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# CONSTRUCTION TOLERANCES AND DEFECT CORRECTION PROCEDURES

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Section 1: Introduction

1.1 General

1.1.1 Service experience has clearly indicated that when structural concepts were extrapolated, such as increased transverse spacing in oil tankers, areas of structural detail became more prone to fatigue cracking if due attention was not paid to the detail design.

1.1.2 Experience with ship structures shows that provided the general concepts of a structural design are adequate then success or failure in structural terms will depend on the quality of detail design.

1.1.3 In a general sense, the problems associated with aspects of detail design are normally associated with cumulative fatigue damage and failure.

1.1.4 Fatigue is failure under repeated loads. There are three phases in a fatigue fracture:
- crack initiation;
- crack propagation; and
- fracture.

These phases are not completely separable. The process may be described as the formation of a crack, because of repeated local plasticity, its progression until a critical size is reached, whereupon it fails. Fatigue accounts for a large percentage of all service failures.

1.1.5 A structural element can be subjected to various kinds of loading conditions, including fluctuating stress/strain, fluctuating temperature (thermal fatigue), or any of these in a corrosive environment or at elevated temperatures. Most service failures occur as a result of fluctuating tensile stresses.

1.1.6 Fatigue cracks generally initiate at high stress locations such as structural discontinuities, weld toes, etc. As these cracks propagate, the ultimate load-carrying capability of the structure is reduced until sufficient fatigue damage is accumulated for the structure to fail at normal working loads. Since fatigue cracks can be possible points of initiation for catastrophic failures or costly ship repairs, it is essential that fatigue is given more detailed consideration in the design of the structure.

1.1.7 Fatigue ageing of structural components is a cumulative process which is largely due to the environment and the loads experienced. It is inevitable that, where stress concentrations are present in association with significant magnitudes of stress variation, fatigue cracking may occur. Factors which influence performance, in that they affect the magnitude of stress ranges and provide stress concentrations, are as follows:
(a) The loading experienced.
(b) The quality of detail design.
(c) The standard of workmanship in the ship construction.
(d) Corrosion rates and magnitudes.
1.1.8 Since the fatigue properties of higher tensile steels are generally similar to those of mild steel in welded connection, the higher allowable general stress magnitudes could entail a shorter fatigue life in standard details. Assuming that the fatigue life is a function of the stress range to the third power, it is clear that detail design requires special consideration to reduce the effects of stress concentrations. If higher tensile steels are incorporated and hence higher stress levels are accepted, then structural details, which would have been acceptable in mild steel structure, might not be adequate.

1.1.9 The occurrence of cracking in ships is of prime concern from both a safety and maintenance point of view. Experience has shown that fatigue cracks in ships’ structures are normally of a self-limiting nature. However, the existence of fatigue cracking may, if not repaired, render the structure susceptible to subsequent brittle or fast fracture. Thus both types of cracks are significant from a maintenance point of view. Fatigue cracks, if not repaired, may also initiate catastrophic failure as a consequence of the more extensive use of structural optimisation leading to a decrease in the level of structural redundancy.

Section 2: Fatigue – General considerations

2.1 Guideline basis

2.1.1 In assessing fatigue performance, the effect of cyclic loading should be taken into consideration. Cyclic wave-induced loads created by the passage of waves along the ship and the associated structural response are the main contributions to fatigue damage and cracking in ship structure.

2.1.2 Every stress concentration and welded joint is a potential site of fatigue cracking and the design should reflect this. To ensure the integrity of the structural members, a detailed fatigue analysis of the design should be performed. This document provides initial design guidance on fatigue and includes recommendations for the improvement of welded joint fatigue strength.

2.1.3 The fatigue strength of a structural detail is dependent on the following factors:
(a) The direction of the fluctuating stress relative to the detail.
(b) The location of initiating crack in the detail.
(c) The geometrical arrangements and relative proportion of the detail.
It may also depend on:
(d) The material (unless welded).
(e) The method of fabrication.
(f) The degree of inspection.

2.2 Fatigue mechanism

2.2.1 Fatigue damage starts prior to the initiation of a crack. With repeated loading, localised regions of slip (plastic deformation) develop. These deformations are accentuated by repeated loading, until a discernable crack finally appears.

