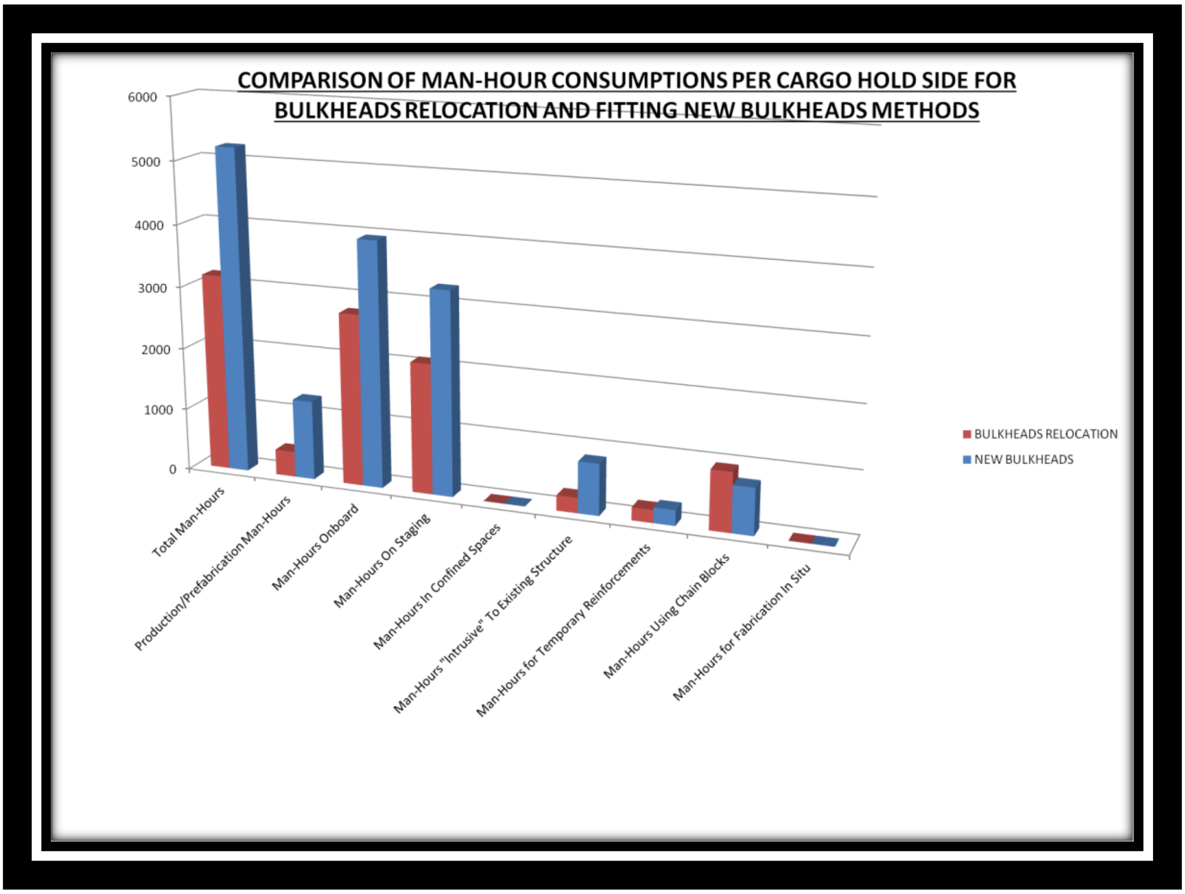


Figure 7-6 Comparison between bulkhead methods
(Author's figure)

The table and graph above compare man-hour consumption from both methods, for the same conversion bottlenecks as discussed in the longitudinal strengthening method, taken out of the man-hour consumption tables of each respective method. The table indicates the numbered sub-processes, as taken from the respective man-hour consumption tables, of each method in which the relevant bottlenecks were present. The graph was generated using the data from the table to produce an illustrated comparison between the two methods, so that the differences between them are more distinguishable.

The table and the graph clearly show the positive result of using the Bulkheads Relocation Method as it produced the same structural result as the Fitting New Bulkheads Method but with much less man-hours consumed. Man hours consumption decrease was anticipated as the Bulkheads Relocation requires much less fabrication as the bulkheads are already existent. However, what was not evident at the time the decision was taken to use this method, was that many of the bottleneck present in this method, would consume less man-hours than the fitting of new bulkheads.

As it can be seen from the table and the graph, the bottlenecks:

- Work on staging
- Work for temporary reinforcements
- “Intrusion” to the existing ship structure,

have been significantly reduced by using the Bulkheads Relocation method. Man-hour consumption using chain blocks is slightly higher, which is expected as the relocation is performed primarily by chain blocks, but overall the reduction in man-hours consumed for bottlenecks has significantly contributed to a significant reduction of man-hours consumed onboard (approximately 1200 man-hours) as well as a reduction in cycle time, compared to fitting new bulkheads, of 12 days, representing approximately a 27% decrease in cycle time.

It has therefore been shown, again, that by using an innovative approach to solve a conversion problem, in this case creating a double hull structure, and through that method reducing the conversion bottlenecks, compared to using a conventional method to solve the same problem, man-hours can be saved and cycle time can be reduced.

The case of relocating the existing bulkheads instead of scraping them and fitting new bulkheads has also made two more significant observations:

- That by re-using existing material on a large scale, significant savings can be achieved in new material usage. In the case study, approximately 600 tons of steel were saved by re-using the existing bulkheads. Also, since no modification was performed on the bulkheads, i.e. they were simply cut and relocated without intruding in their stiffener structure, there were no problems with deformation present and thus no man-hours were required to right any distorted panels.
- That procedures sourced through innovative ideas, can always be optimized. The design and planning department may have given birth to the idea of bulkhead relocation and designed the first procedure, but it was the production department who implemented the process and through communication and feedback, all designed the final and improved procedure, which was eventually used in the majority of the relocations, and described in the case study.

7.4 Building Top Side Tanks with New Material Versus. Re-Using Material

In the case study, the yard initially built the top side tanks by partially re-using material cut from the removed sections of the deck. The idea behind this action was to save material in order to reduce cost, as with the bulkhead relocation method. This required cutting the webs from the deck pieces, fitting new webs designed and built for the top side tanks, and adding more longitudinals between the existing longitudinals of the cut deck section.

Having performed this procedure on two top side tanks, the yard noticed that there were many man-hours being consumed for performing corrective actions to the fabricated product as it appeared to bend during the process of panel construction and welding. It was noticed that this was happening because of the removal of the webs previously fitted on the sections of the cut-out deck which were re-used to fabricate a piece of the top side tank panel. Because of the repetitive heating the plate was subjected to for cutting the webs, it presented deformations in many directions.

In order to resolve this, the yard applied constant loads to the panel during fabrication and welding was performed cautiously, and thus slower, as the plate was left to cool and the load application was re-adjusted to account for the change of the deformations due to the now applied heat due to welding. The yard decided that it would be a good idea to stop re-using material for this application and started building top side tanks using exclusively new materials. The resulting man-hour consumptions of the two methods are shown in the tables below.

Man-hour consumption for Top Side Tank panel (re-used material)

TOP SIDE TANK FABRICATION, RE-USED MATERIAL (MANHOUR CONSUMPTION)			
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	WEB PREFABRICATION		80
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
2	CUTTING THE WEBS	6	
3	CUTTING THE STIFFENERS FOR THE WEBS	3	
4	REMOVING CUT MATERIAL FROM CUTTING MACHINE	10	
5	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	8	
6	ALLOCATING THE MATERIAL FOR PREFAB.	9	
7	FITTING THE STIFFENERS ON THE WEBS	16	
8	WELDING THE STIFFENERS ON THE WEBS	25	
	PLATE JOINING AND PREFAB		
9	CUTTING PIECE REQUIRED FROM DECK PLATING	3	85
10	CUTTING OUT WEBS	15	
11	BURNING OFF PAINT TO FIT EXTRA LONGITUDINALS	6	
12	BRINGING CUT DECK PLATES TO PREFAB. AREA	1	
13	PLACING STEEL PLATES ON CNC CUTTING MACHINE (FOR CURVED PART ONLY)	2	
14	CUTTING THE PLATES TO SIZE	2	
15	REMOVING CUT MATERIAL FROM CUTTING MACHINE	1	
16	NEW PLATE CURVING	2	
17	PLACING PLATES IN PREFAB. AREA	8	
18	BRINGING LONGITUDINALS FROM STOCK TO PREFAB AREA	1	
19	JOINING THE PLATES	8	
20	FITTING THE STIFFENERS ON THE PLATES	36	
	TOP SIDE PANEL FABRICATION		353
21	APPLYING LOADS ON DEFORMED PLATE PANELS (THROUGHOUT INNER WELDING)	31	
22	FITTING WEBS ON THE PLATE PANNELS	49	
23	WELDING FROM INNER SIDE	211	
24	LIFTING PANEL AND TURNING	10	
25	WELD GAUGING	7	
26	WELDING FROM OUTER SIDE	45	
	TOTAL FOR ONE PANEL		518

Table 7-7 Man-hour consumption for topside tank fabrication with re-used material
(Koros, 2008a)

Man-hour consumption for Top Side Tank panel (new material)

TOP SIDE TANK FABRICATION, NEW MATERIAL (MANHOUR CONSUMPTION)			
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	WEB PREFABRICATION		80
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	
2	CUTTING THE WEBS	6	
3	CUTTING THE STIFFENERS FOR THE WEBS	3	
4	REMOVING CUT MATERIAL FROM CUTTING MACHINE	10	
5	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	8	
6	ALLOCATING THE MATERIAL FOR PREFAB.	9	
7	FITTING THE STIFFENERS ON THE WEBS	16	
8	WELDING THE STIFFENERS ON THE WEBS	25	
	PLATE JOINING AND PREFAB		
9	PLACING STEEL PLATES ON CNC CUTTING MACHINE	3	67
10	CUTTING THE PLATES TO SIZE	3	
11	REMOVING CUT MATERIAL FROM CUTTING MACHINE	4	
12	PLATE CURVING	2	
13	PLACING PLATES IN PREFAB. AREA	8	
14	BRINGING LONGITUDINALS FROM STOCK TO PREFAB AREA	1	
15	JOINING THE PLATES	8	
16	FITTING THE STIFFENERS ON THE PLATES	38	
	TOP SIDE PANEL FABRICATION		194
17	FITTING WEBS ON THE PLATE PANNELS	20	
18	WELDING FROM INNER SIDE	112	
19	LIFTING PANEL AND TURNING	10	
20	WELD GAUGING	7	
21	WELDING FROM OUTER SIDE	45	
TOTAL FOR ONE PANEL			341

Table 7-8 Manhour consumption for topside tank with new material
(Koros, 2008a)

7.4.1 Comparison of the methods

Having analysed the man-hour consumptions for the two methods, the table and graph below have been produced, comparing the two methods in terms of man-hour consumption in key sections of the processes, so that the differences between re-using material and using exclusively new material can be shown.

COMPARISON OF MAN-HOUR CONSUMPTIONS FOR TOP SIDE TANK CONSTRUCTION METHODS				
	RE-USED MATERIAL	Sub-Procedures Included	NEW MATERIAL	Sub-Procedures Included
Total Man-Hours	518	ALL	341	ALL
Man-Hours "Intrusive" To Existing Structure	24	9 TO 11	0	NOT APPLICABLE
Man-Hours for Applying Corrective Action	31	21	0	NOT APPLICABLE
Total Fit-Up Man-Hours	109	7, 19, 20, 22	82	7, 15, 16, 17
Total Welding Man-Hours	288	8, 23, 25, 26	189	8, 18, 20, 21
Note: Man-hours in Sub-procedures in the respective Man-hour consumption tables are for one panel				

Table 7-9 Comparison of methods
(Author's table)

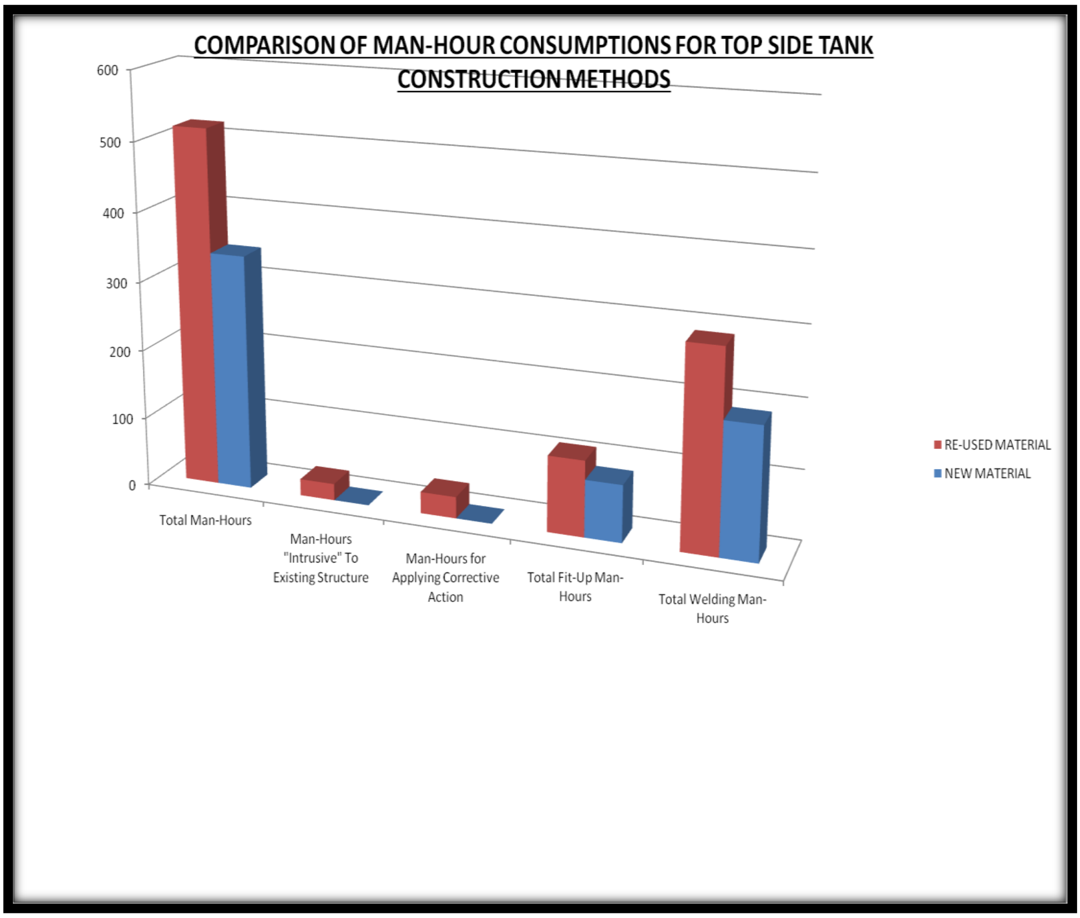


Figure 7-7Comparison of methods
(Author's figure)

As it can be seen, man-hours required to complete one full top side tank panel using exclusively new material, are much less than when re-using material taken from cut-out deck sections of the vessels. Using exclusively new material requires no man-hours for intruding to existing structures and also requires no man-hours for corrective action, which in the case of re-using material was applying loads to the panel so that the new stiffeners could be fitted and the whole panel could be welded.

It can also be seen that by using new material, the man-hours required for total panel fitting and welding are much less, which is the result of not having to work on a deformed plate and also not having to apply welding sequence strategies and having to wait between welds, so that the heat affected areas be cooled, and distortion of the plate be managed.

This comparison of methods has led to an important observation:

Whilst in the case of bulkhead relocation, described previously, re-using material proved very efficient by being cost and time saving for the conversion, as it presented substantial savings in man-hours consumption, in the case of the top side tanks, it presented the exact opposite. The difference between the two, which is also the determining factor of success of material re-usage, is the amount of intrusion in the structure of the re-used section. The bulkheads were not altered at all. They were simply cut and relocated, whereas the deck sections used to create the top side tank were altered by removing their webs. This alteration caused the panels to deform, which in turn required corrective man-hours to be consumed, eventually making the option of using exclusively new material for the panel, the most viable option.

