SAKARYA ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ
SAKARYA UNIVERSITY JOURNAL OF SCIENCE

e-ISSN: 2147-835X
Dergi sayfası: http://dergipark.gov.tr/saufenbilder

Geliş/Received
10.08.2016
Kabul/Accepted
06.02.2017

Doi
10.16984/saufenbilder.298938

Typical cracks in deck of ship-shaped structures and ways to modify and improve the design

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ABSTRACT

Cracks occurred in main deck structure around openings due to pipe penetrations, deckhouses and supports for various equipments have created a major problem and mainly related to the vessels with made of high strength steel material in deck and most frequently found on oil tankers used by buoy loading. This paper will show typical cracks and give guidance on modifications of existing details and examples of good design, where the examples of defects are used from Classification Societies' feedbacks in hull in operation phase. Any discontinuity or opening in deck as well as attachments to deck has been a problem for years and experience shows that it is difficult to find 100% solutions. The purpose of this paper is therefore not to guarantee perfect solutions but is a selection of good solutions that has proved to be better than most. To avoid cracks in deck completely is not guaranteed and is probably not possible.This paper aims to address with a particular attention on oil tankers but will also be relevant to other vessel types including ship-shaped floating offshore structures such as FSO (Floating Storage Offloading), FPSO (Floating Production Storage Offloading), FLNG (Floating Liquefied Natural Gas) and drill-ships.

Keywords: outfitting, structural defect, local reinforcement, shipyard standard, repair process, welding

Gemi formundaki yapıların güvertelerinde sıklıkla karşılaşılan çatlaklar ve dizaynı düzeltme ve geliştirme yolları

ÖZ

Boru geçişleri, güverte evleri ve çeşitli ekipmanların destekleri boyunca güverte kaplamasında karşılaşılan çatlaklar; artan bir problem olmaktadır ve sıklıkla güvertesinde yüksek mukavemetli çelik kullanılan teknelerde karşılaşılmakta olup, en büyük sıklıkla duba yüklemesi yapan petrol tankerlerinde karşılaşılmaktadır. Bu çalışmada; sıklıkla karşılaşılan çatlakları sunmakta olup, kusur örneklerinin Klas Kuruluşlarının, kullanımdaki gemilerden elde ettikleri geri bilgilendirmelerinden sağlandığı, mevcut detayların düzeltilmesi ve iyi dizayn örnekleri hakkında kılavuz sunmaktadır. Güvertedeki her türlü süreksizlik ya da açıklık ve aynı zamanda güverte eklentileri, yıllardır bir problem olarak karşımıza çıkmakta olup, deneyimlerin gösterdiği kadarıyla bu soruna %100 çözüm bulmak zor olmaktadır. Buna bağlı olarak bu dokümanın amacı; mükemmel çözümleri garanti etmek olmayıp, çoğundan daha iyi olduğu

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kanıtlanmış olan iyi çözümlerin bir seçimidir. Güvertedeki çatlaklardan tamamıyla korunmak garanti edilmemekte olup muhtemelen mümkün de değildir. Bu çalışma; özellikle petrol tankerleri üzerine odaklanarak hazırlanmış olup, FSO (Yüzer depolama ve nakil amaçlı açık deniz yapıları), FPSO (Yüzer üretim, depolama ve nakil amaçlı açık deniz yapıları), FLNG (Yüzer sıvılaştırılmış doğal gaz tesisi) gibi gemi formunda yüzer açık deniz yapılarını ve tarama gemileri dahil diğer tekne tipleri ile de ilgili olacaktır.

Keywords: donatım, yapısal kusur, yerel güçlendirme, tersane standard, tamir işlemi, kaynak

1. INTRODUCTION

Normally outfitting reinforcements are being designed to consider the static loads acting on the outfitting parts. Reinforcements installed underneath deck structure are fit particular for this aim, where smooth transfer is targeted. Any stress concentrations (SC) induced by local reinforcement plan have to be taken into account and considered in design phase. Hard points such as corners and geometric discontinuities must be avoided [1].