2.2.2 The initial cracks form along slipped planes. The crack is crystallographically oriented along the slip plane for a short distance. This is sometimes referred to as ‘Stage I’ crack growth. Eventually the crack propagation direction becomes macroscopically normal to the maximum tensile stress. This is referred to as ‘Stage II’ crack propagation, and it comprises most of the crack propagation life.

2.2.3 The relative cycles for crack initiation and propagation depend on the applied stress. As the stress increases, the crack initiation phase decreases. At very low stresses (high cycle fatigue), therefore, most of the fatigue life is utilised to initiate a crack. At very high stresses (low cycle fatigue), cracks form very early. The separation of high and low cycle fatigue is not clear-cut. Generally, the low cycle region is that which results from stresses that are often high enough to develop significant plastic strains. It is usually assumed that the separation zone for low and high cycles is of the order of $10^4$ – $10^5$ cycles to failure.

2.2.4 There are visual differences between high cycle (low stress) and low cycle (high stress) fatigue. In the latter, deformation resembles that seen with unidirectional loading. Strain hardening can occur and the slip bands are coarse. In high cycle fatigue, the slip bands are usually very fine.

2.3 Allowable stresses

2.3.1 For a particular ship type, the allowable stresses are to be in accordance with the requirements of Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships) and the relevant ShipRight Structural Design Assessment (SDA) Procedure Guidance Notes on Direct Calculations.
2.4 Design loads

2.4.1 Applied design loads are to take into consideration the appropriate environmental and dynamic conditions.

2.4.2 All sources of fluctuating stress in the structure are to be identified. These may arise as a result of:
(a) superimposed moving loads, including vibrations from machinery, in stationary structures;
(b) environmental loads such as wind, waves, etc.;
(c) acceleration forces in moving structures;
(d) temperature changes.

2.4.3 For marine structure, it is normally adequate to consider only the cyclic loads induced by the wave and ship motions.

2.4.4 Loading for fatigue is normally described in terms of a design load spectrum, which defines the intensity distribution of a specific cyclic load event and the number of times that each intensity level is applied during the structure’s design life. If two or more independent live load events are likely to occur it will be necessary to consider the phase relationship between them.

2.4.5 Realistic assessment of the fatigue loading is crucial to the estimation of fatigue life. Where no published data for loading exists, reference may have to be made to data from existing structures subjected to similar effects. By recording continuous strain measurements over a suitable sampling period, loading data may be inferred by subsequent analysis of the response. Particular care is to be taken to assess dynamic magnification effects where loading frequencies are close to one of the natural frequencies of the structure.

2.4.6 The design load spectrum is to be selected on the basis that it is an upper bound estimate of the accumulated service conditions over the full design life of the structure. Account is to be taken of all likely operational and environmental effects arising from the foreseeable usage of the structure during that period.

2.5 Stress concentrations

2.5.1 The design and fabrication or construction of all structural details are to be such to minimise stress concentrations.

2.5.2 Fatigue strength is seriously reduced by the introduction of a stress raiser such as a notch or hole. Since actual hull structure elements invariably contain stress raisers like fillet welds, end brackets, cut-outs, etc., it is not surprising to find that fatigue cracks in structural parts usually start at such geometrical irregularities. One of the most effective ways of minimising fatigue failure is by the reduction of avoidable stress raisers through careful design and the prevention of accidental stress raisers by careful machining and fabrication. While this Section is concerned with stress concentrations resulting from geometrical discontinuities, stress concentration can also arise from surface roughness and metallurgical stress raisers such as porosity, inclusions, local overheating in grinding and decarburisation.

2.5.3 The effect of stress raisers on fatigue under uniaxial loading is that:
(a) there is an increase or concentration of stress at the root of the notch;
(b) a stress gradient is set up from the root of the notch; and
(c) a triaxial state of stress is produced.

2.5.4 The ratio of the maximum stress to the nominal stress is the Stress Concentration Factor, $K_c$.

2.5.5 Values of $K_c$ will vary depending upon:
(a) the severity of the notch;
(b) the type of notch;
(c) the material;
(d) the type of loading; and
(e) the stress level.

2.6 Stiffness

2.6.1 Abrupt changes in stiffness of the structure are to be avoided as they can induce local stress concentrations and reductions of fatigue life.