Also, once again it is evident that with effective communication between design, planning and production departments, conversion processes become more efficient.

7.5 Tank Top Reinforcement Methods

The yard, having performed the initial requirement of the first Classification Society for tank top reinforcements (floors and flat bars) to two tanks, were able to produce an actual man-hours consumption table for the method, which is presented below.

DOUBLE BOTTOM FLOORS AND FLAT BARS (PER CARGO HOLD)			
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	PREFABRICATION		382
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	18	
2	CUTTING THE FLOORS	27	
3	CUTTING THE STIFFENERS FOR THE FLOORS	18	
4	REMOVING CUT MATERIAL FROM CUTTING MACHINE	15	
5	PLACING THE CUT MATERIAL ON THE PREFAB. AREA	20	
6	ALLOCATING THE MATERIAL FOR PREFAB.	15	
7	FITTING THE STIFFENERS ON THE FLOORS	96	
8	WELDING THE STIFFENERS ON THE FLOORS	138	
9	PLACING STEEL PLATES ON CNC CUTTING MACHINE FOR THE FLAT BARS	8	
10	CUTTING THE FLAT BARS	27	
	FITTING ON BOARD		5005
11	MARKING AND CUTTING TECHNICAL OPENINGS	48	
12	TRANSPORTATION OF FLOORS TO CARGO HOLDS	15	
13	TRANSPORTATION OF FLAT BARS TO CARGO HOLDS	12	
14	MARKING LOCATION TO BE FITTED	110	
15	BURNING OFF PAINT	177	
16	WELDING PAD-EYES FOR FITTING WITH CHAIN BLOCKS	155	
17	FITTING IN PLACE	1600	
18	WELDING	1720	
19	CUTTING OFF PAD-EYES	78	
20	CLOSING TECHNICAL OPENINGS	110	
21	WELDING TECHNICAL OPENINGS	980	
	RE-WORK IN SITU TO ACCOMMODATE PIPING SYSTEMS		428
22	CUTTING FLOORS IN 4 PIECES	58	
23	FITTING IN PLACE, AROUND PIPING	120	
24	WELDING	250	
	TOTAL MANHOURS REQUIRED FOR 1 CARGO HOLD		5815

Table 7-10 Man-hour consumption for double bottom and flat bars
(Koros, 2008a)

The analysis includes all relevant to the task man-hours, including all the man-hours consumed for access to the double bottom and also those consumed for work in situ to fit the floors around the piping systems in the double bottom, which created problems as explained in section 6.8 of this Thesis.

By switching classification societies, the vessels did not require such extensive work in the double bottom to achieve the required cargo density capability, something which proves that over-engineering had occurred in the first method, because of the first classification society's internal regulations. The second classification society only required the fitting of the flat bars. The yard performed this task in the remaining double bottom tanks, and the result in terms of man-hour consumption per hold, is presented in the table below.

DOUBLE BOTTOM FLAT BARS (PER CARGO HOLD)			
	ACTIVITY AND SUB-ACTIVITIES	SUB-ACTIVITY MANHOURS	ACTIVITY MANHOURS
Nr.	FLAT BAR PREFABRICATION		35
1	PLACING STEEL PLATES ON CNC CUTTING MACHINE	8	
2	CUTTING THE FLAT BARS	27	
	FITTING ONBOARD		1978
3	MARKING AND CUTTING TECHNICAL OPENINGS	16	
4	TRANSPORTATION OF FLAT BARS TO CARGO HOLDS	12	
5	MARKING LOCATION TO BE FITTED	104	
6	BURNING OFF PAINT	58	
7	WELDING PAD-EYES FOR FITTING WITH CHAIN BLOCKS	88	
8	FITTING IN PLACE	640	
9	WELDING	800	
10	CUTTING OFF PAD-EYES	40	
11	CLOSING TECHNICAL OPENINGS	20	
12	WELDING TECHNICAL OPENINGS	200	
	TOTAL MANHOURS REQUIRED FOR 1 CARGO HOLD		2013

Table 7-11 Manhour consumption for flat bars only
(Koros, 2008a)

7.5.1 Comparison of the methods

When comparing the methods it must be taken into account that the floor and flat bar method definitely provides a much higher level of strength and possibly a higher maximum allowable cargo density so comparing them in terms of effectiveness would most likely be unfair. However these methods were both designed and implemented to achieve the same result of cargo density 2. In any case, there are conclusions to be drawn from a comparison, mostly relating to working in confined spaces.

A table and a graph have been created using the man-hour consumptions of each method, comparing the methods in terms of bottlenecks, and also in terms of man-hours consumed for access to the double bottom, a supporting sub-process of these methods, and also man-hours consumed for fitting in place to make one new important point when working in confined spaces, as explained below.

COMPARISON OF MAN-HOUR CONSUMPTIONS PER CARGO HOLD FOR TANK TOP STRENGTHENING METHODS				
	FLOORS & FL. BARS	Sub-Procedures Included	FLAT BARS	Sub-Procedures Included
Total Man-Hours	5815	ALL	2013	ALL
Production/Prefabrication Man-Hours	382	1 TO 10	35	1, 2
Man-Hours Onboard	5005	11 TO 24	1978	3 TO 12
Man-Hours In Confined Spaces	4268	14 TO 19, 22 TO 24	1730	5 TO 10
Man-Hours for access	1138	11,20, 21	236	3, 11, 12
Man-Hours for fitting in place	2548	14 TO 17, 19, 22 TO 24	930	5 TO 8, 10
Man-Hours Using Chain Blocks	1720	17, 23	640	8
Man-Hours for Fabrication In Situ	428	22 TO 24	0	NOT APPLICABLE
Note: Man-hours in Sub-procedures in the respective Man-hour consumption tables are for one full cargo hold				

Table 7-12 Comparison of methods
(Author's table)

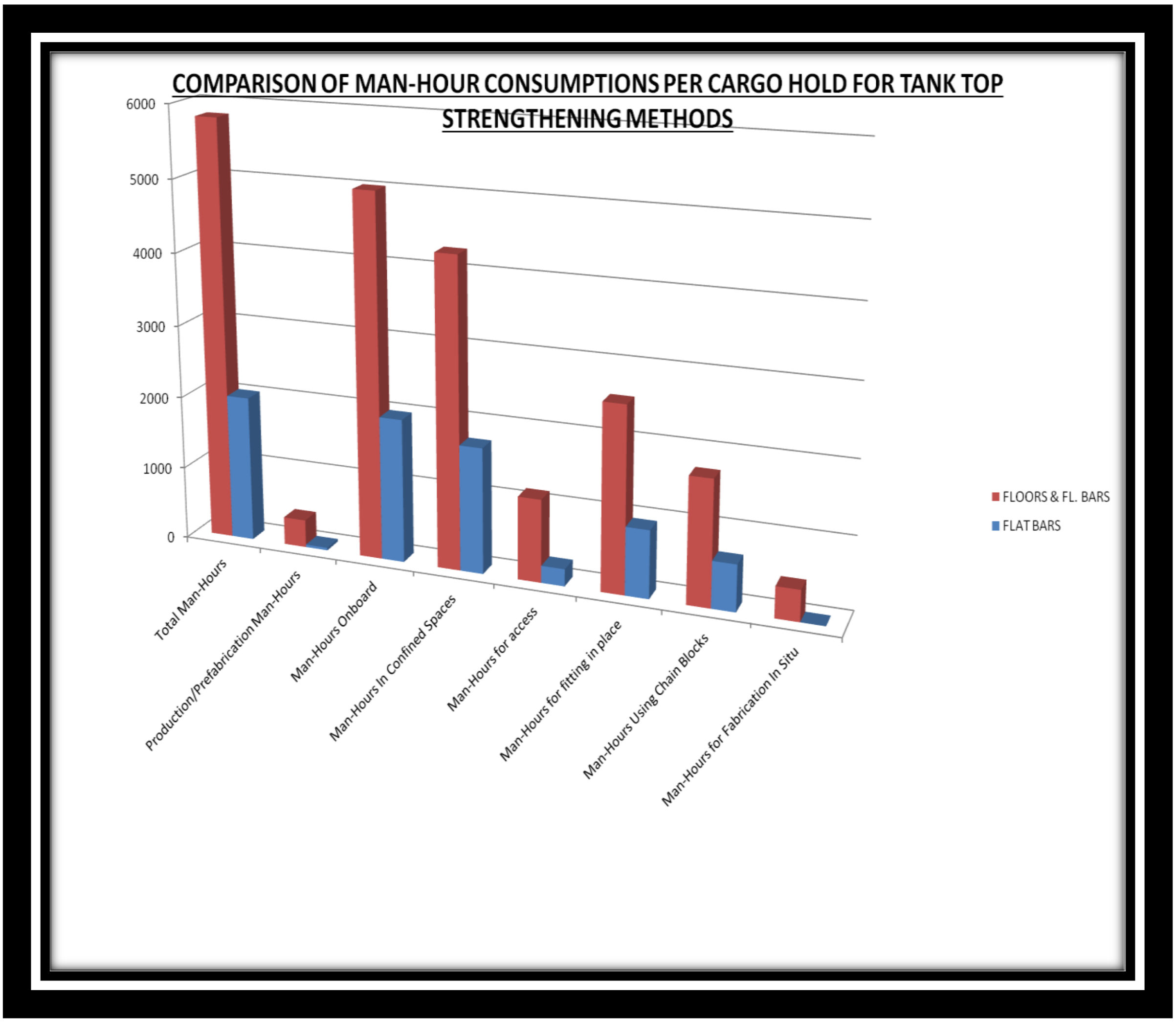


Figure 7-8 Comparison of methods
(Author's figure)

It is immediately noticeable that the flat bar method requires less than half of the man-hours of the floor and flat bar method. It is also noticeable that the bottlenecks of

- using chain blocks
- working in confined spaces, and
- fabrication is situ

Have all been reduced by using the flat bar method.

As it can also be seen, the man-hours for fitting the steel products in place have also been reduced. This is partially because by just fitting the flat bars and not the floors, the number of products to be fitted is less, but mostly it is because the flat bars are easier to be fitted because they are less “bulky”. Having to work with large, designed for production (as large as possible etc.) prefabricated pieces in confined spaces is more likely to slow the progress of work, as maneuvering presents difficulties. The flat bars, being light and maneuverable, are easily fitted and also because of that, surrounding systems, such as ballast piping, do not affect their fitting, as they can be maneuvered around them with relative ease.

It can therefore be seen that by using smaller maneuverable prefabricated pieces of steel to fit in confined spaces, instead of larger prefabricated pieces, even if they have been designed for production, work content is reduced and also bottlenecks are reduced.

Another important lesson when designing and planning for conversion though is, having extensive knowledge of the Classification Societies’ internal regulations regarding structural steelwork, may save man-hours in a conversion.

7.6 Performing the Conversion Afloat Versus in Dry Dock

The case study has shown that these conversions can be performed afloat, without having to place the vessels in dry dock at any point to address longitudinal strength issues. Although this is feasible technically, it can be argued that it would perhaps be faster to perform the conversions in dry dock, as major longitudinal strength related tasks could be performed at a faster pace and sequence which would not be affected by having to manage longitudinal loads during the conversion.

The shipyard performed the conversions afloat, as they do not own a dry dock. Performing any task in dry dock meant that they would have to move the vessels outside their premises to close-by yards and be forced to pay the resulting costs. It is a fact that further to the direct costs of that action, such as the cost of vessel stay in dry dock per day, the yard would have to incur the indirect costs, such as the use of floating crane, as the active dry docks in Greece have very limited crane capacities for the nature of the conversions.

It is a fact that a vessel's stay alongside the berth is much cheaper than the stay in dry dock. The same is true when comparing the cost of pier crane to floating crane. Hence the yard had to develop a method for managing the project's resulting longitudinal stresses while afloat, rather than bear the cost of relocating the vessels to another yard, even for a limited amount of time.

However, for the sake of theoretical comparison, as performing part of the conversion in dry dock could be simpler in other shipyards, an added benefit could perhaps be present in using a dry dock and it must therefore be examined.

In the case when Top Side Tanks are the main stiffening members, such a scenario would perhaps add value to the project, as they cannot be fitted until the longitudinal bulkheads are relocated. Hence relocating the bulkheads as quickly as possible would reduce the overall cycle time of the project. Relocating bulkheads requires caution in longitudinal stress monitoring, as longitudinal bulkheads play a significant role in maintaining longitudinal strength during the conversion. Therefore by placing the vessel in dry dock, concerns about longitudinal strength are minimal and as a result, all the longitudinal bulkhead relocations can be performed at the same time.

The following chart shows the time required to perform the bulkhead relocations whilst afloat and represents actual data from the case study.

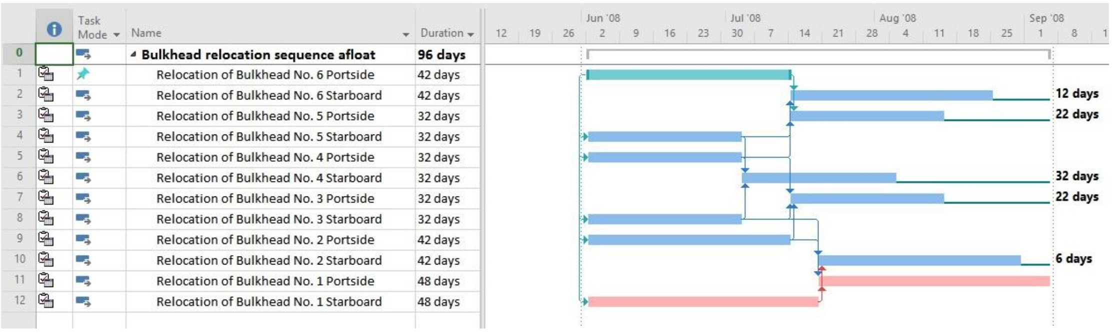


Figure 7-9 Gantt chart, bulkhead relocation, afloat
(Author's figure)

The bulkheads were relocated in a diagonal (zigzag) pattern to reduce the effect of the relocation on the longitudinal strength of the hull, as by not "disconnecting" both port and starboard bulkheads of the same hold from the hull at the same time, provided some longitudinal continuity, even if partial. As it can be seen, the time required to relocate a bulkhead in the parallel middle body of the vessel was 32 days. This can now be compared with the time required to relocate bulkheads in the fore and aft part of the hull. Bulkheads in holds No.6 and No.2 required 42 days each, while bulkheads in hold No.1, in which relocation is the most man-hour consuming compared with the rest (because of the curvature of the hull in the specific area), required 48 days.

It is evident that the further from the parallel middle body a relocation needs to occur, the longer it takes, as the bulkhead needs to be relocated in sometimes smaller sections, as dictated by the "irregularity" of the hull in these areas. Therefore man-hours for working in situ, on staging and in confined spaces are increased. This is however inevitable.

It can be seen that the entire procedure for one vessel required 96 days to be completed.

In theory, performing the procedure in dry dock would not require that the bulkheads be relocated in a diagonal pattern. Instead, as previously stated, they could all be relocated at once. The Gantt chart below is a theoretical indication of this procedure.