Since the reinforcement underneath outfitting are covered in the vessel structure they will also be exposed to combine loads such as hull girder load, sea and tank pressure load, vibration load, etc. In normal yard practice outfitting reinforcements are in general not checked versus those loads and shipyard standard and/or industry recognized practice so that they conservatively deal with vessel loads. This covers suitable connection details of the reinforcement to the hull structure and/or effective modification of the vessel structure around the outfitting parts [5]. Qualified workmanship has a crucial impact since poor fabrication or poor welding can result in structural failure even for a successful design. The work for outfitting might not be carried out by same working manner as structure work and training of the outfitting workers in terms of quality is so crucial [2].

The process for converted, new-built and repaired vessels has different difficulties, in which design can easily be modified at the design stage to select the most efficient as well as cost-effective configuration, compromises have to be performed at the repair stage so as to minimize the required changes and make repair workable and reliable for working on-board where access ways, weight items, etc are important items.

In order to describe the defects found on board vessels and find general categories of defects, it is firstly defined a typical characterization framework that is;

- Category: Design or Construction & Installation.

Design related issues are when ship structures have not been designed to accommodate the load transferred by outfitting items: such failures can be attributed to poor design, poor detail, lack of use of recognized standards for outfitting or poor management of changes, incorrect materials, etc. Construction & Installation related issues are when the source of problem is poor workmanship, misalignment, or incorrect materials compared to the drawings.

- Type of defect: Cracking, Fractures or Deformation, Collapse
- Cause of defect: a defect detailed description
- Area: the location of the defect primarily if it is located in the 0.4L main deck area

This study attempts to address typical cracks shown on the ship and offshore units and recommend guidance upon modifications of existing details and examples of good design, where the examples of defects are used from Classification Societies' feedbacks in hull in operation stage.

A particular attention is paid to oil tankers but will also be relevant to other vessel types including ship-shaped floating offshore structures such as FSO (Floating Storage Offloading), FPSO

(Floating Production Storage Offloading), FLNG (Floating Liquefied Natural Gas) and drill-ships.

2. SHIPYARD STANDARDS

Plan approval mainly focuses on primary structure and may consider reinforcement underneath and around outfitting "shall be according to shipyard practice". Typical reinforcements underneath and in way of outfitting are specific for each shipyard. There are few recognized industry standards. Generally, shipyard standards are not submitted to the classification society for approval. The ship-owner should request the shipyard standards for review and comment, as part of his building contract.

According to class rules some main equipment reinforcements are subject to specific approval. With reference to CSR for Double Hull Oil Tankers as given by Sec. 11 / 3 Support structure and structural Appendages: "3.1.1.2 this sub-section covers scantling requirements for the supporting structure and foundations of the following items of the equipment and corresponding fittings [3]:

a) Deck shipboard cranes, derricks and masts
b) Emergency towing brackets
c) Anchor windlasses
d) Anchoring chain stoppers
e) Mooring winches
f) Bollards and bitts, chocks, fairleads, stand rollers, and capstans
g) Other deck equipments and fittings which are subject to specific approval
h) Miscellaneous deck fittings which are not subject to specific approval

Equipment and fittings whose support structures have to be approved are well identified but equipment and fittings under (g) and (h) are unspecified. Owners should discuss and agree the extent of drawings for approval with the shipyard and this should include reinforcements in way of outfit items.

3. DESIGN AND PLAN APPROVAL

Ship basic design for hull structure normally precedes outfitting installation design. Hull structure design documents for approval might not cover all necessary reinforcements underneath and around outfitting. Further late modifications and changes might not be reflected to vessel structural detail design such as underdeck members. While CSR does require the details for fabrication standard details to be supplied for approval and review this normally does not cover outfitting supports (CSR OT Sect 4/3) [3].

During design plan approval the ship operator / owner should ask the yard to provide the drawings of outfitting arrangement such as supports for piping, electrical, HVAC, mooring fittings, deck attachments, openings, etc. Reproducing of the drawings is more helpful from cost effective perspective compared to changing the structure already fabricated.

