SHIPYARD DESIGN AND CONSTRUCTION

FOR ENVISAGED LIFE TIME

PRESENTED BY:

ODENSE STEEL SHIPYARD LTD.

AT

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ABSTRACT

Shipyard Design and Construction for Envisaged Life Time

Odense Steel Shipyard delivered the world’s first double hull VLCC in December 1992 followed by 5 sistervessels immediately after. Odense is thus the only European shipyard, which so far on a commercial basis has designed and built a series of double hull VLCC’s based on the state of art in the early 1990’s.

Odense’s unique access to real service experience from the Owner, our parent company A.P.Møller, place us in a very good position to comment on the vessels’ structural performance so far, and thereby sharing our knowledge and experience according to the objective of this conference.

At Odense, we were and still are strong believers in the intelligent use of HTS, with proper details, small and exact tolerances and correct application of inspection friendly, light coloured tank coatings. In this way we believe we can provide an Owner with a double hull VLCC having an overall transport economy which is better than a heavier design using more ordinary mild steel and relaxed structural details.

An accumulated service period of more than 40 years and for the first vessel more than 7½ years of operation we believe, is supporting this design philosophy.

This paper describes how we at Odense Steel Shipyard would design a new double hull VLCC based on the lesson learned and experience gained - here, at the beginning of the new millenium.

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1. INTRODUCTION

- Odense Steel Shipyard built the world's first double hull VLCC and delivered it in December 1992. In total 6 sistervessels of the so-called E-class were delivered from December 1992 to September 1995.
- Total time of operation for the six vessels up to now is ∼40 years and ∼7½ years for the first one.
- All six vessels have continuously been in world wide service and presently four are operated by Maersk and two are in bareboat charter with BP.
- The vessels are built to Lloyd's Class. Principal steel structure is also approved by ABS and DNV.
- About 70% of the steel applied is HTS36 and between 800-1000 tonnes steel above Class' requirement has been introduced in specific areas to obtain a safe and sturdy design.
- Odense Steel Shipyard has followed the vessels' performance continuously over the years, partly by detailed feedback from the Owner - our parent company - partly by inspections performed by the Yard's own engineers.

So what have we learned about the structural performance of these six sistervessels designed for an envisaged life time beyond 20 years, and how would we apply our knowledge and experience in designing a new double hull VLCC today?

2. STRUCTURAL DESIGN INCLUDING MATERIAL SELECTION - MILD STEEL HIGHER TENSILE STEEL

2.1 Structural Design History

The design of the E-class VLCC commenced in the late 80's as an ordinary single hull tanker, but was in parallel with the drastic legislation changes following the Exxon Valdez accident transforming, first into a double bottom VLCC and finally into a prototype double hull VLCC, fulfilling the final and still valid legislation.

No specific Rules existed for such a concept then, and the structural design was developed in close cooperation with Lloyd's Register based on their existing and changing Rules, comprehensive direct calculations and experience coupled with sound engineering judgement.

During the design period we were also in continuous contact with USCG in Washington to ensure that we always were on the right track in this rather turbulent period.

Since the 60's, when higher tensile steel was introduced in the Classification Rules and the rolling mills could deliver HTS-quality plates to a reasonable cost, Odense has used HTS36 in the designs.In the early VLCC's up to 30% HTS36 was placed in deck, bottom, sides and heavier sections. In later structural designs for all shiptypes we generally select HTS36, and now also HTS40, whereever it is beneficial, and always with proper precaution and due respect to the latest state of the art.

This philosophy was also applied for the structural design of the E-class VLCC, where ∼70% of the steel became HTS36. It was even contemplated to use HTS40 in certain areas with heavy plate thicknesses, but we abandoned that, at that time, rather premature idea again.

The optimum tank arrangement and corresponding main structural arrangement for a double hull VLCC with clean cargo tanks without superfluous elements and easy to clean and inspect results in designs rather similar to the E-class, which may be seen by comparing with other recent VLCC's. Such designs, without increased ballast capacity arranged amidships, will experience relatively high hogging and sagging still water bending moments in about 90% of their life time.

For the E-class we therefore increased the LR-required section moduli of inner bottom and bottom longitudinals with ∼30% and ∼50% respectively for the extent considered necessary. Other increases were made on sideshell plating (+2mm) and selected areas of transverse elements. All higher tensile steel were taken as HTS36 even where HTS32 according to the stress levels might have been applied.