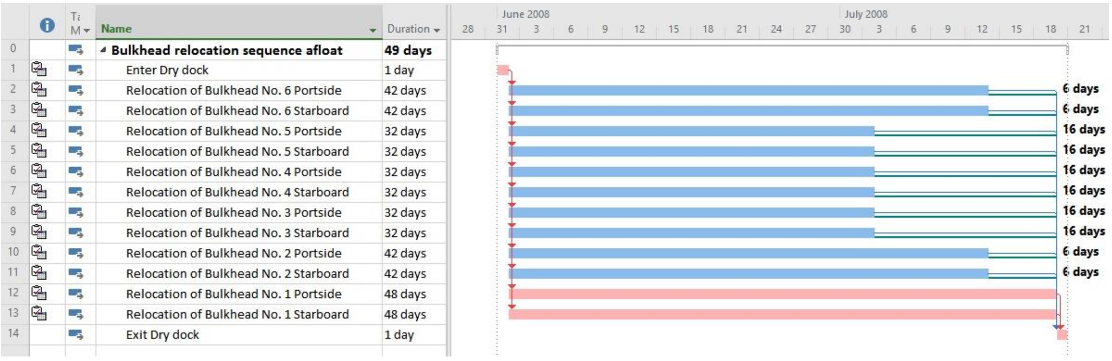


Figure 7-10 Gantt chart, bulkhead relocation, dry-dock
(Author's figure)

By assuming the same time required for each individual relocation, and that they can all commence at the same time, it can be seen that the whole procedure would require 49 days, including one day to enter the dry dock and set up the equipment, and one day to exit the dry dock. Compared to converting afloat, it can be seen that converting in dry dock presents a saving of 47 days, which is approximately 50% of the time required in the "afloat" version. These saved days could theoretically become gained trading days for the converted vessel, which could translate to a bonus for the shipyard as an incentive to deliver the vessel as quickly as possible. In order however to quantify a possible benefit for the shipyard, the extra costs must also be calculated. The following formula may quantify the said benefit.

$$\boxed{\text{BENEFIT}} = \boxed{\text{BONUS}} - \boxed{\text{COST OF CONVERSION IN DRY DOCK}} - \boxed{\text{COST OF CONVERSION AFLOAT}}$$

Figure 7-11 Benefit from Dry-Dock

In the case of top side tank strengthening, in order to demonstrate the difference in cost required for the bulkhead relocation procedure to take place afloat compared to it taking place in a dry dock, the following tables have been prepared. They take into account the assumption that a capable dry dock with adequate lifting means exists in the area where the conversion is taking place, and therefore there is no need for the use of a floating crane to relocate the bulkheads, which would increase the cost of the procedure significantly. The prices for the "conversion being performed afloat" scenario are direct from Salamis Shipyards, and the prices for the "conversion being performed in dry dock" scenario are from Chalkis Shipyard in Greece.

All services required other than wharfage and docking, such as electric power, fresh water, telephone etc, have been assumed to be the same in both cases and are therefore not calculated.

AFLOAT CONVERSION					
Item	**Description and remarks**	**Unit Cost**	**Unit**	**Total units**	**Total**
1	Vessel on berth	$ 350,00	day	96	$ 33.600,00
2	***DRYDOCKING***				
	a) Docking / undocking of vessel, i.e. first and last day of				
	vessel's stay in dock, BRT 22607	$ 7.571,00	x	0	$ -
	b) Vessel's stay in dock	$ 1.817,00	day	0	$ -
	c) Diver assistance	$ 138,00	h	0	$ -
	d) Mounting / dismounting of keel blocks:				
	- central blocks	$ 190,00	pc	0	$ -
	- side blocks	$ 210,00	pc	0	$ -
				TOTAL	**$ 33.600,00**

Table 7-13 Indicative costs for conversion afloat
('Salamis Shipyards,' 2007)

CONVERSION IN DRY DOCK					
Item	**Description and remarks**	**Unit Cost**	**Unit**	**Total units**	**Total**
1	Vessel on berth	$ 350,00	day	0	$ -
2	***DRYDOCKING***				
	a) Docking / undocking of vessel, i.e. first and last day of				
	vessel's stay in dock, BRT 22607	$ 7.571,00	x	2	$ 15.142,00
	b) Vessel's stay in dock	$ 1.817,00	day	47	$ 85.399,00
	c) Diver assistance	$ 138,00	h	10	$ 1.380,00
	d) Mounting / dismounting of keel blocks:				
	- central blocks	$ 190,00	pc	50	$ 9.500,00
	- side blocks	$ 210,00	pc	100	$ 21.000,00
				TOTAL	**$ 132.421,00**

Table 7-14 Indicative cost for conversion in dry dock
(*Chalkis Shipyards*, 2007)

In the dry dock scenario, the vessel would require one day for docking and one day for undocking. The remainder days in dry dock would therefore be 47. During docking, the vessel would require diver assistance, which has been assumed to be 10 hours. In order to dock, the vessel would require keel blocks, and so 50 centre keel blocks are assumed to be used and 50 keels blocks on either side.

By comparing the tables, it can be seen that the difference in cost between the two scenarios is approximately 100,000$. In order therefore for the “dry-dock scenario” to be of benefit to the shipyard, its bonus would have to be more than the equivalent amount.

At this point it is worth considering that the box-girder method, where the main stiffeners (box girders) are among the first structures to be fitted on the vessel and thus all the longitudinal strength issues are addressed, may allow for parallel relocation of all bulkheads of the vessel at the same time. This would reduce the duration of the relocation process to the levels as if in dry dock. In such a case the use of dry dock for the conversion could be a non value adding task to the project in terms of time saving and simply imposing extra cost to the project.

It is the author’s opinion that using innovative designs and procedures in conversions, in which no work in the external under-water hull is required, could make the use of dry dock not necessary, non value adding, but just cost imposing. However, implying that this is a fact for all conversions cannot be substantiated.

Hence the author suggests that the possibility of using innovative methods to address design and planning issues in conversions, such as the use of box girders in the said case, that make the use of dry dock not necessary, minimize cost and cycle time in conversions, may in fact exist, and should be considered when planning and designing for conversion.

7.7 Summary

In this section of the Thesis a quantitative analysis of the benefits and problems of each method has been performed. Having discussed the nature of the bottlenecks, it has been proven that the existence of bottlenecks increases man-hour consumption and the duration of procedures. Their elimination therefore through a dedicated design for conversion philosophy is essential. The use of dry-dock has also been discussed in terms of value to the conversion, and the author’s opinion as to the use of dry-dock in such conversions has been expressed.

Chapter 8. Conclusions / Enhanced Principles of Design For Conversion

8.1 Introduction

Having applied the initial design and strategy for conversion, several conclusions were reached in the case study. Using, inevitably, trial and error, many important lessons were learnt, for the conversions at hand, but also for conversions generally.

This section attempts to summarise the findings so as to produce a new set of “principles” for more efficient conversions in general. This aims to serve as an enhancement to existing conversion theory.

8.2 Goal-Based Design

It has been made apparent that by adopting the Goal Based design concept, conversion success is more likely. In the case study, by designing to reduce conversion time and cost, whilst satisfying all classification requirements, using structures with as much simplicity possible, being the goal, the idea of dealing with longitudinal strength by adding box girders on deck was used.

This was an idea that was conceived after much trial and error whilst trying to make the creation and fitting of top side tanks, to resolve the said problem, as economical, trouble free and fast as possible. Even though box girders on deck may have not been a usual spectacle, in fact they would pose no problems to the vessels’ operation, nor create any safety problems to the crew as they satisfied the class requirements fully, whilst being the cheapest and quickest solution to the said issue.

Furthermore, in the discussion about the benefits of the use of a dry dock to perform the conversions, it is demonstrated that the use of dry dock would reduce the time of moving the bulkheads significantly. This is because it would be possible to cut all the bulkheads at once as the vessel would be supported by the dock and thus concerns about its longitudinal strength would no longer be present. It is also stated however, that had the box girders been used as a main means of longitudinal stiffening, they would have been fitted on the vessel before the bulkhead relocation, providing thus the missing longitudinal strength to the vessel and, in combination with a ballasting plan, the same bulkhead moving sequence could have been applied. This would have achieved the same cycle time as using a dry dock, without the expense of the dry dock. This would have been another success of the goal based design concept.

The benefits of using a goal-based approach in projects and in the design of projects are known by third parties also, a good example of a third party having understood its benefits being Intelligent Engineering, the inventors of the Sandwich Panel System (SPS). As has been explained, SPS is used in repairs and conversion to save cost and time by substituting conventional steel stiffening structures with composite sandwich panels that require a fraction of the man-hours and produce significant strengthening results.

It is the Author's opinion that designers should adopt the Goal-Based design concept in conversions and focus on the what the vessel is meant to do rather on what it "should look like" when designing for conversion. The compromise in "aesthetics" may produce significant benefits engineering-wise which may increase the level of success of the conversion project.

8.3 The Producibility of Designs

In the case study, the design for production philosophy was incorporated in the design for the conversion in all the major tasks as explained previously in this Thesis:

- Top side tanks
- Box girders
- Modified T beam longitudinal stiffeners
- Hatch covers and hatch coamings
- Girders/floors and flat bars for the double bottom stiffening

All the above were designed based on the fundamental principles of design for production as given by Larkins (Larkins, 2007), yet some failed to be as cost saving as initially thought and required significant re-design.

This was because much attention was paid to the producibility of the design in terms of fabrication of components, as it would be done in a ship-building project. The difficulty of fitting the fabricated structures in the donor vessel's hull was misjudged.

It is the producibility of the conversion design in the context of avoiding modification to the donor vessel's hull that is one of the main factors that may contribute to the design's success. The producibility of the design should not only be considered during prefabrication stage, but rather should be looked at as a holistic concept, taking into account the ease or difficulty of fitting its related structures on the vessel.

As it has been discussed, designers tend to disregard the existing structure of a vessel and rather tend to design the “end vessel” as if starting from a blank sheet of paper. As it has been shown in the case study, this approach is expensive and inefficient. It carries hidden costs and risks and must be avoided. A strengthening method contained in the initial design in the case study included the fabrication and fitting of top side tanks. This method required much modification to the donor vessel’s hull and its benefits were largely disputed. Even though it was a procedure which had the benefits of relatively easy production due to the repetitive nature of its sub-structures etc, during the fitting-on-board process, it created much difficulty. As it was a structure intended to be fitted inside the hull, and thus be connected directly to the existing stiffening structure of the hull, the work required on the stiffening structure was significant. Also, as the structure was intended for longitudinal strength, its continuity was imperative. This required that the transverse bulkheads be cut, so the top side tanks passed through. This level of intrusion into the vessel’s hull slowed the whole project down and increased costs significantly.

It is therefore understandable that avoiding modification to the donor vessel’s hull can be very benefitting for the success of the conversion.

The box girder example can also be used as the best example of avoidance of interference with the existing structure of the vessel. This method required only external work which allowed easy access, easy fitting, minimal work in confined spaces, as it required no modification to the vessel’s structure. Referring to the producibility of the box girder design, in terms of steel production, it has been shown that it is a very easily and fast produced structure as all the principles of design for production are adopted. It is a simple structure which can be produced in a repetitive manner, in standard workstations, with minimal components and can be placed on the deck without interference, for maximum effect. However it is the lack of significant work onboard that made it a success rather than its ease of fabrication.

8.4 Re-Using Existing Materials

It is perhaps inevitable that in every conversion, there will be some steel cut-outs. As mentioned in the theory, the cut out pieces could be re-used to save man-hours and material in the conversion.

In the case study, when attempting to re-use cut out pieces of the vessel’s deck to make a part of the longitudinal top side tanks, the amount of effort put in to straighten them, after some of the longitudinal stiffeners had been cut, demanded so much effort, that the idea was eventually abandoned. Also when comparing making topside tanks by using exclusively new material and re-using material in the method comparison discussion, it was found that constructing topside tanks out of new materials required less man-hours than constructing them by re-using material.

On the other hand, relocating the vessel's existing bulkheads proved the most favourable option in terms of man-hour consumption and cycle time when compared to fitting new bulkheads and scrapping the existing ones. Also approximately 600 tons of material was saved.

The reason for this difference in conclusion, when comparing re-using material to using new material in the two methods, lies solely on the level of intrusion into the re-used material's structure. As described, the bulkheads' structure was left intact when relocated, whilst the pieces of deck used to fabricate the topside tanks were altered, which created distortions which required significant amount of re-work to be corrected. On the other hand the relocated bulkheads were not distorted in any way during the relocation, which is one of the main reasons that made this method successful.

It is therefore evident that re-using materials whilst avoiding interference with their existing layout/ structure is another innovative idea that can lead to substantial cost and time saving in conversions in general.

8.5 Common "Bottlenecks" in Ship Conversion

The word "bottlenecks" is used by the Author to describe situations which are often in ship conversions and impede the progress of the conversion project. Misjudging the magnitude of bottlenecks was what slowed the conversion down and forced designers to look for alternative procedures to address the conversion issues.

When comparing the procedures it was shown that it is possible to eliminate or at least reduce bottlenecks by redesigning the procedures. Thus a clear conclusion is that conversion design and planning must be performed in such a way as to reduce bottlenecks for maximum efficiency.

8.5.1 Work in confined spaces

Work in confined spaces is common in ship-conversion; the reason being that by definition conversion takes places within the confines of an existing vessel. This bottleneck was present in all the methods described in the case study, from the strengthening works in the double bottom, to the fitting of the box girder on deck. It is a situation that cannot be avoided but can be significantly reduced by correct design and planning. For example even in the most unlikely place for confined-space man-hours reduction, the double bottom, by substituting floors (which were admittedly result of over-engineering) with the flat bars, the relevant man-hours were significantly reduced. This was mainly because the flat bars could be easily manoeuvred in the confined space of the double bottom. On the other hand, confined-space man-hours were present in the deck area also referring to the box girder method. This is because welding the girder internally was unavoidable. However, these man-hours were far less than those in the previous method used to address the same issue, the top-side tank method.

The conclusion is that even if working in a confined space may be unavoidable, reducing these man-hours is definitely possible.

8.5.2 Work on staging

Staging, as shown creates many direct and indirect man-hours; the direct being the ones required to set it up and bring it down and the indirect, the extra man-hours that the working environment on staging creates due to lifting equipment limitations, work-floor weight capacity limitations and others.

Although staging cannot always be avoided, it can be re-arranged to reduce direct man-hours. In the case study, when moving the bulkheads, the set-up of the staging was re-designed which made setting up and bringing down much quicker, thus aiding the bulkhead relocation procedure.

However, there are cases where staging can be avoided. Once again the example of the top side tanks versus box girders is relevant. By replacing the top side tanks which required much work under-deck and thus on staging, with the box girders which required work on deck, staging requirements were eliminated.

Hence, it is possible to reduce or eliminate the need for staging with proper and effective conversion design and planning.

8.5.3 Situations where existing structures become obstacles

The level of the significantly retarding effect that the hull's structure may have in a conversion procedure, especially in areas that cannot be considered confined, was not known to the Author prior to the execution of the conversions in the Case study. For this reason this is presented in this part of the Thesis, rather than in the conversion theory section.

As has been explained, one of the main differences between ship-building and ship-conversion, is that in the latter, one has to deal with existing structures which is a fact that creates constraints. These constraints tend to be larger when the size of new components to be added to the hull increases, and they get even larger when the new components have to pass through existing structures.

Designing for production dictates that products (panels, blocks etc) be as big as the production facilities allow for reasons of cost saving, as explained previously.

However, not fully understanding how these structures will be fitted in place in an existing hull will create problems. As in the case of working in confined spaces where prefabricated products flow is hindered by the surroundings of that particular area, sometimes the hull itself and its structures can play the part of the confined space surroundings, even if the area meant for new product fitting is not considered confined, but rather is considered quite large. Large areas in hulls, such as cargo holds may seem like they cannot constrain material flow at all, but in reality, the details of new product fitting in those areas may be hiding secret constraints.

This was a lesson well learnt in the case study, particularly when trying to fit the prefabricated Top-Side tanks through the hull's transverse bulkheads, for longitudinal strength member continuity.

When designing and planning the Top-Side tank method, the shipyard considered this an easy method for maintaining and enhancing the hull's longitudinal strength, as the tanks could be easily prefabricated, lowered to the tank top with the yard's 50 Ton crane, and then lifted in place using that same crane. When fitting the tanks, it was a known fact that some work would have to be done inside the tanks, i.e. in a confined space, for final fitting and welding, and also on staging as this work took place below the deck, but this was considered inevitable and also insignificant compared to the benefits of easily fitting large pieces of prefabricated steel structures to solve one of the conversion's major issues. This however, as it was proven, was a misconception, as maintaining longitudinal continuity of the strength member was a much more difficult task than originally anticipated.