The building contract should have provisions for management of changes to design and approved plans. For example, comment such as "any modification of the approved drawing is subject to approval" is usually made to give the owner the opportunity to review all yard changes during production [5].

4. INSPECTION

Since the underneath reinforcement and around outfitting structure might not be on the operator / owner`s plans, the only chance to verify the compliance with the outfitting drawings is during survey. The survey should not just concentrate on the compliance with approved documents and drawings but should also pay attention to the outfitting drawings.

During the hull block survey time the outfitting reinforcement might already be installed, hence the surveyor has the chance to check compliance of the reinforcement with the outfitting drawings [8, 9]. When outfitting items are fitted at a later stage, the final survey of the outfitting parts and relevant reinforcement hull structure can be performed at the outfitting survey. Whenever feasible, the outfitting surveys should be carried out at the hull block stage. The outfittings have to be supported by underneath structure. Patrol surveys are also useful road map to check out the compliance [2].

The operator / owner`s outfitting surveys should cover the following checks for;

- Used material grade and sizing,
- Missing supporting structure,
- Fabrication misalignments,
- Non-completed and undersize welds,
- Mis-cuts,
- Correct surface treatment and painting,
- Corrosion protection,
- Interferences.

5. DAMAGE TYPES AND PROPOSED MODIFICATIONS

This guide identifies the influential parameters and provides guidelines on improvement of structural connections with respect to outfitting design. It also provides reference illustrations of local structural failures experienced in some existing tankers and the corrective measures as compiled by the Tanker Structure Cooperative Forum and from Classification Societies' data files [1, 4].

5.1. Pipe Penetrations

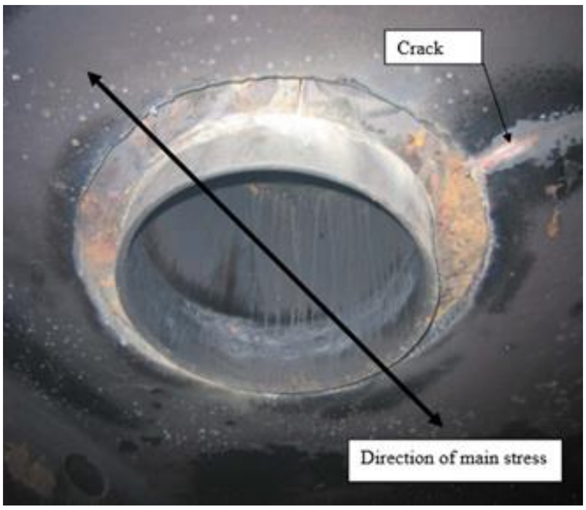

Figure 1. Crack in way of pipe penetration in main deck [1].

Figure 1 shows inert gas pipe with a doubler plate that is welded on the deck top only. The hole in main deck has been cut with an oxy-acetylene torch leading to in a very rough edge. This could be very relevant case on how not to design it. The rough cut edge has created a crack to propagate and this likely occurred very quickly. The edge is supposed to cut correctly and the edge should be flush ground at all around. An insert plate would be a better way for a good solution [4]. The best design for a pipe that does not actually need to protrude through the deck, especially if access below deck is tough, is the "improved design" shown on Figure 2.

It should be stressed out that a doubler plate should always be welded through both sides and not like above where the underside is not welded.

In machinery space typical transverse bulkheads, etc the doubler plate application is feasibly acceptable on condition that both sides are welded but on main deck structure in the cargo hold area that it is not advised.

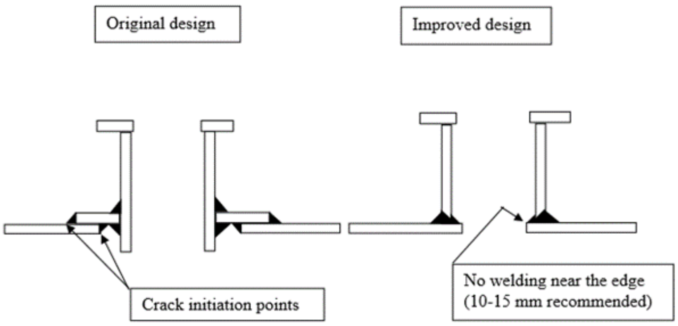

Figure 2. Sketches of damage and repair for pipe penetration.

