Not Repeating the Past - A Case Study of Fatigue Fracture in Midship Cargo Tanks

Ryan Salamati
ABS, Hamburg Germany

Dr. Michael B. Kennedy
Hellespont Ship Management GmbH & Co. KG, Hamburg Germany

Abstract

Applying lessons learned from existing designs is the cornerstone for improving the safety of marine transport. Double hull tanker designs built in the 1990s are now approaching their 3rd Special Survey and beyond. Designers and rule makers should review these double hull designs (pre-CSR) and their successes and failures for lessons that can be carried forward to current and future designs. More recent double hull tankers built to the CSR requirements will not have their 3rd and later Special Surveys until 2021 and later. This paper describes a fatigue failure in way of deck longitudinals at the connection to vertical stiffeners on the transverse webs in the midship cargo tanks of a particular vessel. Although relatively minor in and of itself, it was repeated in the same tanks more than 40 times. This study indicates areas where special attention may be necessary in other pre-CSR tanker designs (i.e. up to end of 2006 contracts), where the same structural details are employed. The failure, its lessons and general future concerns regarding oil tanker structure design is discussed.

1 Introduction

A late 1992 delivered Suezmax(148,500 dwt) double hull tanker was raft inspected in the midship cargo tanks (4 Port,4 Stbd) during its 17.5 year intermediate survey. Since the time of its construction (Keel Laid 1992), the ship was classed ABS +A1. At the time of this survey the vessel had no service limitations and the structural inspection was for no other purpose than the Intermediate Survey requirement. There were no pending steel renewals.

In addition to the rafting inspection for the close-up survey, the ship had ultrasonic thickness measurements (UTM). Two experienced class surveyors were rafting the port and starboard tanks concurrently. Each tank raft had both a surveyor and an owners' representative. Chipping and hammering had been used to "clean" the rust, scale and cargo residues. Several webs had been surveyed and no failures had been identified.

The port side rafting identified a fracture on the top side connecting weld of the flat bar vertical stiffener in way of the under deck longitudinal. This finding prompted the surveyors to expand the scope of close-up surveys while rafting in midship port and starboard cargo tanks.

Fig.1 Discovery - The Fracture When Cleaned
20 identical cracks were found in 4Port and 21 were found in 4Stbd.

2 Structural Investigation

The ship was an in-service oil tanker which had passed its Special Survey 3 with no significant steel renewals. However, while rafting during the 17.5 year Intermediate Survey a fracture in a weld in a top side flat bar vertical stiffener on deck transverse in way of the under deck longitudinal was discovered. The explicit survey requirement had found one crack. After a discussion with the ship operators/management, the scope of the close-up inspection whilst rafting was expanded. More "identical" fractures were found during rafting. The total findings during rafting exceeded more than 10 in each tank.

Subsequently, it was agreed to raft and inspect adjacent cargo tanks. These checks were not explicitly required by the survey rules, but were left to the discretion of the attending surveyors. A thorough examination was made of the webs in these adjacent tanks, especially those nearest the tank bulkheads, by the surveyors who were now familiar with the specific tank structure in the midship tanks which was subject to cracking. Several webs and the bulkhead itself were examined and no similar fractures were found. All the fractures were in the midship Cargo Oil Tanks 4Port and 4Starboard and none were found elsewhere in the vessel.

The following sections of the midship drawings (figures 2, 3, and 4) show the structure where the fracture was found. It is in "Detail E" which shows how the stiffeners pass through slots in the web frame.