Based on extensive direct calculations and studies of behaviour of single bottom VLCC's with up to 6 meters spacing between webframes, we found it possible to keep our preferred spacing of ∼5.3 meters between main transverse elements, i.e.: double bottom floors and webframes.

In order to reduce number of elements and thereby possible stress concentrations and later coating performance risks the spacings of longitudinals were selected between 940-1000 mm, even that such a solution tend to increase the hull weight compared to designs with smaller spacings.

It is stated by experts, that the average yearly corrosion rate in inerted cargo tanks is ∼0.1mm. As plates according to the Class may be accepted with an under thickness tolerance of ∼0.3mm and estimation of diminution of hull plating and structure will be based on the nominal thickness, it was and is important for us to ensure that such under tolerance do not exist, if it exists the disadvantage to the Owner will be up to 3 years on such plates.

In total we have introduced between 800-1000 tonnes steel above Class' requirements for each of the E-class VLCC's. This was done in close cooperation with the Owner's technical department in order to obtain a safe and sturdy ship.

The latest ships in the series were delivered after ShipRight and Enhanced Scantling Notation were introduced by Lloyd's, and due to the design and construction of the vessels they obtained these, and it was confirmed that the remaining ships in the series also could obtain the new notations.

2.2 Structural Operation History

The structure of all six vessels has up to now on the whole functioned without problems as envisaged and passed all surveys without remarks.

Since delivery routinely inspections of the structure have been carried out by the crew, and we are informed about their findings, and can assist immediately if needed. If something is found that may improve the operational performance, we will be involved too and introduce the agreed and approved modification as soon as possible on the following newbuildings in the series. For example it was found that extra and slightly modified drainholes were needed in some brackets on the tanktop in the center cargo tanks to speed up the latest part of the unloading procedure on the first vessel in the series, and the next were modified as requested.

Recently some fractures of different depth was found in the cargo tanks P+SB, at the hopper knuckle weld toe at the innerbottom in way of the main transverse elements behind.They have now all been repaired, and the weld toes have been modified throughout to increase the fatigue life of this detail suitably. Will be discussed further in part 3 "Fatigue Aspects and Structural Details". Repairs, modifications and the necessary analyses were carried out in close co-operation between Owner, Classification Society and Builder.

There have been some local buckling problems with webplating of primary elements in the forepeak region for the first vessels in the series, which were rectified by adding a few extra stiffeners and closing some openings. After the Rules for Structure Forward were modified according to the Industry's experience and guidelines were developed for the master regarding draft vs. filling rate of the forepeak to avoid unacceptable slamming forces at light conditions, nothing further has been observed.

We also found that the anchor bolsters, especially when placed relatively low, may experience unforeseen pressures from the sea, and must be designed and especially supported accordingly to avoid damage of the supporting structure.

2.3 Structural Design for a New VLCC

The main structural concept for a new VLCC will in our opinion still be very similar to the E-class and only minor changes will be introduced to better exploit, for the benefit of both Owner and yard, all the new installations we have got during the last 10 years: Robotized stations for welding of flat and curved blocks, laser cutting and welding now being tested and applied in specific areas, new 1000 tonnes more flexible gantry crane etc.. Minor details, cruxial for even better fatigue performance, will be designed according to the latest state of the art, it is after all 10 years ago we designed the E-class, and the world has in the meantime improved the knowledge about this discipline much.

To increase the fatigue performance of the E-class all sections above 250 mm depth in the cargo region were either slabs or symmetrical T-bars and drain holes were specially arranged to avoid built-up of residue on the horisontal ones. According to feedback from the Owner, it would however be beneficial for the cleaning process of the bulkhead longitudinals in the cargo tanks to avoid such T-bars, while there are no problems in the ballast tanks. For a new design we will therefore change to unsymmetrical T-bars or L-bars where improved cleaning is requested ensuring that the required fatigue life still is obtained otherwise.

To obtain an optimal structural design it is further important that the Owner at an early stage specifies if full flexibility for the following load cases are required or not:

- Filling rates for all tanks in the cargo area - to cater for corresponding sloshing forces and extra steelweight involved
- Unsymmetrical loading of all cargo tanks abreast for arbitrary level differences or within certain limits - this may also have a notable influence on the steelweight

2.4 Design Process

During the last three years Odense has put great efforts into the development of a new and innovative ship design tool. The new and improved technologies, which is being developed, will enable us to make a design in shorter time, which evidently will be of importance for both Owner and builder.