Figure 3. Crack in way of opening in deck [1].

Figure 3 shows a scupper pipe in main deck and although difficult to say how it was welded, it is probably that the welding has been close to the edge of opening. A rough cut opening is also a possible reason for the crack, although on the picture that it looks OK.

Once again the opening should be cut out correctly and smooth flush ground. Welding on or near the edge is not advised.

Figure 4. Crack in way of pipe penetration in main deck [2].

Figure 4 shows pipe penetration for heating coils. The picture on the left shows a doubler plate on the main deck top with the pipes going through the doubler. To add to the problems the cut out in deck is oriented in the transverse direction.

Photograph on the right shows repair using insert plate, which is much better than doubler welded on top. The latter should only be used in machinery space and aft and forward structure where longitudinal stresses induced by hull girder load are not a concern.

In this case, the risk of cracks would be reduced if the opening was cut out in the longitudinal direction, as the effective loss of deck area is less.

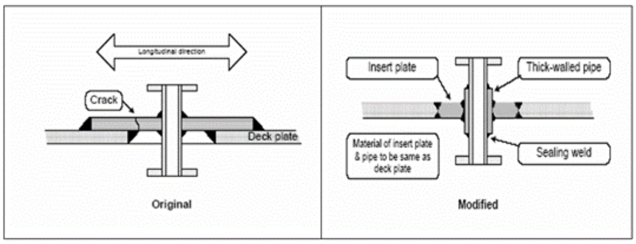

Figure 5. Recommended sketches of damage and repair / modifications for pipe penetrations.

Figure 6. Crack in way of pipe penetration in main deck [3].

Figure 6 shows a COW (Crude Oil Washing) machine connection flange to deck. A crack can be seen extending from underneath a doubler ring/flange probably due to rough-cut and lack of grinding of the hole in deck.

The repair on the right hand side shows a new flange/insert plate with increased thickness. In addition, the hole is machine-cut nice and smooth.

5.2. Deck openings

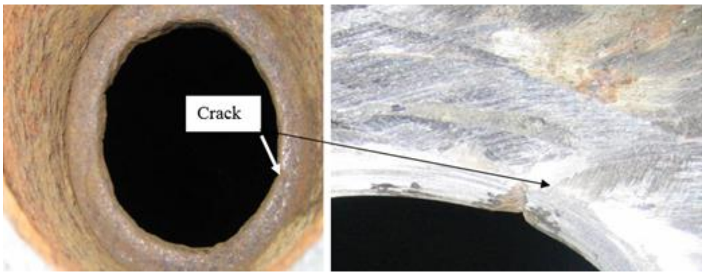

Figure 7. Crack in way of opening in deck.

Figure 7 shows a high-level alarm hole in deck. A pipe stub piece is welded to deck with hole in deck smaller than the pipe diameter. Photo on right hand side is taken after removal of pipe and grinding of the deck – crack is still visible. In this case a deck insert ring plate should be inserted to remove the crack before a new hole is cut, see sketch below. This will require back welding from below.

The method of welding a pipe stub or coaming to deck with a smaller cut hole in deck is the method we recommend, as all welding may be carried out from top side. It requires that the hole is cut properly (cut by oxy/acetylene torch is ok provided it is cut with a template or guide) and ground perfectly smooth. See also Figure 8 below.

If a crack occurs in a hole in deck, an insert needs is to be fitted as shown Figure 8. This will require welding also from below.