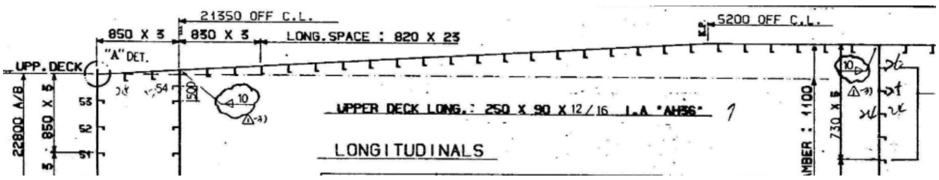

Fig.2 Midship Section Drawing

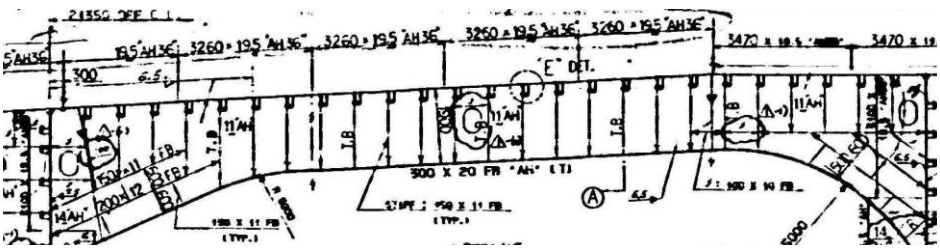

Fig.3 Longitudinal on the Web

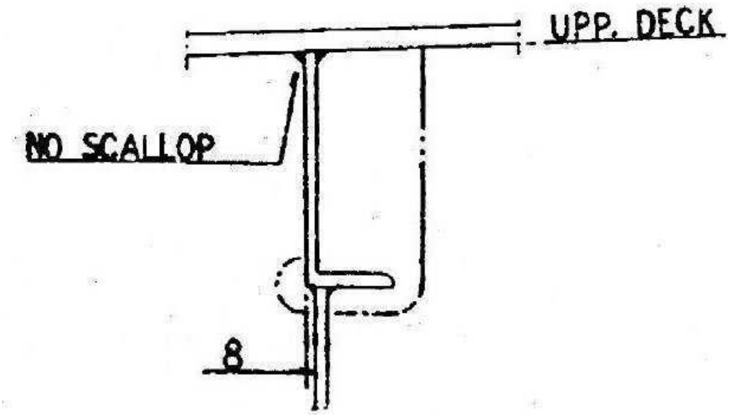

Fig.4 Detail "E" with Underneath Vertical Connection

The requirements for a 17.5 year oil tanker require a dry docking and the ship was scheduled and en-route for such a docking. There were to be steel renewals for other unrelated discoveries and it was agreed to fully stage the midship tanks, further investigate the newly discovered stiffener fractures and make the appropriate repairs.

In the dock COT 4P and 4S were staged, the web/longitudinal connections were all cleaned and both a visual examination and, at the request of attending Surveyors, a Magnetic Particle Inspection (MPI) was performed.

Fig.5 Opposite Side of Web - Staging Wire Shown

Fig.6 Vertical Stiffeners Connecting Longitudinals to Web (after weld repair)

Fig.7 A Suspect Connection - The Weld

Fig.8 The Fracture - MPI Crack in the Weld Parallel to Deck

The Class report describes the fractures as follows (it repeats for all fractures).
Web frame No. 78, found fracture on top side weld of the flat bar vertical stiffener in way of the under deck longitudinal at No. 23 and 24.

The table below shows all locations. For ready reference:

- frame 77 is the aft bulkhead of cargo tank 4P and 4S. Frame 78 is first web forward.
- frame 87 is the forward bulkhead of cargo tank 4P and 4S. Frame 86 is first web aft.
- longitudinal 1 is the first longitudinal next to the centerline (C/L) bulkhead.
- longitudinal 25 is the first longitudinal inside the cargo tank next to the water ballast tank (WBT).

	WEB	C/L	Lon	Lon	Lon	Lon	Lon	Lon	Lon	Lon	Lon	Lon	Lon	WBT
4Port	77													
4Port	78										23	24		
4Port	79									22	23	24		
4Port	80			3				19		22		24	25	
4Port	81										23	24		
4Port	84										23		25	
4Port	85									22	23	24		
4Port	86									22	23	24		
4Port	87													
4Stbd	77													
4Stbd	78							19						
4Stbd	79									22	23	24	25	
4Stbd	81										23	24		
4Stbd	82		1	3	4	5								
4Stbd	83						12							
4Stbd	84							19	20					
4Stbd	85										23	24	25	
4Stbd	86									22	23	24	25	
4Stbd	87													