Picture 44 Topside tank passing through transverse bulkhead
(Koros, 2010)

As explained in the case study, the Top-Side Tanks had to be lifted and then pulled through a cut opening in the transverse bulkhead using chain blocks and then fitted in place. The oversized opening in the transverse bulkhead had to be closed after the top side tank was pulled through and fitted in place. Some common characteristics with working in confined spaces are evident:

- Material flow is reduced due to surrounding structures
- Access points creation is needed for prefabricated piece to be fitted in place
- Final fitting can only be performed using chain blocks

This therefore, as a procedure, may have initially looked as one which would have benefitted the conversion progress as it qualified for all Design for Production parameters, but as it was eventually demonstrated it hid constraints which were not initially thought of, making the procedure require major improvement, which later came in the form of on-deck Box Girders.

8.5.4 Situations where fabrication of products in situ is required

One example as such in the case study, was when attempting to fit floors in the double bottom, especially in areas where ballast piping, which was already existent in that area, had to pass through the new, to be fitted floors. The prefabricated floors had to be cut in smaller pieces, and then re-fabricated around the piping and re-welded. In this case all the work that had gone in prefabricating the floor was lost and further re-work was required. When replacing the floors with the flat bars, the man-hours required for fabrication in situ were completely eliminated.

8.5.5 Small scale "intrusion" into the existing vessel structure

Further to the general intrusion described previously, where designers disregard the existing structure of the vessel to be converted and perform major cut offs, add-ins and generally extensive modifications, intrusion in the vessel's existing structures is present in smaller scale as well. Small scale intrusion was present in the Top Side Tank fabrication method, the Top Side Tank fitting onboard and elsewhere in the case study when cropping small stiffeners, parts of bigger stiffeners etc. Intrusion is essentially a waste of previously consumed man-hours, fitted material and generally work performed. It is by definition waste, a non-value adding activity. Avoiding intrusion, in small or large scale, will make conversions simpler, thus faster and cheaper.

8.6 Communication Between Departments Leads to Improvement

In the case study it is evident that had there not been an open and structured line of communication between production, design and planning and the budget control departments, there could have been no trial and error, no re-designing of structures and procedures, no improvements and therefore no cost savings through lessons learnt.

Some of the most apparent examples are:

- Replacing the Top Side Tanks with Box Girders on Deck as a main longitudinal strengthening member for the converted vessels,
- The development of a simpler way to relocate the longitudinal bulkheads of the vessels to create the double side section of the hull and
- Using exclusively new material to fabricate topside tanks instead of re-using material.

These improvements were only possible due to feedback and gained knowledge from the Production department who communicated the flaws of the initial designs and procedures to the Design and Planning department who then redesigned the procedures to avoid bottlenecks. In fact, all knowledge gained would not have been possible to be collected and evaluated had there not been a system of communication between departments in place.

8.7 Performing Conversions Afloat

The benefits of using a dry dock to perform major conversions where the longitudinal strength of the vessel is affected have been discussed. The dry dock will support the vessel and works can be carried out with safety and speed.

In the case study the vessels were converted afloat as the shipyard did not own a dry dock and also felt that the risk of performing the conversion afloat was manageable. However, the Author performed a comparison between the two methods both in terms of speed and thus time saving, but also in terms of cost by using actual shipyard pricing, assuming that a dry dock with adequate lifting capacity for the task was available.

As it was expected, it was shown that bulkhead relocation, the procedure which was the most significant in terms of long-lasting longitudinal strength loss, could be performed in approximately half the time compared to the afloat condition. This was because the safety and support of the dock allowed for simultaneous bulkhead relocation, whereas when afloat the bulkheads had to follow a more conservative relocation sequence for safety. The benefits therefore of using a dry dock for longitudinal strength purposes in conversions are significant.

It is however the Author’s opinion that similar benefits can be had without the use of dry-dock. If the vessel is stiffened significantly before any action that would cause longitudinal strength loss, and if a ballast procedure is adopted to counteract the bending moments of the hull, then perhaps the support of the dry dock can be simulated.

Referring to the case study, by using the box girder method and fitting the box girders before the relocation occurs, so that the main stiffening system of the vessel is in place, and by using the same ballasting sequence, it is possible that that the bulkheads could be relocated in the same sequence as in the dry-dock scenario. Having already performed the afloat conversion and having seen the risks and the behaviour of the vessel, the Author believes that this relocation sequence could have been possible when afloat.

It is the author’s view, contrary to current bibliography which states that conversions of such magnitude and affecting longitudinal strength, require the use of dry-dock (*OECD*, 2008), that unless conversions require major modifications which directly affect the vessel's water tightness, stability which cannot be controlled by the vessel's own means, or involve hull lengthening, the use of dry dock is not required technically but can be beneficial to the project in terms of cost and time saving. However, it is possible that by using external stiffening structures (preferably permanent for reasons previously discussed) and a carefully planned ballast management sequence, the dry dock benefits can be simulated and the extra cost of dry dock become unnecessary.

As however the above was not possible to be confirmed in the case study, as it did not extend to that point, and as all conversions are not performed in the same prism of prevailing conditions, an evaluation of the potentially added benefit of performing the conversion in dry dock, should be performed on a case by case basis.

8.8 Enhanced Principles of Design for Conversion

This sub-section presents a series of "principles" representing the sum of valuable conclusions drawn from the Thesis. They aim to serve as valuable advice for design for conversion.

By avoiding designing a vessel based on "how it should look" and rather designing it to work by doing "as little work possible" whilst making maximum use of the vessel's existing structures, is in the Author's opinion a design ideology which will be successful in conversions, as it has been shown.

In synopsis, this thesis has identified seven main principles that form the basis for successful design for ship conversion:

1) Design must include the minimum amount of changes possible in the vessel's structure (be as least intrusive as possible) to avoid unnecessary costs. Designers should consider using:

2) Innovation and radical thinking which are essential in both design and planning by:

a. Using goal based design philosophy, as innovation in structures is possible and may prove more successful than conventional design

b. Re-using material where possible, with none or minimal modification so that the added benefit is not lost because of excessive man-hours consumed for corrective action. Also,

3) The principles of Design for Production must be applied when designing for conversion, but

4) Always taking into account and minimising the common conversion bottlenecks:

a. Work in confined spaces

b. Work on staging

c. Situations where existing structures become obstacles

d. Situations where re-fabrication of products in situ is required

e. Intrusion into the vessel's existing structure

In this respect,

5) Design for conversion must be performed in tandem with planning for conversion, and complemented by

6) A communication system between management departments which must be in effect as it leads to improvement, for which there is always room in design for conversions. Finally,

7) Evaluation of the benefits of the use of Dry Dock should be studied on a case by case basis as even if not always necessary it may be beneficial. However, it is possible that through following the previous principles for design and planning to provide the vessel with adequate strength, the benefits of dry dock may be simulated and its expense saved.

The above set of principles represents the sum of conclusions drawn from the sum of experiences and analyses pertaining to this Thesis. These are applicable to conversions in general, given:

- the common nature of conversions which stems from the common environment of conversion application, an existing vessel's hull,
- the fact that they represent knowledge gained from procedures which were applied to different parts of vessels' hulls, ranging from the double bottom to the deck, side shell and centerline bulkheads, in and outside the parallel middle body area, thus encapsulating a wide spectrum of situations present in many conversions,
- the fact that they also stem from knowledge gained from conversions not examined exclusively in this case study, such as the double hull tanker conversion (Koros, 2009a) and the ferry garage deck conversion (Koros, 2006b) which were performed under the management of the author, and from knowledge gained from studying third party conversion specifications (appendix III)
- the fact that all conversions will require the addition of new structures and/or modification of their existing structures to serve their new purpose and/or contain their new cargo type,
- the fact that "in many cases conversion projects will affect the longitudinal strength, structural integrity and stability of the vessel" as mentioned in the OECD report, page 14, paragraph 50(*OECD*, 2008), as was exactly the case in the conversions discussed in the case study of this Thesis

- the fact that conversions can be said to be the bridge between shipbuilding and ship repair (*OECD*, 2008), a statement that was complemented by the findings of this Thesis which suggested exactly the same.

The conversion principles can be used for a suitable approach to designing for conversion, with the aim of reducing the cost of conversions and their duration, whilst producing vessels acceptable to the shipping market and abiding by the prevailing Classification Society and IMO regulations.

Chapter 9. Summary and Further Work

9.1 Summary

The Thesis has considered the reduction of costs in ship conversions, through the introduction of a structured approach to dedicated Design for Production.

The available bibliography was studied and the relevant knowledge which could lead to the desired result was extracted. This was combined with the experience of the Author in ship conversion and the analysis of results from the Case Study, to produce a set of principles for a structured approach to Design for Conversion.

The main core of the Thesis begins by examining available bibliography. In this section a general discussion on ship conversion is made, the significance of the condition of the donor vessel is discussed; market conditions and other commercial considerations that influence conversion are analysed, leading to the market conditions that created a favourable environment for tanker to bulk carrier conversions in 2007, as those discussed in the Case Study.

By examining bibliography it was found that although much material was available on ship-building and ship-repair, there was little on ship-conversion and none specifically on design for ship-conversion. The Author then discusses variants in approach to design for ship-building and later analyses the characteristics of Design for Production, which can form a basis for Design for Conversion. It is generally stated that ship-conversion may be technically placed between ship-building and ship-repair and the Author recognizes the resemblance of ship-conversion to ship-repair in the sense that in both cases there are restrictions, imposed by the fact that work is carried out in an existing hull, and suggests that a way must be found to minimize these restrictions. The role or regulatory bodies is then discussed, focusing on the Goal-Based approach to regulation that IMO has suggested, and the benefit of a similar approach to design for conversion is noted as a way to minimize restrictions.

The fundamentals of project management are then examined, which are applicable to ship conversions, the need for clear communication between the departments of ship-converting companies is stated and finally risks in ship-conversion are identified as well as their relative importance and the need to manage them for success in conversions. It is generally noted that project management should be as “strong” as possible. It is considered essential to create a collaborative team which involves all major Stakeholders in the project so that a strong line of communication is established for consideration of design, production and approvals, as a holistic program. In this way risk management will be enhanced, a fact very important to manage production risks effectively.

The next section of the Thesis focuses on defining cost effectiveness in ship-conversions. It identifies the factors that influence the cost effectiveness of conversions, both internal and external, and provides two equations through which cost effectiveness can be measured. Cost effectiveness is examined both internally (Shipyard) and externally (Owners), as the Author explains that factors affecting either party will in the end affect the Shipyard, directly or indirectly. The section ends by suggesting that external factors, such as market fluctuations, cannot be controlled and thus attention should be paid in minimising the internal risks of conversion, which are associated with conversion performance, and especially with the duration, cost, and the quality of the finished product of the conversion.

The next section discusses the basic principles of conversion design and planning, describing the theory which is available through bibliography, experience and common practice in conversions. Specifically, the need for Goal Based Design, factors influencing design producibility, the main differences between Design for Production and Design for Conversion, the existence of ship conversion “bottlenecks”, the possibility of re-using material and finally the potential benefits of using a dry-dock for conversion are examined. This section forms the basis for the design and planning of the conversions of tankers to bulk carriers.

The next section discusses the main design and planning issues for converting tankers to double hull bulk carriers. It examines the importance of the extent of the modifications carried out in the donor vessel’s cargo section, ways to deal with the loss of longitudinal strength, ways to create the double hull structure, and issues having to do with the strength requirement of the tank top.

It also presents the main conversion strategy issues, identifying four main conversion steps, namely the extraction of unnecessary tanker equipment, fitting bulk carrier cargo equipment, creating the double hull structure and fitting top-side tanks as main longitudinal strengthening members.

It discusses the different available options and the related associated technical challenges to satisfy the requirements for performing each of the steps. This section forms the basis for the design and the conversion strategy presented in the next section, the Case Study.

The Case Study examines the conversion of two single sided 40,000ton DWT tankers to double hull bulk carriers. The conversions were performed by applying the theory set out in the previous sections and in the four steps as outlined in the strategy. A detailed description of the actions taken is given along with the problems encountered. Some of the procedures in the conversion were performed with success, within budget and time frame, whilst others presented challenges which made the shipyard re-examine the conversion design and strategy. The most notable examples were the decision to substitute the top-side tanks with box girders fitted on deck, as this reduced restrictions encountered when working inside the hull of the vessels, and a more efficient method for relocating longitudinal bulkheads. Another important note in this section is that the conversions took place with the vessels afloat rather than in dry-dock, by using hogging monitoring and ballast system management to counteract the bending moments on the hulls.

Having discussed in the Case Study the difficulties associated with each procedure and having presented replacement procedures and improvements, the next section attempts to determine if the reasons (bottlenecks) said to be making procedures inefficient, were indeed the problem, and if so, how effective were the new procedures in eliminating the said reasons.

It does so by analyzing the man-hour consumption of each procedure and the time needed for its application. It then breaks down the man-hour consumption of each procedure, to determine the man-hours consumed by bottlenecks. By examining if bottleneck man-hours have decreased when comparing original and revised methods, it determines whether the bottlenecks were indeed the cause of the problem and if the new procedures were effective in reducing them and thus presenting a better alternative for the conversion. By identifying common causes of procedure ineffectiveness, a set of global principles for conversions can be generated.

This section also examines the benefits of using a dry-dock for the conversion and indeed shows that its use can be of significant benefit to the conversions by reducing conversion duration. The Author then states his opinion that the benefits of using a dry-dock can be simulated if external strengthening members (in this case the box girders on deck) are used on the hull along with a ballast management system and these could help avoid the extra cost of using a dry-dock.

The final section of the Thesis summarises the findings so as to present new knowledge obtained through the different sections of the Thesis and produces a new set of "principles" as a dedicated approach to Design for Conversion. These principles combine knowledge obtained from bibliography, past conversion experience, new conversion experience through this Thesis and are applicable to a wide range of conversions, as explained at the end of the section.

9.2 Further Work

The thesis has considered the reduction of costs in ship conversions, through improved design and organisation. A number of principles have been developed based on the experience gained in the course of the conversion project which has been studied, and in subsequent development of alternative, improved methods. In the course of the work several potential avenues for improvement of conversion have been identified.

In considering the maintenance of longitudinal and local strength during the conversion process and into the ship service, the potential for use of the Sandwich Panel System (SPS) process has been mentioned. This was not considered for the project, nor for the improvement proposals. SPS is a specialised system which has been applied to repair and conversion work on a case by case basis. It has also been used in a modest way for ship construction.

The use of SPS could be further studied for use in conversions, for example as part of strengthening the deck of a ship prior to cutting openings. It also has potential for strengthening a hold bottom, based on the uses of SPS as a means of repairing similar structures, essentially making the plating thicker. In the case of repair this is to avoid plate replacement after corrosion, for conversion it could provide a lower cost alternative to additional stiffening. It would also be interesting to perhaps design Sandwich Panel based main longitudinal strengthening structures to compare to the box girders on deck.

Risk was identified as intrinsic to conversion work, taking into account for example:

- The condition of the existing ship
- Difficulties in removing and refitting steel structures leading to cost and time overruns

Risk was considered during the conversion project, especially the easily identified major risks including the maintenance of longitudinal strength and keeping the ship from hogging or sagging as work progressed. Other risks were only picked up during the work. A useful future area of work may be the development and use of formal risk registers for such major conversions. Risk management generally is a major element in large scale projects, for example warship construction, or offshore oil related projects. It features less in the ship repair and conversion sector and there may be benefits to be gained in this field.

Work could also be considered to apply the principles identified in this thesis to other projects, with different ship types. Because of the nature of conversions, as often opportunistic projects, establishing a timeframe for this may prove difficult but it would provide useful further confirmation of the principles developed.

Chapter 10. Appendices

10.1 Appendix A, Vessels Trading After the Conversion

The managers of the vessels at the time had reported that the vessels were taken in well by charterers after they were delivered to them. According to them, the vessels traded successfully after the completion of the conversion, achieving in some cases slightly above average charter rates, due to their "conventional age reduction certificates", their double hull design, their new hatch covers and newly fitted cranes.