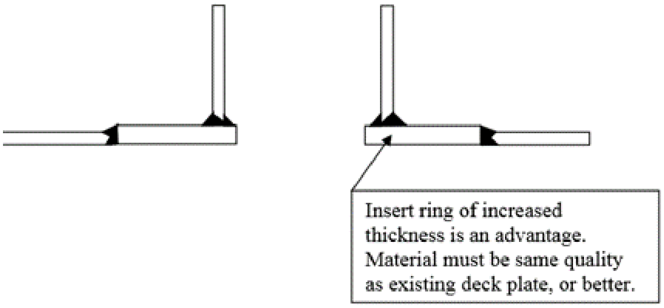

Figure 8. Recommended sketches for repair / modifications for insert ring.

5.3. Small deckhouses

Figure 9. Crack in way of deckhouse corner [1].

Figure 9 shows a crack at the corner of a deckhouse in the midship area. Recommended modification is to fit a longitudinal soft bracket with increased thickness and welded full penetration to deck. Toe should preferably be ground flush with deck as shown on Figure 10.

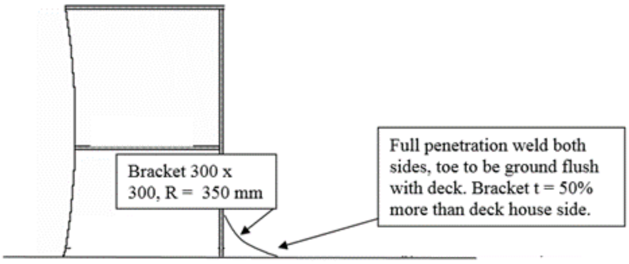

Figure 10. Recommended sketches for repair / modifications for deckhouse corner [5].

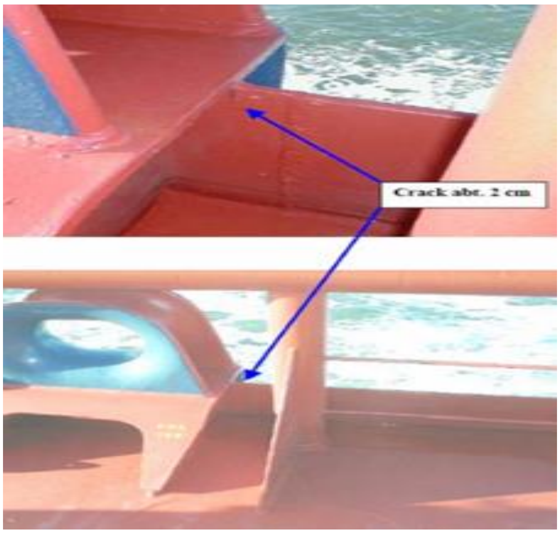

Figure 11. Cracks in gutter bar.

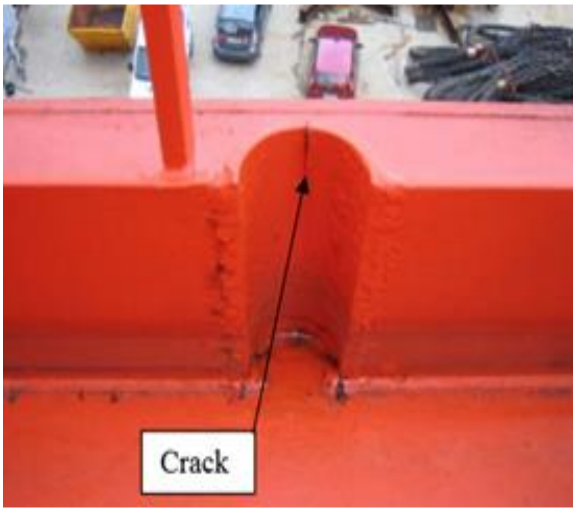

Figure 12. Cracks in gutter bar (in closed view).

The Panama Chock foundation top plate being attached to the gutter bar as shown by Figures 11 and 12 causes the crack. If at all possible, nothing should be welded to the gutter bar. If a Panama Chock foundation is welded to the gutter bar, nothing should be welded to the upper part of the gutter bar, i.e. in this case the foundation top plate should have been lifted to clear the top of the gutter bar. Hence, it would be better to have a continuous gutter bar.

Another possible solution is to use one of the designs shown on next page, see Figures 13 and 14. This may be used on both sides of Panama Chocks, bulwark etc. in the midship area.