The fast modelling capability combined with ability to control the status of each ship component will enable the designer to create a quick but adapted image of the ship including structure, major piping systems and equipment at the time of the contract.

The graphic representation and walk-through capabilities will offer the Owner a unique possibility to evaluate the model and to get important influence during the early design period.

The immediate impact of these features is to cut down the design period through timely decisions on a much improved foundation. This shorther period may be utilized to evaluate several possible solutions and/or reducing the lead time of the vessel, impacts beneficial for both Owner and builder.

3. FATIGUE ASPECTS AND STRUCTURAL DETAILS

Since the design of the E-class we have experienced an explosion in the development of software specially aiming at structural design assessment and fatigue design assessment in particu- lar, which will allow us to analyse the expected fatigue performance of selected details better and much quicker than 10 years ago

Besides the fatigue performance experience we now have from the E-class, we also, together with very capable partners, have participated in a highly interesting and informative Brite-Euram project over the last four years titled "Fatigue Based Design Rules for the Application of High Tensile Steels in Ships", so we are very well prepared and equipped to do an even better VLCC-design today.

<u>We will especially focus on the following points</u>:

- Discuss with the Class(es) and follow their requirements/advice for obtaining FDA, SafeHull or similar notations.
- Manufacture with the fine tolerances obtainable with todays design and production methods, (Precision Engineering), to avoid time consuming adjustment work in shops and especially in the building dock..
- Reduce number of stress concentrations by reducing number of elements, even if this is not weight-optimal. For instance maximize spacing of transverse webframes/double bottom flooring and longitudinals in deck, bottom, innerbottom and on longitudinal bulkheads.
- Arrange "fatigue friendly" T-bars wherever possible.
- End connections of minor elements (stiffeners and brackets etc.) in general with soft toes and keyholes.
- Where a secondary member is carried through a primary member (f.ex. a side shell longitudinal through a transverse webframe) we will in general apply the slot method for cut-outs and thereby avoid collars and clips.
- Further where secondary members intersect primary members, achieve the required connection area by welding to the webplate only, if at all possible, and thus avoid any additional stiffener/bracket connections with unnessary stress concentrations.
- Arrange the block division such that block butts, and especially grand block butts, are kept away from highly stressed areas

With todays fatigue tools it is relatively fast do a detailed analysis of any critical detail. The fatigue life of the hopper knuckle weld toe at the inner bottom were calculated with the latest available methods by Lloyd's Register, and the results given in the table below clearly illustrates the drastic influence of just a different weld profile:

No.	Weld profile	Calculated Fatigue Life (years)
1	Normal weld	4.3
2	High weld (flange angle 90°)	3.0
3	Low weld flank angle and concave weld profile (radius 13.5mm)	22.2
4	Low weld flank angle and concave weld profile (radius 35mm)	59.5
5	Low weld flank angle and concave weld profile (radius 35mm from 40° point	63.3

Calculations are based on a the trading pattern known and expected for the E-class vessels.

4. COATINGS AND CORROSION PROTECTION

4.1 Coatings

The quality of the coating in the water ballast tanks has a particularly high priority in the view of both Owners and builders. When the ship first is finished and put into service it is rather difficult and time-consuming to repair possible coating defects, and with a coating area of about 220.000 m² the involved costs are exceedingly high.

At Odense, it is therefore the coating of the water ballast tanks that is decisive for the working flow in the paint shops and also for the VOC-emission (Volatile Organic Compounds) limitations required by the environmental authorities. To obtain the optimum flexibility it is consequently of utmost importance to choose proper coating systems and procedures, and structural design without compromising the quality.

To illustrate the cost differences the following recent relative figures per sq.m.might be illustrative:

• Coating applied at the builder	100
• Repair in WBT on board	400

4.1.1 Stripe Coat

Experience from the E-class has shown, that by increasing the amount and control of stripe coating of difficult sprayable areas, we have been able to raise the quality substantially, and the pay back clearly confirms that the extra effort is worth-while.