2.7 Vibration

2.7.1 If possible, precautions are to be taken in the design against the possibility of excessive structural vibration being induced, for example, by machinery. This would entail investigation of the natural frequencies of the members and of the sources of excitation.
2.8 Potential modes of failure

2.8.1 The potential modes of fatigue failure are dependent upon the direction of the applied stress relative to the position of the weld and the position of stress concentrations due to structural discontinuities.

2.8.2 For longitudinal butt welds in plates, dressed flush, and lying parallel to the direction of applied stress, the initiation of potential fatigue failures is expected to be found at weld defect locations. In the 'as-welded' condition, fatigue cracks may be initiated at the weld start-stop positions or, weld surface ripples.

2.8.3 For transverse butt welds in plates, essentially perpendicular to the direction of applied stress, the fatigue strength depends largely upon the shape of the weld profile. Fatigue cracks normally initiate at the weld toe.

2.8.4 Cruciform fillet weld joints may be separated into two distinct types depending on whether or not the fillet weld transmitting direct load, i.e. non load-carrying or load-carrying cruciform joints.

2.8.5 In the case of the non load-carrying cruciform joint, the fatigue crack will initiate at the weld toe and propagate through the thickness of the load bearing plate in a plane perpendicular to the direction of the applied stress.

2.8.6 In load-carrying cruciform joints, in addition to the weld toe, acute stress concentration occurs at the root of the fillet weld and generally fatigue cracks are initiated at the root of the weld and propagate through the weld throat. The fatigue life of such connections can be improved either by increasing the throat size of the fillet weld or by requiring improved weld penetration. In high stress regions however, such measures may not be adequate and there is then a need to specify a full penetration weld in order to achieve the necessary fatigue life for the joint.

2.8.7 Tee-joints, since they represent a semi-cruciform joint, would be expected to demonstrate similar fatigue characteristics to the load bearing cruciform joint. However, if bending stresses are induced in the base plate material of the tee, which are of a similar or greater magnitude than the direct stress in the tee, then a fatigue crack may initiate in the base plate at the toe of the fillet weld and propagate through the base plate.

2.8.8 Where tee or cruciform connections employ full penetration welds, and the plate material is subject to significant strains in a direction perpendicular to the rolled surfaces, it is recommended that consideration be given to the use of special plate material with specific through thickness properties, as detailed in Ch 3,8 of the Rules for Ships.

2.8.9 For welded stiffeners and girders, fatigue cracks can be expected to be initiated at weld toes and may be associated with local stress concentrations at the weld ends of connecting end brackets or stiffeners.

2.8.10 The most common sites for potential fatigue cracks therefore are:
(a) toes and roots of fusion welds;
(b) machined corners; and
(c) drilled holes, cut-outs or other openings.

2.8.11 The main conditions affecting fatigue performance are:
(a) high ratios of dynamic to static loads;
(b) loading frequency;
(c) welding;
(d) complexity of joint detail; and
(e) environment.

2.8.12 For ships operating for long periods in low air temperatures, the material of exposed structures will need to be specially considered.

2.9 Welds

2.9.1 Some commonly used weld details have low fatigue strength. This applies not only to joints between members, but also to any attachment to a loaded member, whether or not the resulting connections are considered to be structural.

2.9.2 The heat-affected zone (HAZ) is of great importance to the fatigue strength of welds because this is usually the region where a fatigue crack will develop. Moreover, when the reinforcement of a butt weld is not removed, or when fillet welds are used, a resulting sudden change of section occurs, and stress concentrations occur at the weld toe.

2.9.3 For the specification of welding and structural details, see Pt 3, Ch 10 of the Rules for Ships.
2.10 S-N curves

2.10.1 A material’s fatigue characteristics are fatigue strength and fatigue limit.

2.10.2 The fatigue strength is the stress value beyond which the material will fail at a specified number of stress cycles.

2.10.3 The fatigue limit is the fatigue strength corresponding to an infinite number of stress cycles.

2.10.4 The S-N curve represents the dependence of the life of the ‘specimen’ in a number of cycles, N, to the maximum applied stress, S. N is usually taken (unless specified otherwise) as the number of stress cycles to cause a complete fracture in the ‘specimen’.