Picture 45 M/V SALVOR T entering the port of Tuapse Russia for loading

(Balalaev, 2009)

The vessels were converted at Salamis Shipyards using a design that proved favourable to the charterers and at an exceptional quality. For these reasons the vessels were chartered by First Class houses, such as NOBLE, DREYFUS, EVERDERE and others, the managers reported.

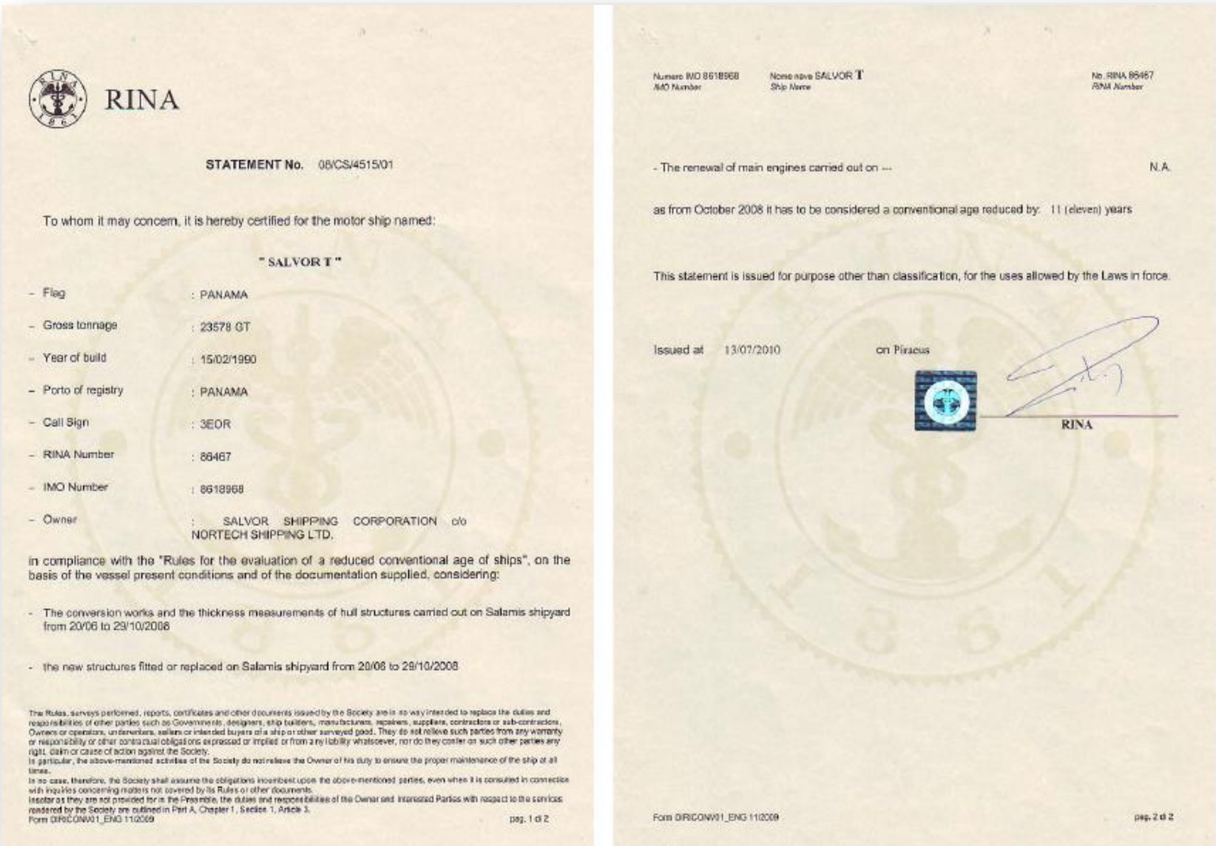
The overall feeling of the market was that the sister ships were in "as new" condition, also backed by the class's conventional age reduction certificate, and their double hull design offered more cargo protection in the event of vessel collision, but also reduced humidity risk on the cargo hold walls due to the void space between the side longitudinal bulkhead and the side shell when the vessels were laden.

10.1.1 Conventional age reduction certificate

The Italian Classification Society (R.I.NA.), a member of I.A.C.S., who oversaw the conversions, the special surveys and eventually classed the vessels and issued all the relevant certificates, has a vessel condition assessment scheme called the “Rules for the evaluation of a reduced conventional age of ships”. This scheme allows vessels that have undergone major modifications to be assessed for commercial purposes, based on the type and amount of work that has been performed upon them, and be given a certificate stating that said vessels are as if a number of years younger than their actual age. The maximum conventional age reduction possible is fifteen (15) years.

The evaluation is based upon the amount of steel renewal and addition, the installation of new systems and engine of the vessel, the protective coating applied, the hull steel thickness etc. (www.rina.org)

Both vessels achieved an 11 year conventional age reduction, 12 years being the maximum that can be achieved generally, without replacing the vessel’s engine. In terms of quality this is the best indicator, if not proof, that the conversions were successful.



RINA

STATEMENT No. 08/CS/4515/01

To whom it may concern, it is hereby certified for the motor ship named:

" SALVOR T "

- Flag : PANAMA
- Gross tonnage : 23578 GT
- Year of build : 15/02/1990
- Porto of registry : PANAMA
- Call Sign : 3EOR
- RINA Number : 86467
- IMO Number : 8618968
- Owner : SALVOR SHIPPING CORPORATION c/o NORTECH SHIPPING LTD.

in compliance with the "Rules for the evaluation of a reduced conventional age of ships", on the basis of the vessel present conditions and of the documentation supplied, considering:

- The conversion works and the thickness measurements of hull structures carried out on Salamis shipyard from 20/06 to 29/10/2008
- the new structures fitted or replaced on Salamis shipyard from 20/06 to 29/10/2008

The Rules, surveys performed, reports, certificates and other documents issued by the Society are in no way intended to replace the duties and responsibilities of other parties such as Governments, designers, ship builders, manufacturers, repairers, suppliers, contractors or sub-contractors, Owners or operators, underwriters, sellers or intended buyers of a ship or other surveyed good. They do not relieve such parties from any warranty or responsibility or other contractual obligations expressed or implied or from any liability whatsoever, nor do they confer on such other parties any right, claim or cause of action against the Society.
In particular, the above-mentioned activities of the Society do not relieve the Owner of his duty to ensure the proper maintenance of the ship at all times.
In no case, therefore, the Society shall assume the obligations incumbent upon the above-mentioned parties, even when it is consulted in connection with inquiries concerning matters not covered by its Rules or other documents.
Insofar as they are not provided for in the Preamble, the duties and responsibilities of the Owner and Interested Parties with respect to the services rendered by the Society are outlined in Part A, Chapter 1, Section 1, Article 3.
Form DIRCONV01_ENG 11/2009 pag. 1 di 2

Numero IMO 8618968 / IMO Number — Nome nave SALVOR T / Ship Name — No. RINA 86467 / RINA Number

- The renewal of main engines carried out on --- N.A.

as from October 2008 it has to be considered a conventional age reduced by: 11 (eleven) years

This statement is issued for purpose other than classification, for the uses allowed by the Laws in force.

Issued at 13/07/2010 on Piraeus

RINA

Form DIRCONV01_ENG 11/2009 pag. 2 di 2

Picture 46 M/V SALVOR T Conventional Age Reduction Certificate

(Nortech Shipping, 2009)

10.1.2 New cargo handling systems, hatch covers and cranes

The vessels were fitted with newly designed and built hatch covers. This meant that the risk of water ingress through the covers, which could destroy dry cargoes, was minimal. New hydraulic systems were fitted as well, which in turn meant that the operation of the covers would not be disrupted due to a system malfunction.

The vessels were also fitted with three (3) cranes each. This gave the vessel autonomy in discharging operations and were therefore preferred by charterers for voyages where discharging would have to performed offshore on barges and then be taken to shore to be discharged on land. Although the cranes were bought second hand, they were fully refurbished and issued with a set of new certificates making them fully capable of commercial operation.

Picture 47 M/V ADMIRAL T after completion of her conversion
(Koros, 2010)

10.1.3 Double hull cargo holds

The vessels were converted to be double hull bulk carriers, a feature that was greatly favored by charterers. Grain and other edible commodity traders, such as DREYFUS, NOVEL and others, preferred the vessels over others and chartered them subsequently. The vessels were ideal for the transportation of such cargos due to their double hull cargo holds, as it was explained by their managers. The reason for this is that condensation can build up on the side shell plating in hotter climates which could affect the quality of the cargo that would come in contact with that condensation. The risk of condensation build up is minimized when the plate of the cargo hold does not come in contact with water on its external side. This is exactly the case with the double hull cargo hold.

Picture 48 Double hull cargo hold No.1 of M/V ADMIRAL T
(Koros, 2010)

FIXTURE NOTE

VOYAGE CHARTER

VOY No. 5

MV "SALVOR T" / SOLVADIS / CP 09.06.10

DETAILS

VESSEL	:	SALVOR T
CHARTERERS	:	SOLVADIS
C/P DATE	:	09.06.2010
CARGO	:	ABT 35,100MT SULPHUR IN BULK
IFO/MDO DELY	:	592,80 / 70,00
IFO/MDO SUPPLIED	:	.... / .... (supplied at ....)
LOADING	:	1-2 sa ALWAYS AFLOAT KAVKAZ or KERCH
DISCHARGE	:	1-2 sb ALWAYS AFLOAT JORF LASFAR or SAFI
FREIGHT RATE	:	USD 24,50 PMT bss JORF USD 26,00 PMT bss SAFI
PAYABLE	:	95% WITHIN 3 BANKING DAYS AFTER SIGNING/RELEASING BSL
LOADING RATE	:	6,000 TNS SHINC
DISCH. RATE	:	5,500 TNS SAT SHEX JORF 4,200 TNS SAT SHEX SAFI
DEMURRAGE	:	USD 16,000.00 PER DAY / PRO RATA
DESPATCH	:	HALF
DURATION	:	VOYAGE ABT 30 DAYS
LAYCAN	:	14-16 JUNE 2010

COMMISSIONS

2,50% ADDRESS :	SOLVADIS	$\}$ 3,75% TTL BY CHRTRS
1,25% BROKERAGE:	MONTAN SHIPPING	
2,50% BROKERAGE:	SEAWIND MARITIME LTD	

Picture 49 Fixture note at market levels for M/V SALVOR T, account SOLVADIS (*Nortech Shipping*, 2010)

FIXTURE NOTE

MV "SALVOR T" / NOBLE / CP 08.07.2010

DETAILS

VESSEL	:	SALVOR T
CHARTERERS	:	NOBLE
C/P DATE	:	19.03.2010
RATE/HIRE	:	USD 16,000.00
		- ILOHC: 4,000.00
		- C/E/V : 1,000.00 PMPR
DURATION	:	1 T/C TRIP MIN 60 / 65 DAYS WOG
CARGO	:	FULL CARGO FERTILIZERS
DELIVERY	:	JORF LASFAR
REDELIVERY	:	DLOSPS 1 SP IN CHOPT SPORE/JPN RGE, PICO
LAYCAN	:	26 / 27 JULY
DELY BUNKERS	:	ABT 378.60 MTS / ABT MGO 28.70 MTS
REDELY BUNKERS	:	ABT SAME QTIES AS ON BOARD ON DELY
BUNKER PRICES	:	USD 425.00 PMT IFO & USD 670.00 PMT MDO

COMMISSIONS

3,75% ADDRESS	:	NOBLE	6,25% TTL BY CHRTRS
2,50% BROKERAGE	:	HOWE ROBINSON	
2,50% BROKERAGE	:	SEAWIND MARITIME LTD	

Picture 50 Fixture note at market levels for M/V SALVOR T, account NOBLE
(*Nortech Shipping*, 2010)

10.2 Appendix B – Quality of the Conversion Product, the Benefits of Double Skin Bulk Carriers

10.2.1 Bulk Carrier Designs

Until the middle part of the 20th century, the cargo holds of ships carrying dry cargo were generally partitioned into upper and lower holds. This was convenient for the carriage of cargo in boxes and in bags, and the partitioning deck itself contributed to the strength of the hull structure. Bulk carriers with topside tanks did not emerge until the 1950s. At the time, bulk cargo volumes were increasing and there was a growing need for ships that could carry loose, unpackaged dry cargos. (N.K.K, 2009)

In modern days, bulk carriers can be in structural terms be categorised loosely in five categories:

1) Single-skin bulk carriers with Topside Tanks and Hoppers

The triangular shaped topside tanks situated under the main deck and the double bottom and hopper tanks at the bottom of the ship help to strengthen the hull, enabling the cargo holds to be made larger. Furthermore, the hold structure makes it possible for the cargo to be loaded without the need for trimming, allowing bulk carriers to carry large volumes of cargo efficiently. (N.K.K., 2009)

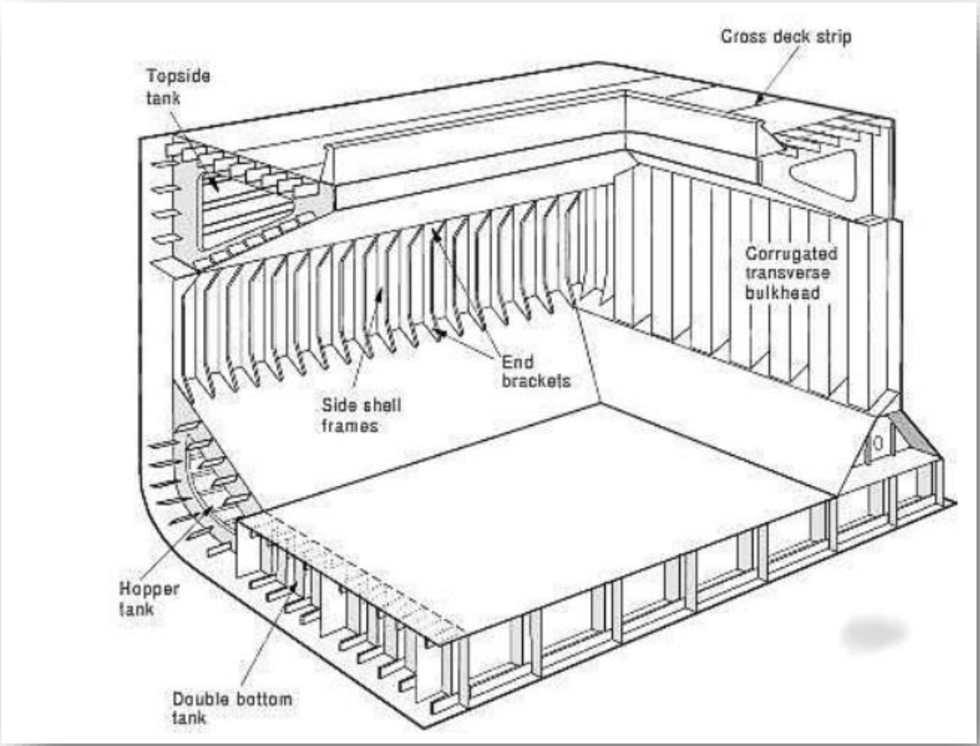


Figure 10-1 Bulk carrier arrangement
(*Bulkcarrierguide.com*)

2) Ore Carriers

Ore carriers are designed and constructed in such a way so as to be able to carry cargos of very high density which occupy small volume. Therefore due to the high specific gravity of the cargo, cargo holds are relatively small and are accompanied by large side tanks, as shown in the figure below. The side tanks have been used in the past for transportation of oil in some vessels, known as combination carriers. (N.K.K., 2009)

This design is used only in large vessels, Capesize and larger, whose primary cargo are heavy ores and thus do not require much cargo space volume.