The concept has been
- Paint specially formulated for brush application of stripe coating
- Colour of stripe coat different from the full coat
- Control after stripe coating
- Careful choise of equipment and continuous improvement

4.1.2 Steel Quality

Experience has shown us that many "steeldefects" can be eliminated by careful stripe coating, for example free edges not rounded by grinding, rough surface weldings and welding spatters, but the stripe coating procedure must be strictly observed. Then we dare say that a certain degree of minor "defects" in the surface quality could be tolerated, also for extended guarantee periods of up to 10-15 years.

The major problems in our opinion are welding undercuts, edge burrs and poorly made start/stops of weldings. A limited amount of such defects may be repaired in situ but generally they are not tolerated as they will result in rust runners after few years of operation

It is evident, that correct made welding quality without defects and rounded free edges will facilitate the subsequent coating job, and thereby secure a long life for the surface protection.

It is also worth to bear in mind, that properly made welding do not need to cost extra, while grinding and stripe coating indeed requires extra manhours.

4.1.3 Film Formation

In our experience one of the most important parameters in judging the lasting quality of the coating applied is the regularity of the coating's film formation. On the contrary one will find that the coating system can not live up to the expected life time, even if the required film thickness is amply fulfilled, but the film formation is irregular.

4.1.4 Traffic Areas

Problems is now and then found in "traffic areas" used during the building period and in areas where scaffolding is applied. These problems are due to impurities caught in the paint film, but they are not always of any significance for the corrosion protection as they generally are situated in the surface of the coating. They may, however, disturb an otherwise positive impression during later inspections on board.

The problems can to a great extent be avoided if the structure is designed so lifts may be used to reduce the number of "traffic areas".

4.1.5 Dry Film Thickness

Dry film thicknesses have to suit the chosen paint products i.e. the formulated dry film thickness for the product.

During many years we have used a two-coat system of 2x300 my in water ballast tanks, while erection butts are treated with a three-coat system of 375 my. Experience shows that dry film thicknesses below 220-200 my may become critical.

For a new VLCC we will still choose a two-coat system, but we expect that the total dry film thickness will be increased, partly because coating products with increased amount of solid matters,due to te enviroment, will be applicable and partly as a safeguard for future prolonged guarantee periods.

4.1.6 Design

Access conditions in the water ballast tanks of double hull VLCC's are normally good and cause no problems for the painters. We will however aim for a further reduction of the number of structural elements and arrange for good access conditions without use of scaffolding, wherever possible.

4.2 Supplementary Corrosion Protection

All water ballast tanks in the E-class are protected by 10 kg zinc anodes dimensioned for minimum 5 years life time at 50% ballast time and a capacity of 5mA/m². A new VLCC will be equipped similarly with the addition of an impressed current system for the outside hull.

5. FABRICATION AND WELDING PRACTICES FOR ENHANCED VESSEL LIFE

5.1 Tolerances

The importance of being able to work with fine fabrication tolerances can not be overestimated in our experience. Already 10 years ago, when we planned how to produce the E-class series, we decided to fabricate all sections above 250 mm depth as T-bars, and to do it ourselves to achieve the level of accuracy needed to apply the slot-method, especially for double bottom blocks. With this method we are able to push sections (e.g. bottom and innerbottom longitudinals) through the slotted cut-outs in 3-6 primary members (e.g. floors) already mounted on a panel and afterwards finish all welding by robots. It "only" requires the necessary tolerances which for a typical T-bar is: Height ±0.9mm, for the slot: Gap floor/T-bar 0 to -2.0mm and if a supporting stiffener is fitted to the transverse member the gap between stiffener and T-bar should be between -1.0 and -2.0mm.

By such Precision Engineering we obtained better quality, better coating preparation, reduction in number of stress concentrations, better welding quality and possibility to make uniform and high quality robot weldings not to forget the corresponding reduction in number of manhours and increased throughput.

5.2 Fabrication and Welding

Since the E-class we have pursued the Precision Engineering philosophy on the container vessels we have built in the meantime. New installations such as robot welding stations for plane and curved block welding will be key units for a new VLCC too.

Our welding and cutting equipment is constantly being modernized and we have already for some time been testing laser processes in our shops for high quality cutting and welding. We have today approved methods for laser welding in selected areas.

In our aim to further improve the fabrication processes at Odense, we have in many years looked for a method to reduce the heat input and corresponding shrinkage effects by welding. Laser welding seems to be the answer, and we are deeply involved in projects, studies and tests to find out how exactly to achieve the required quality every time, so this method can be generally approved and applied in line with other welding methods.