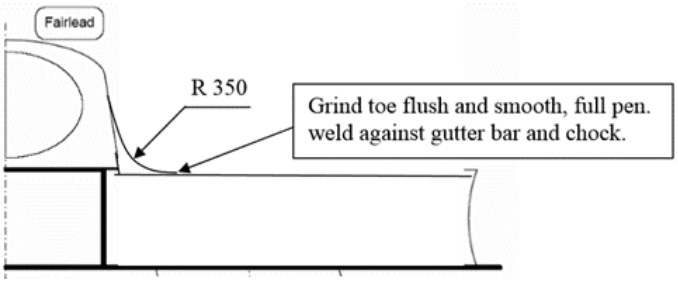

Figure 13. Design to improve the notch in the gutter bar. Bracket with minimum 15 mm thickness.

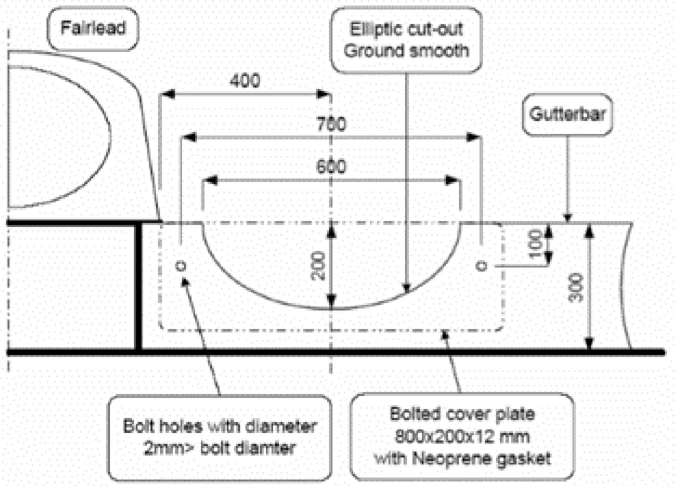

Figure 14. Design to reduce the stress in the gutter bar locally. The elliptical cut out should be ground perfectly smooth.

5.4. Pipe supports

Pipe supports, manifold supports etc. frequently cause cracks in deck, also when positioned on doublers. Longitudinal stresses are combined with pillar bending in the fore and aft direction causing transverse cracks as shown on Figure 15.

Figure 15. Cracks on pipe supports on hull main deck [6].

To avoid longitudinal stresses causing the supports to bend and increase the stress around the support connection to deck, more flexible supports will improve the situation. The below sketch shows an arrangement for anchoring a section of piping between expansion joints and leaving the other supports flexible. Figures 16 and 17 show for repairs and modification details.

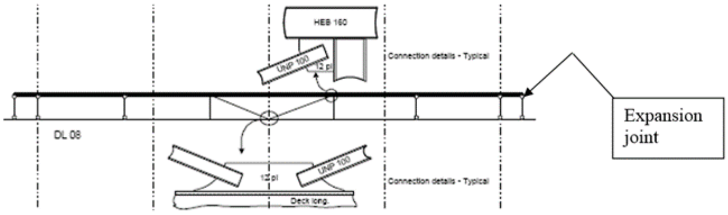

Figure 16. Recommended sketch for repair / modification on the pipe supports.

Figure 17 shows the flexible supports while Figure 18 shows the longitudinal bracings to anchor the pipe in the longitudinal direction on the main deck.

Figure 17. The flexible pipe supports.

Figure 18. The longitudinal bracings to anchor the pipe.

5.5. Helicopter deck supports

Helicopter deck supports are in principle much the same as pipe supports and must be supplied with enough bracing to reduce the local bending of the supports. The remaining local bending can be taken care of by fitting fore and aft brackets, as shown on Figure 19.

Figure 19. The applied repair / modification details on helicopter supporting structure [7].