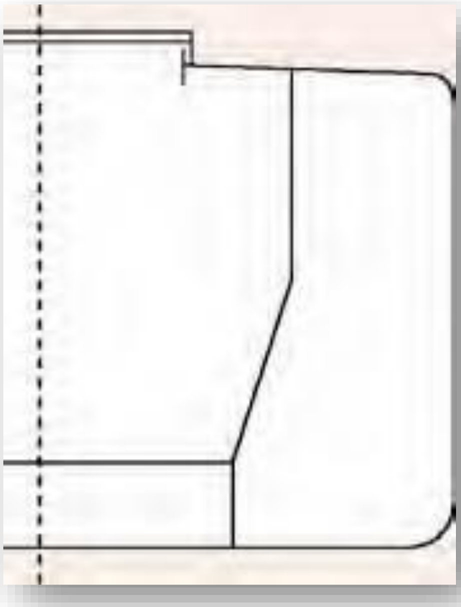


Figure 10-2 Ore carrier mid-ship section
(N.K.K., 2009)

3) Open hatch bulk carriers

These have very wide hatch openings which improve the cargo handling efficiency as there are no obstructions during loading and discharging. It is because of the large hatch openings that they can load exceptionally large size cargo and also cargoes other than in bulk form can be loaded, such as pulp products, steel coils and containers.

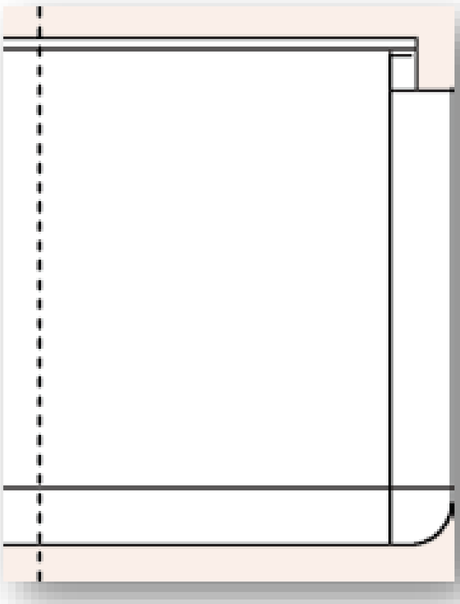


Figure 10-3 Open hatch bulk carrier mid-ship section
(N.K.K., 2009)

4) Wood chip carriers

Because of the very low specific gravity of the cargo, these vessels are not fitted with Topside tanks, whist they have very high freeboard, as they require maximum cargo hold volume. Wood chip as a cargo tends to have higher temperature than the ambient as it tends to self-heat. This creates corrosion problems in the holds as it generates humidity in the form of ship sweat (imsbc) which affects the coating, especially in lower ballast tanks. This type of vessels can also carry cargo such as soybean meal. (N.K.K., 2009)

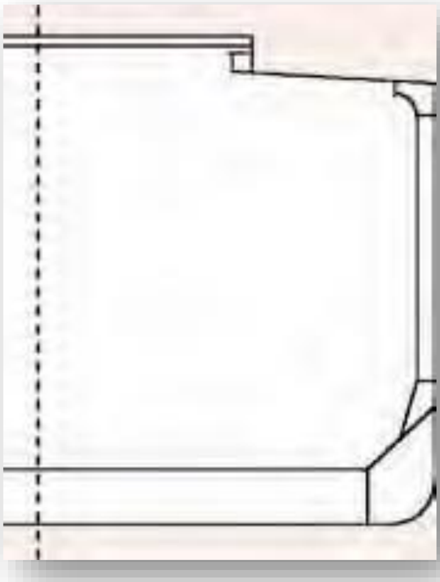


Figure 10-4 Wood chip carrier mid-ship section

(N.K.K., 2009)

5) Double skin bulk carriers

Double skin bulk carriers have an extra longitudinal bulkhead along the side shell creating a double skin structure. All the side shell framing and general stiffening structure is contained within the double skin structure.

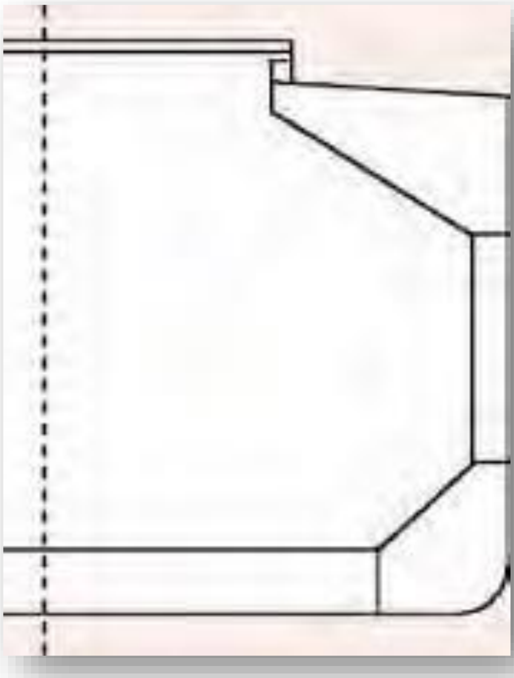


Figure 10-5 Double skin bulk carrier mid-ship section
(N.K.K., 2009)

With the exception of ore carriers and wood chip carriers, which are specialty carriers, normal bulk carriers used to transfer multiple bulk cargos, fall within the other three categories. Open hatch bulk carriers can also be considered double skin bulk carriers, without topside tanks, so therefore the two major categories are single skin and double skin bulk carriers.

It is the author’s opinion that double skin bulk carriers posses some characteristics which make them “better” than single skin carriers.

10.2.2 The Benefits of Double Skin Bulk Carriers

The grounding and subsequent hull rupture of the single hulled tanker “Exxon Valdez” resulted in massive pollution of the Alaskan coastline by crude oil. Congress in the USA legislated the use of double hulled tankers to help contain the cargo in the event of grounding or other hull rupture. Recent tanker disasters with older single hulled tankers have re-enforced this anti-pollution viewpoint.

A spin-off effect has led to the proposed introduction of double hulled bulk carrier designs.

It is the author's opinion that Double Hull bulk carriers are regarded as a better option to conventional single skin bulk carriers by many parties, including ship owners, operators, Hull & Machinery Underwriters, Protection & Indemnity Clubs and Charterers. The double skin of a bulk carrier offers protection as well as value to the vessel.

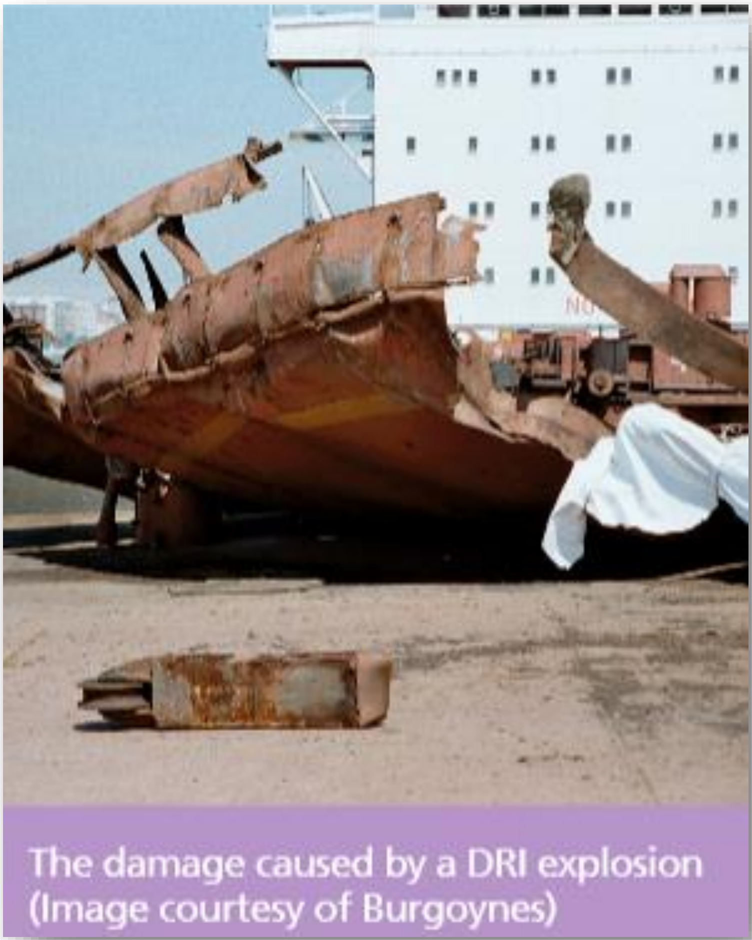
The second skin provides a second barrier for water ingress in the cargo holds, in case of side shell breach. The double-hull structure makes the vessels stiffer and helps to prevent hold flooding in case of side shell rupture. Therefore, from this point of view, a double skin bulk carrier vessel is safer than one with a single skin structure (Spyrou *et al.*), as it reduces the risk of capsizing, sinking.

This second barrier's protection is especially relevant when referring to carriage of cargos of Type B of the International Maritime Solid Bulk Cargoes (IMSBC) Code, which when wet will evolve into flammable gas, evolve toxic gases, emit corrosive gases, or self heat and ignite (*Lloyd's Register et. al*, 2013)

Such cargos can be (IMO, 2004):

- **Direct Reduced Iron (DRI) (B)**, which is a metallic material of a manufacturing process formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. DRI may react with water and air to produce hydrogen and heat. The heat produced may cause ignition. Oxygen in an enclosed space may be depleted.

- **PYRITES, CALCINED (Calcined Pyrites)** is the residual product from the chemical industry where all types of metal sulphides are either used for the production of sulphuric acid or are processed to recover the elemental metals – copper, lead, zinc, etc. The acidity of the residue can be considerable, in particular, in the presence of water or moist air, where pH values between 1.3 and 2.1 are frequently noted. Highly corrosive to steel when wet. Inhalation of dust is irritating and harmful.
- **HAZARD,** in contact with water may evolve hydrogen, a flammable gas that may form explosive mixtures with air and may, under similar conditions produce phosphine and arsine, which are highly toxic gases. This cargo is liable to reduce oxygen content in a cargo space.



Picture 51 Damage caused by a DRI explosion
(*Lloyd's Register et al*, 2013)

The secondary barrier provided by the second skin, plays also a primary role in reducing humidity in the cargo hold steel structure, known as "ship sweat". According to the American Club (American Club, 2014), ship sweat appears as tiny beads of moisture condensing onto the ship's metal work. This phenomenon typically occurs on the sides of the hold when the sea temperature is lower than the ambient temperature in the cargo hold. This results in the reduction of temperature of the adjacent metal to a value below the "dew point" of the surrounding air.

The air in the space between the outer side shell and the cargo hold side bulkhead acts as an insulation jacket preventing direct heat transfer through the hull metal between the cargo and the sea. The lack of temperature difference prevents moisture from building up on the surface of the cargo hold bulkhead. This lack of moisture provides further protection to cargos that may be sensitive to moisture. Such cargos can be dangerous to the vessel and its crew if in contact with moisture (IMO, 2004). Such cargos are:

- **FERROSILICON**, in contact with moisture or water it may evolve hydrogen, a flammable gas which may form explosive mixtures with air and may, under similar circumstances, produce phosphine and arsine, which are highly toxic gases.
- **FLUORSPAR**, may liquefy if shipped at moisture content in excess of their Transportable moisture limit. See section 7 of the Code. Harmful and irritating by dust inhalation.
- **WOOD PELLETS** are light blond to chocolate brown in colour; very hard and cannot be easily squashed. Wood Pellets have a typical specific density between 1,100 to 1,700 kg/m3 and a bulk density of 600 to 750 kg/m3. Wood Pellets are made of sawdust, planer shavings and other wood waste such as bark coming out of the lumber manufacturing processes. They tend to swell if exposed to moisture. Wood Pellets may ferment over time if moisture content is over 15% leading to generation of asphyxiating and flammable gases which may cause spontaneous combustion.

Moisture buildup prevention of the double skin structure allows the extra protection of other sensitive cargos such as rice, among many others. According to The American Club, condensation is one of the primary hazards to rice. Fresh water condensation that accumulates on bagged rice is caused by temperature differences between the cargo, the air in the cargo hold and the vessel's steel structure, which result in sweat, as mentioned above. According to the German Insurance Association (www.tis-gdv.de), its sensitivity to moisture, makes Rice a product which is particularly at risk during transport.

By regulation, double hull vessels are not allowed to carry fuel oil in the double bottom tanks, as is commonly the case with single skin bulk carriers. The absence of fuel oil in the double bottom, which has to be heated, eliminates any chance of heat transfer to the cargo holds. This makes the transport of some dangerous cargos safer, such as seedcake.

According to The Standard Club (Standard Cargo, 2011) the main hazard of seedcake cargo is the risk of self-heating and spontaneous combustion. Self-heating leading to spontaneous combustion in a cargo of seedcake can be triggered by microbiological activity or exposure to a source of elevated temperature in the hold or both. Two of the main heat sources in such situations are hot Fuel Oil Tanks and hot Fuel Oil Lines.

Picture 52 Smoking seedcake cargo caused by heat emitted from the double bottom fuel oil tank beneath the cargo
(Standard Cargo, 2011)

Another benefit of the absence of fuel oil tanks in the double bottom is the prevention of pollution. In case of vessel grounding and breach of keel plating, oil spills and thus environmental pollution, is avoided.

A considerable number of cargos, such as coal, are highly corrosive to the ship's structure (*Lloyd's Register et al,* 2013). The double skin structure allows for primary structural members to no longer suffer from corrosive effects by being in direct contact with such cargos. The primary structural members of the vessel's side shell are protected by the inner plating of the double skin. In this respect, they can also be maintained with greater ease during the vessel's voyages, by the crew, as the double skin structure is fully accessible when the vessel is in transit. This is not possible in single skin bulk carriers as structural members are exposed to cargo and as such they are not accessible during transit.

Further benefits arise with respect to hull damage during cargo loading and offloading. The external skin is no longer in direct contact with mechanical tools (grabs), therefore the damage and detachment of frames that often arises from such contact can be prevented. Double-sided structures have flat sides in the cargo holds and as a result, pounding, scraping and jarring are not required at the final stage of the cargo discharge process, something that contributes also to a lower probability of damage in the hold. Also, the cargo discharging time is reduced. (Spyrou *et al.*)

Other benefits of Double Skin Bulk Carriers include reduction in operating expenses and higher Sale and Purchase (S&P) value. The smooth-sided cargo-hold design reduces the need for inspection and facilitates maintenance. Due to their lack of stiffeners, the internal hull is easier to clean, and maintenance and repair of hold coatings are more efficient and less costly.

Spyrou (Spyrou *et al.*) states that the resale value of a double skin vessel can be $200,000 more than that of a similar single skin bulk carrier and also, the reduced cost due to less cleaning time in ports to amount to $12,500/year. He goes on to say that an extra benefit arises from the lower risk of being “off hire”.

10.2.3 Extra Benefits of Newly converted Double Skin Bulk Carriers

Newly converted double skin bulk carriers have many benefits compared to vessels of the equivalent age. Having undergone major conversion, the amount of newly added steel will be substantial and all the areas of interest for cargo carriage will be newly surface treated and coated. A major conversion allows for repairs to bring vessels up to standard, therefore it is not unlikely to see vessels undergoing conversion, to undergo at the same time a special survey. Therefore the newly converted double skin vessel will leave the shipyard with “fresh” certificates.

One of the biggest problems in ageing bulk carriers is water leakage, leading to cargo contamination and other dangerous situations with wet and/or moist cargo, as described previously.

According to GARD (www.*Gard.no*, 2004), the main causes of Wet Damage Claims are leakage through the hatch covers, through pipes, bilges and defects in the vessels’ steelwork.