Fig.7 Table of Fracture Locations

It should be noted that **no** similar fractures were found in the ballast tanks.
4 Port and 4 Stbd are the tanks located near midships where the hull girder bending moment stresses are at their maximums. It is also the location where the sea forces cause the largest wave-induced hull girder bending moment dynamic stresses to cycle. MPI examination showed the same type of crack in all the above mentioned locations.
A contributing factor could be the extensive use of high tensile steel in the midship section. Either AH32 or AH36 (no DH) steel was used in midship section. Deck longitudinal stiffeners were constructed using AH36 steel. Corrosion wastage was well within acceptable class limits. The ABS Rules at the time did not give full credit for the high tensile strength steel, as a Q factor of 0.78 and 0.72 for H32 and H36 respectively was applied to the hull girder and deck beam required section modulus. However this approach did not explicitly consider or compensate for fatigue "wear" from greater plate deflection amplitude because of the thinner steel. Note that the vertical stiffener was not high tensile although it was fillet welded to the high tensile deck longitudinal.
At Special Survey No.3 two and half years earlier no fractures had been seen.

3 Preventative Actions

The fractures in almost all aspects were identical. The ship was 17.5 years old and Special Survey No.4 close-ups would be at least as detailed as that for Special Survey 3 and future Intermediate Surveys. Given that the original design exhibited satisfactory history for more than 15 years before a detectable failure, the suggested repair plan to grind out the fracture and then build it up and re-weld with the same design, was accepted by class as a permanent repair. The corrective action was applied to each fracture. An example of the process used for one of the failures in Fig.7, follows:
Web frame No. 78, weld gouged out and built up/re-welded, on top side weld of the flat bar vertical

stiffener in way of the under deck longitudinal at No. 23 and 24.
The locations for which this repair was carried out were identical to those in the above table Fig.7 (Table of Fracture Locations).

4 Development of the IACS Harmonized Common Structural Rules (CSR)

This vessel was not subject to fatigue analysis during its original design in the early 90s when the use of double hull tankers was first mandated. However, fatigue strength started being analyzed in the rules from the mid-90s (i.e., ABS SafeHull and improving in today's IACS CSR). If CSR had been in place when this midship design was first reviewed CSR would have "required" (Fig. 9) re-design to improve this midship section. Similar fatigue cracks should not be expected on CSR vessels which have a required fatigue life of 25 years. CSR differs from the prior Rules that were in force at the time of the design and construction of this tanker. The analysis scope by many class societies also has improved with the incorporation of varying degrees of Finite Element Analysis in most designs (e.g. SafeHull).
To help prevent this situation CSR includes the following requirements:

- more detailed prescriptive rules and/or structural detail factors.
- reduction in scantlings is less than proportional to yield limits.
- fatigue life calculations that do not give credit for higher yield limits.
- analysis is generally more comprehensive with more required areas.

Overall the CSR deck longitudinal section moduli would have been significantly more - this pre-CSR design has Hog/Sag of 333,500/335,500 t-m whereas a CSR design had 410,000/280,000 t-m primarily because of prescriptive fatigue requirements. For example the deck longitudinal (L-shape) in this design is 250x90x12/16 "AH36". A similar present CSR design uses AH32 and 400x12(web)+150x12(face). This increase comes mainly from prescriptive fatigue strength requirements.
The vertical stiffener was made of mild steel and it was fillet welded to the deck longitudinal. The required fillet weld and the leg length are unchanged between CSR and pre-CSR. The type of connection in the original design is poor ("hard"). CSR should help to eliminate the stress concentration via fatigue consideration of the connection type.
We believe that extensive use of details similar to the original design are not commonly used in current designs. However, they could be used again, but the overall the structure should be improved by the application of the fatigue criteria included in the CSR and that should reduce the chances of fatigue damage on such a connection. New designs could incorporate a similar detail but it would likely not be subject to as much fatigue damage because of better overall structure behavior due to the application of the newer fatigue criteria.
The early design details of this vessel have been identified to the ABS personnel involved with the development of the Harmonized Common Structural Rules. This vessel is being analyzed as part of the calibration of the Harmonized CSR.
A fatigue analysis was carried out to assess the damaged deck longitudinals in accordance with the CSR criteria. As shown in Figure 9 the fatigue life of the damaged stiffeners was predicted to be 13 years, well below the 25 year minimum requirement.