5.6. Mooring and towing fittings

Under deck stiffener at front of chock foundation appears to be misaligned and aft edge not supported at all. The under deck support is completely inadequate for the loads applied. Normally all four sides of the foundation should be supported. In this case the aft edge of the chock foundation could have been welded to transom plate/gutter bar. In the cargo area, this should be avoided. Figure 20 shows panama chocks torn off poop deck by tug.

Figure 21 shows strengthening fitted under the sides of the roller. The best under deck support would be a short piece of pipe, with diameter equal to the base of the pedestal, which should be attached to surrounding stiffening [10].

Figure 20. It shows 2 off 40 t SWL panama chocks torn off poop deck by tug.

Figure 21. Recommended sketch for underdeck strengthening.

6. CONCLUSIONS AND DISCUSSIONS

This paper aims to identify the influential parameters and provides guidelines on improvement of structural connections. It also provides reference illustrations of local structural failures experienced in some existing tankers and the corrective measures as compiled by the Tanker Structure Cooperative Forum and from Det Norske Veritas (DNV) and American Bureau of Shipping's (ABS) feedbacks in operation phase.

Following concluding remarks may be drawn for better design and repair / modification details, which can be used for ship-shaped floating ship and offshore structures. It should be noted that all those recommended repair details have been justified by both analytical and numerical analyses.

Stanchions or supports:

- Consider reducing or eliminating pipe sections (internal corrosion).
- Use open type rolled / fabricated sections such as T, L, I, X, H, etc.
- Align with underdeck structure (largest member is preferable)
- Provide backup to flange.
- Use doublers only when appropriate, when under compression only.
- Use collar plates on stiffener cut-outs directly beneath supports.

Through fittings (pipes, radar stands, etc):

- Where possible pass fitting through deck with sleeves
- Ensure sleeve pipe is either seamless or if welded pipe the external weld reinforcement is ground flush.
- Use ring support for larger pipe (e.g. 200+ mm diameter)
- Tie ring support into underdeck framing system.

Deck openings (e.g. coamings):

- Ensure the plate edges of the deck opening are machine cut and smooth i.e. no notches.
- Welding of fittings and coamings to the deck to be well clear of opening edges.
- Manholes, access openings, etc shall be avoided around concentrated loads and high stress regions.
- Bracket toe heights to be within 10-15mm. The purpose of the bracket "nose" is only to facilitate the effective wrap weld.
- Use soft toe terminations.
- When outfitting dimension is large and its stiffness is high, consider splitting the item.
- Check hull girder loads when working with structures longer than 3 frame spaces.
- For tall structures (e.g. radar mast) consider vibration loads.
- Lack of access (for maintenance purposes) is to be avoided.

Underdeck backing:

- Transitions to extend to stiffener/frame break. Partial transitions are to be avoided.
- Use conservative load calculations (including global and local stresses) and assume no support from the deck plate.
- Use deck inserts where shear loads are high.

Gutter bars:

- Continuous gutter bars should be treated like a sheer strake.
- Avoid connections to the upper edge of ship side gutter bars.

Installations of brackets and collar plates:

To prevent local distortions and to minimize the magnifying effects of structural notches, consideration is to be given to additional brackets and collar plates (or lugs) at the critical joints and cut-outs respectively. Alternatively, different stiffening systems may be considered to minimize the critical spots in highly stressed regions. For example, utilization of the horizontal stiffeners with appropriate tripping brackets for floors in double bottom, instead of vertical stiffeners would eliminate the critical spots at the face bar toes on the flange of longitudinal.

Softening hard spots:

To minimize the stress concentration at hard spots, such as bracket toes, tapered face plate, and welded connections of the face plate of transverses and bulkhead plating, the welded joints may be softened by providing a large radius at bracket toes or a cope hole with proper reinforcement of surrounding panel to prevent local instability.

At critical structural joints, the fatigue strength can be improved by reducing the magnitudes of nominal stresses and/or minimizing stress concentrations. In addition, it may also be advisable to consider the following improvements on the fatigue strength:

- Utilizing better contour shapes for cut-outs, such as the cope holes,
- Having bracket toe and the surrounding weld deposit ground smooth with an appropriate radius

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