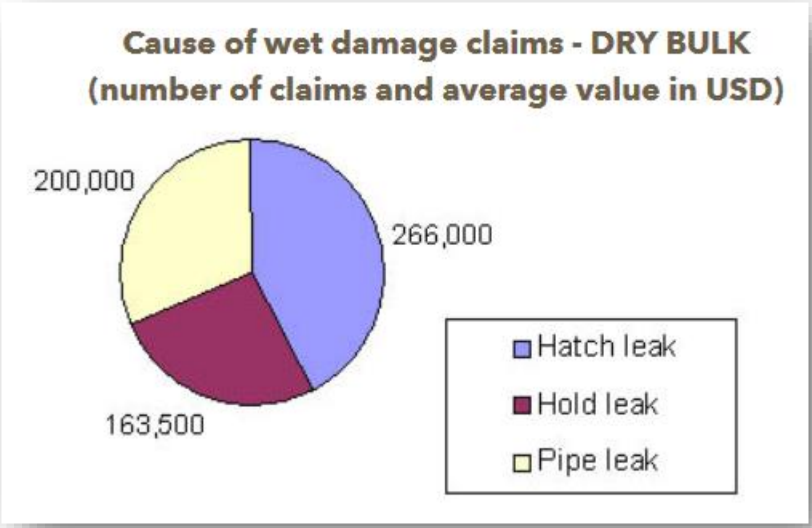


Figure 10-6 Cause of wet damage claims by frequency and average value
(www.*Gard.no*, 2004)

By default, converted vessels will be fitted with new hatch covers and coamings. Therefore no leakage problems are likely.

Newly converted vessels will have all pipes related to the cargo area, such as sounding pipes, cargo hold bilge pipes and others, fitted new by default as these systems were not relevant to the vessels' previous scope of operation.

The double skin of the vessels will either be fitted new, or the existing will be checked thoroughly, repaired and re-certified.

The above reduce the probability of cargo contamination by water making newly converted vessels more "attractive" to operation and cargo related concerns compared to existing bulk carriers of equivalent age.

In the case of converted double skin bulk carriers originating from single skin tankers, there is an issue of reduced cargo capacity to be considered. As the hull will be fitted with a second skin, the resulting cargo hold volume will be reduced as the second skin will create new ballast space between itself and the outer side shell. This trade off is inevitable in such cases and may lead to reduction of hire, as cargo intake is decreased. It can, however, be minimized by reducing the lost volume as much as possible.

It is the author's opinion that whilst a reduced cargo volume will reduce hire, the benefit of extra cargo safety for all the reasons described above, will reduce the charterers' risks, thus their cost of insurance, which may compensate to some extent for that loss of hire.

10.2.4 Disadvantages of double hull bulk carriers

According to Amtec Consultants (*www.amteccorrosion.co.uk*, 2003), the environment in the double skin ballast tanks will be such that will accelerate corrosion rates, due to temperature difference between the cargo area and the side shell in contact with the sea.

It is the author's opinion that the same is true in single skin bulk carrier top side tanks and hoppers. Also this is a problem which is solved by applying a more resilient coating to the structures affected, and by applying regular checks and maintenance whilst operating the vessels.

It is the author's opinion that the benefits of double skin bulk carriers overwhelm the disadvantages, thereby making double skin bulk carriers a better alternative to single skin bulk carriers.

10.3 Appendix C – Pamanax Tanker to Bulk Carrier Conversion

10.3.1 Commentary

This is a conversion specification for a Long Range 1 (LR1, Panamax) Tanker to Bulk carrier. This specification (*Salamis Shipyards*, 2007) was given to Salamis Shipyards to produce a quotation for the conversion by the owners of the vessel to be converted. It is understood that the owners seeked quotations elsewhere also.

This conversion never took place, for reasons which the author of this thesis, who was also Project Manager for conversions at Salamis Shipyards at the time, believes are related to the total cost, time required and complexity of this conversion. This conversion specification dictates major changes to the vessel's structure, for reasons which it does not make clear. The intrusion to the ship's hull is, the author considers, at maximum levels, demonstrating that at least some improvement is possible.

<u>Tank Top</u>

The specification dictates that the existing tank top be cut and the vessel fitted with a new tank top plating which is now raised to 3 metres. The author does not understand why the tank top needs to be raised, as ballast space necessities are adequately covered by the existing double bottom volume, the side tanks and the double deck construction. It is assumed that the tank top is raised for longitudinal strength, which, if this is the case, it is a very poor solution for adding longitudinal strength as it severely decreases cargo intake capacity. The specification also dictates fitting new girders and floors, which is understandable as it is understood that the owners required higher cargo density allowance than what the vessels where built for originally. It would be worthwhile however, to see if the new requirements would be met either by more simple stiffening which does not require scrapping the whole tank top, or even much access openings, or even by applying SPS sandwich paneling solutions. Two major conversion bottlenecks are apparent here, Intrusion, and Work in Confined Spaces. Minimizing them would reduce conversion cost and time.

Hoppers and Stools

The existing hoppers and stools are to be cut and new ones are to be fitted. The author suggests that this is for two reasons, the new height of the tank top and the new cargo density requirements. Again this can be avoided by not altering the height of the tank top and by applying simpler stiffening alternatives, or even SPS. Again Intrusion and Work in Confined Spaces are present.

Transverse bulkheads

The transverse bulkheads are all to be cut and relocated and also new ones to be fitted. The reasoning behind this action is not defined in the specification. After removing the longitudinal bulkhead the vessel would have remained with six cargo tanks/holds, which in the author's opinion is satisfactory. The level of intrusion in the vessel's structure is once again in the author's opinion beyond any allowable limits as far as reducing cost is concerned. Also the work on staging required, along with all the extra temporary stiffening works required to complete this task, the time it will require and all the situations where the vessel's structure will act as a confined space (under-deck area for example), in the author's opinion question the value of the possible, not mentioned in the specification, benefits.

Top Side Tanks

This thesis has examined in great detail the addition of top side tanks as strengthening members. For all the reasons mentioned in the "Evaluation of Methods used to address Design and Planning Issues in the Conversion" section, the author suggests that fitting Box Girders on deck instead, would be a better option.

Performing the conversion in dry dock

It is important to note that this vessel is already a double sided vessel. It therefore needs no longitudinal bulkhead relocation. If the tank top is not raised, the transverse bulkheads are left as they are, hoppers and stools are strengthened locally and box girders are used instead of top side tanks, then it is the author's opinion that this conversion could be performed afloat.

As the only loss in longitudinal strength would result from the loss of the longitudinal bulkhead and the deck openings, then by fitting the box girders on deck prior to cutting out structures, the strength of the vessel would be adequate to undergo the remaining conversion works.

General

The designers of this conversion completely disregarded the existing structure of the vessel, thus requiring major changes to be made to obtain a new layout whose benefits, compared to a layout produced with fewer changes to the vessel, are not defined in this specification, and also the author fails to identify. However there may be added benefits, but their value perhaps is not worth the extra conversion cost and time.

This conversion could be performed in a simpler way which would certainly reduce time and cost, simply by avoiding or minimizing the common conversion bottlenecks as described in this Thesis.

10.3.2 Specification

BRIEF CONVERSION SPECIFICATION

PANAMAX OIL TANKERS CONVERTED TO BULK CARRIERS

Doc. Code	10166-100-007
Performed by	lhb
Issued	30.10.2007
Rev.	0
Rev. date	-

This brief conversion specification and the drawings listed below describe and outline the requirements for the conversion of a number of 84000 DWT Panamax Product tankers from being double skin Oil Tankers to become Bulk Carriers.

The vessels to be converted to comply with governing rules and regulations listed below and shall be gearless.

Manager:

Consultants for the conversion:

Reference Documents:

General Arrangement, Preliminary	10166-101-001
Tankplan, Preliminary	10166-101-002
Midship section drawing, Preliminary	10166-201-002

The drawings, diagrams/schematic sketches listed above and appended to this specification, shall serve as guidance only, and shall be replaced by detailed drawings for Classification and Owner’s approval.

1 - SHIP GENERAL

VESSELS BEFORE CONVERSION

Main dimensions: **LOA = 228.60m, Lpp = 218.70m, B = 32.24m, D = 21.60m**

Existing Class: **DnV** Q**1A1 Tanker for Oil and Caustic Soda E0 W1-0C**
Register notations: **bis, inert, cow**

Vessel description:

Double skin, single decked, single screw oil tanker, with machinery space and 5-deck accommodation block with wheel house on top, located aft. Casing and funnel as a separate block on main deck, aft of the accommodation block.
Double bottom, double sides and double deck in way of cargo tanks, arranged for water ballast. Fuel oil tanks in engine room. Stool tanks in cargo area, all arranged with cofferdams against outer shell. Coated cargo tanks of mild steel which consist of six (6) pairs of tanks separated with a continuous longitudinal vertically corrugated bulkhead on stools, extending from tank top to main deck. The cargo tanks are transversally separated by five (5) vertical bulkheads on stools.

One pair of slop tanks located in front of engine room. Slop tanks and cargo tanks are separated by a combined transverse cofferdam and horizontal corrugated bulkhead.

Ballast pump room is located in centre, between the slop tanks.

Cargo and bunker line station is located on main deck at midship, including one hose handling crane. Pipelines for bunker and cargo are arranged on main deck.

VESSELS AFTER CONVERSION

Vessel description:

The vessels are to be converted to bulk carriers, complying with governing Rules and Regulations for Bulk Carriers. The double sides will remain, however the breadth of the double sides do not satisfy minimum requirements, and the vessels are therefore to be regarded as single skin bulk carriers.

Converted to nine (9) cargo holds for dry bulk cargoes, with nine (9) side rolling hydraulically driven cargo hatches. No. 4 Hold is floodable.

The conversion, with respect to steel-work will affect the cargo area.

Moulded draught for scantling (and SWL) is reduced to 14.50m, i.e. the vessel will be assigned B increased freeboard in accordance with ICLL-66 protocol 88.

Overall description of the conversion:

All steel- and cargo outfitting on main deck area to be removed.

Bunker filling station to be relocated aft.

C/D between E.R. and cargo area (frames 39 to 40) remains. Bulkhead at frame 40 shall be watertight.

Cut-outs shall be made in maindeck for the cargo hatches and the double deck space, previously used for water ballast, remains as a void space.

The centreline longitudinal vertically corrugated bulkhead and stool, all to be removed.

The existing tank top to be removed and replaced with new tank top at 3.0m above base line and the double bottom to be strengthened by longitudinal girders, generally at 850 mm spacing.

The cargo area will have eight (8) transverse vertically corrugated bulkheads on stools at bottom, whereof three (3) of the existing bulkheads are relocated and two (2) remain as is, while the three (3) additional bulkheads are constructed from the removed centreline longitudinal bulkhead. All existing transverse stools to be replaced.

The existing inner shell remains as is. New longitudinal hopper side plates to be added at bottom side and tank top. Existing longitudinal hopper plating is to be removed.

New topside tank with longitudinals and transverse webs to be added below the inner deck plating.

Doubler plates to be fitted to existing main deck and upper ship side.

Permanent means of access shall be prepared for the double side space in the cargo area as necessary.

Mechanical ventilation arrangement and CO_2 fire protection system to be arranged in all cargo holds in accordance with class/ statutory requirements.

The conversion of the vessels and the selection of equipment to be installed shall be governed by the following considerations:

Environmental protection
Efficient usage of structural materials
Ease of maintenance and inspection

<u>PRINCIPAL PARTICULARS, CAPACITIES & REGULATIONS</u>

Principal dimensions	**Before conversion**	**After conversion**
Length over all	228,60 m	228,60 m
Length betw. p.p	118,70 m	118,70 m
Rule Length acc ICLL	220,10 m	220,10 m
Breadth moulded	32,24 m	32,24 m
Depth Main deck (mld.)	21,60 m	21.60 m
Draught SWL	16,06 m	14,50 m

Capacities	(100%) m3	(100%) m3
No's of cargo tanks/ holds No's of slop tanks No's of water ballast tanks Cargo tanks/ holds Water Ballast	6 2 14 90439 28755	9 0 14 appr. 87600 appr. 33000
Cargo Hatches (size) Side rolling/ Hydraulically driven	-	 13.50m x 14.85m (L x B)
Deadweight	m-t	m-t
At mld draught 16.056m At mld draught 14.500m	abt 84000 -	- abt 71000
Tonnage (International)		
Net tonnage (NT) Gross tonnage (GT)	19867 43398	20975 44289
Equipment Letter	P	P
Freeboard type	A	B

Note:
Final capacities have to be established and verified after the conversion.
The deadweight to be determined as the difference of total displacement of ship at the assigned draught and trim and the lightship weight.
The total displacement to be calculated including shell and all appendages.

Cargoes:

The vessel to be designed for the carriage of the following cargoes:

IMO Class: 4.1, 4.2, 4.3, 5.1, 7, 9 and MBH, and BC Code Group C cargoes + Ore & Grain (DnV Part 5, Ch.11, Sec.2)

Max density of Cargo is 3.0 t/m^3
New Class notations:

The vessels will be classed by DnV and Class notations are:
DnV Q1A1 Bulk Carrier ESP, BC-A, IB(+), Holds 2, 5 and 8 may be empty, E0, DG-B, SCC

ESP	Enhanced Survey Programme
BC-A	designed to carry dry bulk cargoes of cargo density below/above 1.0 t/m3 and above with specified holds empty, at maximum draught
IB(+)	Inner bottom strengthened for Grab Loading
E0	Unattended Machinery Space
DG-B	Arranged for Dangerous Solid Bulk cargoes
SCC	Meaning that the ship is built in compliance with the subdivision and damage stability requirements in accordance with revised SOLAS Ch.II-1 (IMO MSC194(80))

Rules and Regulations:

The vessel should be designed, constructed and equipped in accordance with the international rules, regulations and guidelines, including amendments, as relevant, being current as of date of keel laying or similar stage of construction:

Rules and Regulations of the National Authorities
International Convention for the Safety of Life at Sea. SOLAS
International Convention for Pollution from ships, MARPOL
International Convention of Preventing Collisions at Sea
International Convention on Load Lines
International Convention for Tonnage Measurements
IMO/ISO/ILO/IEC regulations and guidelines as relevant
Suez Canal Regulations, including tonnage measurement
Panama Canal navigation regulations, including tonnage measurement
Australian Marine Orders, part 32 (Cargo and Cargo Handling – Equipment and Safety Measures)
IACS unified requirements concerning bulk carrier safety
USCG Rules and Regulations for Foreign Vessels operating in the Navigable Waters of the United States
EU regulatives

Certificates:

All relevant certificates and approvals from Class and Authorities for unrestricted trade to be paid for and supplied in triplicate, one (1) original and two (2) copies, by the Yard.

2 - HULL
STEELWORK

General

The conversion, with respect to the structure will affect the cargo area only.

Following main items to be performed:

Pre-fabrication of tank top, new hopper side plating and topside tank with structural members
Coating of pre-fabricated members

Docking of vessel
Re-arrange water ballast pumps to forward part of the engine room
Removal of all cargo deck arrangement
Cut-outs in main deck for new cargo hatches
Removal of bulkheads and tank top
Fitting of tank top, hopper side plating and additional inner structure in double bottom
Fitting of doubler plates/straps on main deck and upper side
Fitting of top wing tank with internal structure and stringer in double side
Fitting of additional longitudinal stiffeners in double side
Re-fitting of corrugated part of transverse bulkheads and fitting of additional bulkheads. All transverse bulkheads to have new lower stools
Watertight division of WB tanks to be relocated in accordance with new tank plan
Fitting of hatch coamings and cargo hatches
Fitting of new air- and sounding pipes in water ballast tanks where appropriate
Cleaning of existing deck & side double skin water ballast spaces, double bottom ballast spaces and cargo tanks
Surface preparation for coating in way of existing and new structure
Re-coating of ballast tanks and cargo holds as necessary, stripe coating of welding seams
Implementation of required cargo monitoring instruments
Inclining test/ Final stability calculations (both intact and damage)
Production of new calibration/sounding tables for all affected tanks
Revision of documentation and certificates

The existing hull to be opened (cut-outs) in main deck in way of new cargo hatches. Centreline longitudinal corrugated bulkhead on stool, tank top, lower hopper side plating, and slop tank bulkheads all to be removed. Complete new sections of tank top and girders in double bottom to be fitted. New lower hopper side plating and topside tank sections with sloping plates and stiffening members to be fitted on both sides, forming the new inner skin for the water ballast tanks between ship side and the inner skin. Existing double deck space shall be closed at the top of the double sides, P&S, and at the openings for cargo hatches and thereby form void spaces. Doubler plates shall be fitted on upper deck and upper part of sides (sheer strake).