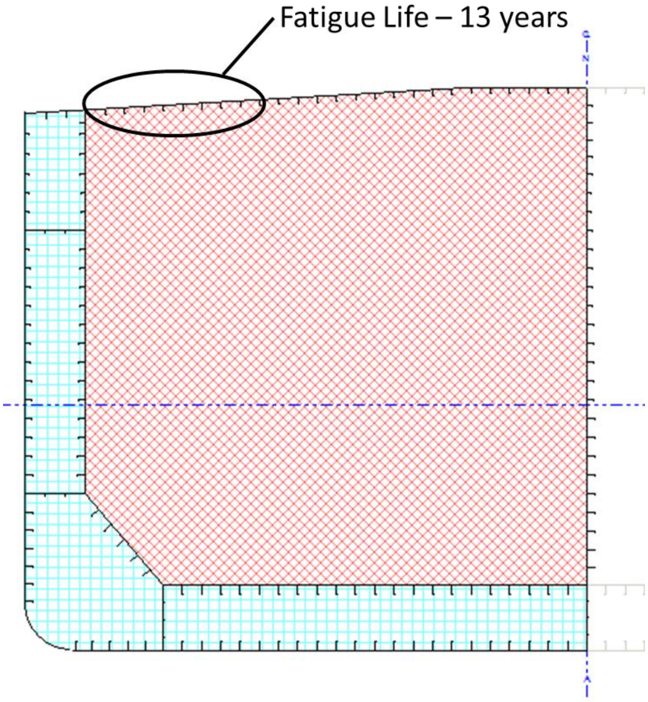

Fig.9 CSR Fatigue Results

5 Immediate and Future Concerns

Many Suezmax designs changed the detail of the deck longitudinal so that it passes through the deck transverse web without being attached to a web stiffener. This moves the fatigue hotspot from the web frame stiffener connection with the flange of the longitudinal and generally improves the overall fatigue profile of the connection. Based on the review of damage records for similar size vessels ABS has advised that they are not aware of similar widespread fractures in vessels with this deck longitudinal detail.

In the future, CSR designs should reduce the occurrence of the failure discussed in this paper given the more thorough assessment of fatigue during design evaluation.

We understand that fatigue criteria included in the rules is better now than it was 20 years ago and CSR incorporates "experiential factors" (i.e. safety factors) based on designs with satisfactory service experience. We can do better today using computers to model the details with plate thickness mesh elements analyzed at many more connections than just the hopper and we can better simulate fatigue with more realistic scenarios.

Details are important in both design and in fabrication. Fatigue fractures occur more frequently in outfitting connections to the deck [TSCF information paper TSCF_IP_001_2011_outfitting.pdf - available on www.tscforum.org], but generally fatigue may happen in joints that seem to be "un-important".

With regard to fabrication tolerances, designers typically do not consider fabrication errors in their "optimal" designs and yet fractures will often initiate at a fabrication failure and at poor details. It is noted that the CSR fatigue criteria is intended to account for fabrication misalignments as permitted under IACS Rec. 47. The process is such that the new construction surveyors inspect the actual yard fabrication and if misalignments are found outside the "Limits" of IACS 47, the structure is re-worked to bring any excessive misalignments to within the "Limits".

6 Conclusions

The requirements of industry and governments have required substantial design changes. It is believed that CSR represents a significant improvement in structural analysis. CSR could fall short of its objectives unless safety margins, conservative designs, and good quality control during fabrication are adhered to. Fatigue failures are costly and long remembered. It is important for all stakeholders, especially ship builders, to recognize potential fatigue hotspots and treat them appropriately when creating quality designs and during their fabrication.

The importance of a thorough inspection regime during operation should not be overlooked. A comprehensive structural survey with experienced operators and surveyors is vital to a safe ship throughtout its life. There is an unfortunate systemic fault in our industry – there is no clear delineation between design and operation when analyzing structural failures. CSR was and is a big change in the Rules. Every failure must be analyzed and its reason identified in order for CSR to evolve and that its experience base encompasses real structures in operation. With proper feedback the learning curve can be shortened and the number of fractures that develop into major structural failures minimized.