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Typical heat input figures for laser vs. other welding methods are :

1) Panel welding 15-25 mm thickness

- one sided submerged arc welding 8.0-12.0 MJ/M
- laser beam welding (25 kW) 1.0- 1.5 MJ/M

2) T-bar and stiffener welding with typical throat thickness 3.5-4.0mm

- submerged arc welding double fillet 3.0- 3.5 MJ/M
- mig/mag double fillet 1.3- 1.7 MJ/M
- laser beam welding double fillet (2x6 kW) 0.3- 0.4 MJ/M

The opportunity for further improved tolerances and Precision Engineering seems therefore evident

Important changes in design and fabrication methods could be expected at Odense when general use of laser welding and cutting become possible e.g.: Fabrication of 1) L-bars with same high tolerances as the T-bars we already make and 2) recurrence to fabrication of high dimension flat panels, butt welded by lasers and sections (longitudinals) fitted by the same method, all with so high dimensional accuracy that primary supporting members (webframes, floors etc.), with slotted cut-outs, can be pulled into correct position without stucking problems.This has so far only been possible with big cut-outs, which required fitting of clips and/or collars.

6. INSPECTION AND ACCESS

In view of the enhanced requirements for in-service inspection and the huge areas to inspect on a double hull VLCC, especially in the coated ballast tanks, it was decided to apply a light colour coating here on the E-class. This has highly improved the quality and ease of visual inspections both during construction and in service, and is now a general Odense standard, which of course will be repeated on a possible new VLCC.

With Odense's special relationship to the Owner of the E-class, it is not surprising that we co-operated closely from the start of the design cycle to obtain satisfactory conditions for inspection and access. The Owner has many years of experience with operation of VLCC's. This and our aim to combine strength and access elements and also exploit these for access during the building period to reduce staging, resulted in the following arrangement:

1) Ballast tanks

- In double bottom access to all bays through ample openings. Special escape routes for stretcher with injured person leading to lifting positions to upper decks in each end of the tank. The condition of the coating and double bottom structure with few and simple elements is thus easy to inspect.
- In double sides stringers in two levels throughout, where openings are fitted with safety grids or protected by safety rails. Sloped ladders in each end of tank allow you to inspect condition of

coating and structure for the full depth in two bays. Elsewhere it is relatively easy to arrange temporary means for close inspection.

2) Cargo Tanks

- In the side cargo tanks P+SB, where all boundaries are smooth and without elements, except upperdeck and transverse bulkhead in one end only, no permanent access elements have been arranged. Access to the horisontal stringers on the transverse bulkheads via sloped ladders with safety rails fitted around on each stringer. Stretcher with injured person can be lifted to upperdeck from each end of tank guided from the ladders placed fore and aft.
- In center cargo tanks, where transverse webframes with strut and bulkhead longitudinals are fitted, and transverse bulkhead in one end is supported by stringers and vertical stiffeners, same arrangement is made as in the side cargo tanks. Besides this, one bulkhead longitudinal P+SB below upper deck is increased to a width of 1.2m, allowing inspection of the surrounding areas to be carried out throughout.

This is what the Owner required for permanent access in the E-class tank area. When access elsewhere is necessary, it is preferable to use temporary means in his opinion. Other Owners may have different requirements, or maybe the authorities will issue rules some day, and we will of course follow these. However, for a new double hull VLCC we will use the same arrangement as design basis, as operation experience with the E-class have been satisfactory.

7. AFTER DELIVERY SUPPORT

Wrongly designed structure, systems, materials and equipment which is not suitable for the intended purpose are all main contributors to a shipowner's future maintenance costs, and the builders future lack of credibility. Therefore we are systematically collecting service experience by providing reports and feedback to our design engineers, by having dedicated people inspecting and scrutinizing structure and coatings plus all major equipment at the world wide manufacturers, here again together with design engineers.

Last but not least we are cooperating very closely with A.P.Møller over the whole life time of the vessels to learn about their actual performance over the years, and if requested participate in the solution of possible problems encountered.

Experience from this vast database represents a unique opportunity for us at Odense to improve the design and maintainabitility of future vessels, such as for example new double hull V VLCC's with enhanced life time.

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