The longitudinal elements in the new structure are to be sufficiently supported by the structure at forward and aft end, with modifications of the existing structure and introduction of new structural elements as required in accordance with strength calculations and Class requirements.

The vessel's new structure to be of all welded steel construction.

Normal strength mild steel - grade A shall be used as construction material, except where otherwise specified or required by Classification Society.

New transverse corrugated bulkheads and lower stools to be built of high tensile steel NV-36. Doubler plates shall be of same material quality as existing plating.

The new structures to be designed placing emphasis upon ease of construction, access for inspection, maintenance, coating and repair of the structures.

Permanent means of access in double side C/D to be prepared for in way of cut-outs in existing plate framing and necessary walkways and ladders to be provided in accordance with authority requirements.

Special care shall be taken at design and fabrication stages of the new sections for minimizing the risks of cracks.

A work procedure to ensure proper alignment / connection of vital constructional elements to be made, and to be approved by the Owner.

Steel weight estimates:

Existing steel to be removed/ scrapped: Abt. 2700 tonnes
New steel built-in: Abt. 4700 tonnes
New high tensile steel built-in: Abt. 355 tonnes
Steel to be removed and refitted Abt 490 tonnes
Hatch covers steel weight Abt 430 tonnes

Scantling Criteria for new hull sections:

Scantlings of the new hull sections to be in accordance with the requirements of the Classification Society.

Midship section scantling Section Modulus and Moment of Inertia to be based on the most severe of following sagging and hogging moments:

Ballast condition, departure or arrival including ballast exchange sequences
Minimum Class requirement

All new steelwork shall be of full scantling with no reduction for coating allowances or corrosion control.

All new wing ballast tank sections shall be strengthened for partially filling, where sloshing effects are considered

Tank top to be dimensioned for a UDL of approx. 26 t/m^2 in all holds, i.e. cargo holds completely filled with bulk of density 1.3 t/m^3.

The scantling calculations to include:

Midship section analysis
Longitudinal strength calculations.
Local strength calculations according to Class rules

Framing / Stiffening:

The double bottom to be re-built with new longitudinal girders added at a spacing of 850mm, extending from existing lower longitudinal frame members to the new tank top. New transverse floors to be added, extending from top of existing floors to the new tank top

The top wing tanks to be built with longitudinal stiffeners supported by transverse frames.

Preparation of new steel constructions

The new tank top- and double bottom structure, and the new longitudinal upper wing tank structure to be pre-fabricated, with over measures, and completed as far as practical before the vessel is docked for rebuilding.

Special consideration to be given:
with regard to plate quality and thickness
to coating in existing cargo skin tanks when cutting out openings in existing structures

Doubler plates/straps to be fabricated in accordance with Class requirements to ensure satisfactory weld connection between straps and existing structure.

Cut-outs in strength members for piping etc. shall be fitted with stiffeners for strength compensation, and the edges shall be grounded smooth.

All openings shall have rounded corners.

In all tanks, particular care to be given to provide good drainage. Slots, notches, air and drain holes to be provided.

Clips for staging, brackets, lifting eyes, etc. required for construction purposes, to be removed and scars grounded down and undercut built up prior to grit blasting and coating.

All parts of the new structures to have ample access for maintenance and corrosion protection.

Structure in tanks should be arranged placing emphasis upon ease of access for inspection, maintenance, coating and repair of the structures.

Before painting, all temporary eye plates, lugs, brackets, launching clips etc., connected to the new structure to be removed and scars ground down and well cleaned.

Welding

All welding to be of best practice and shall be in conformity with approved Classification drawings and to approval by the Classification Society surveyors.

Welding procedures in general covering edge preparation, alignments, undercutting pin-holes, gaps, welding sequences, permisables defects, welding consumables inspection, etc. shall be submitted to, and approved by the Owner before commencement of work.

Welding:
automatic welding to be used as far as practicable
to be carried out round the ends of all lugs
to be completed to the greatest possible extent before blasting of welding seams and painting
to be executed in a sequence giving minimum stresses and deflections of the hull structure
double continuous fillet welding normally to be used throughout

Watertight lugs to be fitted at both sides of all beams / stiffeners penetrations in watertight bulkheads / decks.

Rust and loose mill scale to be removed from surfaces before welding.

Accuracy in construction

Steelwork fabrication tolerances for all new steel work shall not exceed those stated in IACS Shipbuilding and Repair Quality Manual.

Particular attention should be paid to:

Completion of inner skin structure within the tolerances
Fairness of panels and structural joints
Flatness of flat panels

Alignment and construction tolerances of and between pre-fabricated units to be within the IACS limits. Misalignment in excess of those limits to be dealt with by part or complete renewal and not by fairing.

Markings

Hull markings shall be corrected and renewed as required by the conversion.

New freeboard marks to be marked on both sides midships.

All new ventilation piping, manhole hatches and sounding pipes to be marked with tank number by welding seams.

MATERIAL PROTECTION

General

The new structure is to have a painting system.

All painting and coating work shall be done in accordance with the instructions and recommendations from Owner and paint manufacturer regarding:

Method of application
Climatic condition, temperature, humidity
Surface preparation
Overcoating time, maximum and minimum
Curing time

The Builder is to arrange technical supervision by the paint manufacturer, contractor or applicator during preparation and application.

Owner's and paint manufacturer's representatives shall have full access to inspect all phases of the painting work.

Technical supervision and guarantee to be provided by paint manufacturer and the Builder during preparation and application.

Guarantee regarding the protection by, and durability of coating of minimum five (5) years to be provided by the Builder and the paint manufacturer.

Paint specification and surface preparation to be of high standard and in compliance with SOLAS and MARPOL with respect to toxic and environmental requirements.
Prior to fabrication, all steel work to be shot-blasted.
All dry film thicknesses shall be as recommended by supplier for a five (5) year system.

Surface Preparation

All steel materials are to be grit blasted using steel grit, to SA 2.5 in accordance to ISO 8501-1 standard and primed with 20 microns zinc shop primer, according to Builder’s practice and compatible with subsequent coating.

Surface treatment is to be given to new structure, welds, pinholes, sharp edges, undercuts, slag, new pipes etc.

All welding seams, scallops, cut-outs, cut edges etc to be smoothened and cleaned prior to coating.

The following steelwork to be performed:

All weld spatters and slag to be removed
Porosity and pinholes in welds to be repaired (re-welded)
Undercuts and scars, roller indentions and other surface irregularities deeper than 1 mm to be welded and grinded. If less than 1 mm grinded smooth.
All rough section butts and rough hand welds to be ground

Sharp extrusions to be grinded smooth
All free edges of steel members by gas cutting and sharp edges, to be smoothly grinded and rounded to radius of the edge of approx. 2 mm, and approx. 3 mm in coated tanks, or to a radius acceptable to paint manufacturer.

Paint Application

All surfaces at the new structure to be cleaned of oil, fat, salt, dust, etc., and be clean and dry before application of any coating. Surfaces that could have been contaminated by salt deposits to be washed with fresh water before preparation of coating.

Preparation and coating application will be in paint manufacturer's approved atmospheric conditions and contractor to provide appropriate equipment to this end.

Pre-fabricated constructions shall be painted before installation.

Minimum and/or maximum overcoating time of paint application to be in accordance with paint manufacturer's recommendation.

Two stripe coats to be applied as part of the scheme in water ballast tanks, at least according to paint manufacturer’s recommendations.

Inspection

All new steel structure and surfaces shall be inspected and approved before application of any paint.

After final coating the total dry film thickness to be inspected and measured for acceptance by Builder, Owner’s Superintendent and paint maker's supervisor. The final inspection for acceptance should be carried out by the representatives from the Owner, Builder and paint supplier, and acceptance to be duly signed by all parties.

Painting schedule - External

The vessel shall have new anti-fouling according to agreement between Builder and Owner.

Painting schedule - Internal

Installed equipment to be protected during painting.

Painting / Coating with final thickness of more than 250 microns to be applied with at least 2 coats.

All fittings inside tanks to be coated as the rest of the tank.

Internal painting:

Cargo holds	1 x 50 micr. Zinc Epoxy primer
	1 x 150 micr. Epoxy system
	1 x 150 micr. Modified Epoxy finish

Ballast tanks 2 x 200 micr. two-component Modified

Epoxy, light colour
All ballast tanks to be stripe coated

Brand of coating to be agreed on between Owner and Builder.

3 – EQUIPMENT FOR CARGO

Manhole hatches for ballast tanks

To obtain access to wing water ballast tanks new manholes in main deck shall be prepared and installed at aft and forward end of each tank, including a watertight trunk through the C/D of the inner deck.

New manholes to top wing water ballast tanks in cargo area to be fitted with a low coaming, 100 mm in height.

Manhole covers to be fastened with stainless steel bolts and nuts.

Access hatches for cargo holds

Access hatches shall be prepared and installed at aft and forward end of each cargo hold, including a watertight shaft through the C/D of the inner deck.

Cargo hatches

Nine (9) weather-tight hatch covers of transversally side rolling type, arranged on high hatch coamings on the weather deck to be arranged on high hatch coamings on the weather deck and operated by means of external hydraulic motors.

Clear opening of hatches No. 2 - 9: 13.50 x 14.85 m (length x width).
Hath No.1 to be designed separately due to irregular geometry.

The hatch cover of each hatch to consist of one cover rolling on port side and one rolling on starboard side. The hatch covers to be designed with flat top plating and to be of double skin, box beam construction / pontoon type.

The hatch covers to be of HS steel construction.

UDL Cargo timber load: 1.75 t/m² (Weather load only).

Hatch cover no.4 to be dimensioned as top of water ballast tank, and to be fitted with ventilation pipes with air breather or PV valves, which should avoid vacuum, overpressure and entering of water into cargo hold.

Cargo holds ventilation

The cargo holds to be ventilated by natural supply and mechanical exhaust system with capacity according to authority requirements.

Fixed fire extinguishing

A fixed carbon dioxide (CO_2) system shall be installed in all cargo holds according to authority requirements.

Cargo and Ballast monitoring and control

Monitoring of all cargo handling, operations and monitoring of ballasting, cleaning, bilging and bunkering, all tank levels and continuously monitoring ship's stability including trim, heel and draughts, to be arranged at cargo control station in the deck office.

One (1) micro-processor based cargo monitoring and loading computer including two (2) color screens capable of displaying 2 different presentations simultaneously, two (2) keyboards and printer to cover the following functions:

Bilge alarms in all cargo holds.
Mimic diagram for all WB, Bilge and FO. systems.
Remote control of all valves in WB and bilging systems, indicating open / closed included on the mimic diagram.

Input from tank level monitoring system to be input to stability module. The system to provide a continuously monitoring of the ship's stability and strength, such as trim, daft, deadweight, bending moments, sheer forces, grain trimmed and untrimmed, etc.

Loading Computer

The on-board loading computer to be upgraded according to revised stability calculations and to new calibration tables for ballast tanks.

4 – SHIP EQUIPMENT

Mooring equipment

Two (2) existing combined windlass / mooring winches in cargo area to be re-located.

Some of the mooring fittings forward to be relocated including the fore mast.

All towing equipment according to Class requirements.

5 – EQUIPMENT FOR CREW AND PASSENGERS

Ladders and platforms in water ballast tanks

Ladders are to be provided fore and aft of each tank in connection with access manholes on main deck. Ladders to extend from main deck to tank top. Platforms are to be arranged in accordance with class requirements.

Ladders in cargo holds

Ladders are to be provided fore and aft of each cargo hold in connection with access hatches on main deck. Ladders to extend from main deck to tank top.

8 - SHIP SYSTEMS

Ballast system

Ballast pumps two (2) pcs. 1100m3/hr and ballast water ejectors two (2) pcs 300m3/hr to be relocated from ballast pump room frame 39 - 45 to forward part of engine room. All pipe work to be modified accordingly.

Water ballast ring main line including branch lines and stripping branch lines (stripping branch lines of GRP material) from frame 39 - 239 to be rearranged i.w.o. new steel structure under tank top of cargo holds.

Bilge system

Bilge wells with arrangement for satisfactory drainage when bulk cargoes are carried to be arranged on port and starboard side aft in each cargo hold.
Two main bilge lines to be located in double bottom ballast tanks. Remote operated branch line valves to be located in double bottom ballast tanks. Port and starboard branch lines to be connected respectively to port and starboard main lines.
Main cargo bilge lines to be connected with shut off valves to bilge pumping system in machinery space.

Fire and deck wash system

Fire main line and hydrants to be re-arranged on main deck according to authority requirements.

Foam fire extinguishing system

The foam system is no longer required and foam main line with valves and accessories to be removed from main deck. Foam tank with pump and accessories to be removed from machinery area.

Air pipes for Ballast tanks

Air-/vent pipes from re-built water ballast db/wing tanks in cargo area to be of suitable size and re-arranged above main deck, with outlets located above damaged waterlines and inward location according to damage stability calculations

Air pipes shall be fitted at the highest part of the tank and shall be self drained under normal trim conditions and to have float-type closing devices.

Sounding pipes for Ballast tanks

Where appropriate existing sounding pipes for water ballast tanks shall be used.

If required, new sounding pipes of suitable size to be prepared and fitted for all wing-/double bottom water ballast tanks.

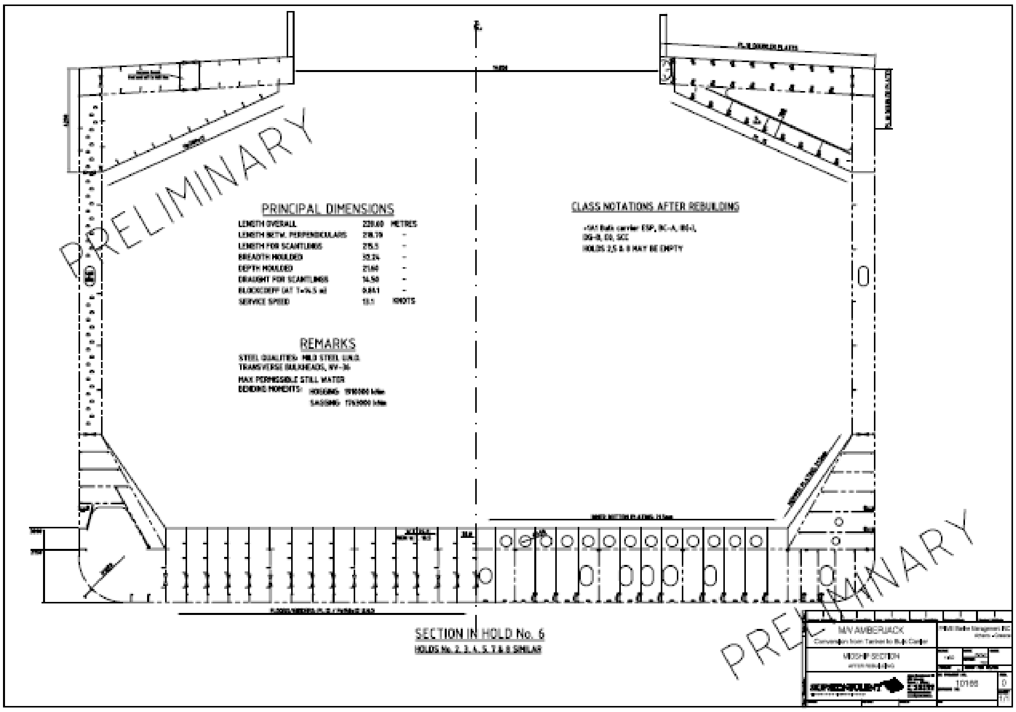
Sounding pipes to be arranged as straight as possible. Exact x-, y-, and z- coordinates for all sounding pipes to be made available.

Welded sleeves shall be used for sounding pipes passing through deck and joints.

Sounding pipes in cargo area, extending above deck to be fitted with stainless steel cap. Threaded collars of stainless steel to be fitted on upper end of sounding pipes.

All sounding pipes to be laid to the bottom of tank and to be self-clearing with gradual slope over full length. End parts to be fitted with striking plate / doublers for protection of bottom / shell.

All supports for sounding- and air pipes to be of angle bar and bolts to be secured by welding.



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