2.10.5 Usually no distinction is made between the number of cycles to initiate a crack and the number of cycles to propagate the crack completely through the specimen, although it can be appreciated that the number of cycles for crack propagation will vary with the dimensions of the specimen. Fatigue tests for high cycle fatigue are usually carried out for $10^5 - 10^7$ cycles and sometimes to $5 \times 10^8$ cycles for non-ferrous metals. For a few important engineering materials such as steel and titanium, the S-N curve becomes horizontal at a certain limiting stress. Below this limiting stress, which is called the fatigue limit, or endurance limit, the material can presumably endure an infinite number of cycles without failure.

2.11 Complexity of joint detail

2.11.1 Complex joints frequently lead to high stress concentrations due to local variations on stiffness and load path. Whilst these may have little effect on the ultimate static capacity of the joint, they can have a severe effect on fatigue resistance.

2.11.2 If fatigue control is the dominant criteria, the member cross-sectional shape is to be selected to ensure smoothness and simplicity of joint design, so that stresses can be calculated and adequate standards of fabrication and inspection assured.

2.11.3 The best fatigue behaviour will be obtained by ensuring that the structure is designed and constructed so that stress concentrations are kept to a minimum and that, where possible, the elements may deform without introducing secondary deformations and stresses due to local restraints.

2.11.4 Stresses may be reduced by increasing the thickness of the parent metal and this would theoretically increase fatigue life due to a reduction of the nominal stresses. However, it should be borne in mind that fatigue strength decreases with increasing thickness above a reference thickness value.

2.12 Surface properties

2.12.1 Since fatigue failure is dependent on the condition of the surface, anything that changes the fatigue strength of the surface material will greatly alter the fatigue properties.

2.12.2 Most mechanically finished metallic parts have a shallow surface layer in residual compression. Aside from the effect on surface roughness, the final surface finishing process will be beneficial to fatigue when it increases the depth and intensity of the compressively stressed layer and detrimental when it decreases or removes this desirable layer. Thus sandblasting, glass bead peening, burnishing, and other similar operations generally improve fatigue properties.

2.13 Residual stress

2.13.1 Residual stresses arise when plastic deformation is not uniform throughout the entire cross-section of the detail being deformed. They therefore comprise a system of internal stresses in the material balanced within the material itself and can exist in the absence of any external loading. Thus if there is an area of tensile residual stress in any cross-section at one part of a material there must be a residual compressive stress at some other point. There would in addition be a variation of stress through the thickness of the material, particularly for thicker sections.

2.13.2 In a welded joint residual stresses are induced as a consequence of local heating and cooling cycles associated with the welding procedure and in particular the shrinkage of the weld metal. The actual situation in a welded joint is complicated by practical factors such as the type and size of joint, the welding process used and the weld procedure. In a butt weld for example, high residual tensile stress will exist in the direction of the weld and at right angles to it. In the case of multi-pass or high energy welding these residual stresses may reach the level of the yield strength of the material. As such tensile residual stresses can occur in locations where fatigue cracks are likely to initiate, it will be appreciated that they can lead to a proportional reduction in the fatigue strength of a joint when it is subjected to additional dynamic tensile loads.
2.14 Compressive residual stress

2.14.1 The formation of a favourable compressive residual-stress pattern at the surface is probably the most effective method of increasing fatigue performance. As indicated in 2.13, residual stresses are locked-in stresses which are present in a part which is not subjected to an external force. Only macro-stresses, which act over regions which are large compared with the grain size, are considered here.

2.14.2 In general, for a situation where part of the cross-section is deformed plastically while the rest undergoes elastic deformation, the region which was plastically deformed in tension will have a compressive residual stress after unloading, while the region which was deformed plastically in compression will have a tensile residual stress when the external force is removed. The maximum value of residual stress which can be produced is equal to the elastic limit of the metal.

2.14.3 The high compressive residual stresses at the surface must be balanced by tensile residual stresses over the interior of the cross-section.

2.14.4 The improvement in fatigue performance, which results from the introduction of surface compressive residual stress, will be greater when the loading is one in which a stress gradient exists than the case when no stress gradient is present.

2.14.5 It is important to recognise that improvements in fatigue properties do not automatically result from the use of shot peening or surface rolling. It is possible to damage the surface by excessive peening or rolling.

2.14.6 In order for the desirable effect of surface cold-working to be maintained, the cold-working process is to be accomplished in the final heat-treated condition and subsequent thermal treatment eliminated when feasible and closely controlled when essential. Exposure of cold-worked surfaces to elevated temperature initially results in stress relief of the plastically deformed zone and ultimately in recovery or perhaps re-crystallisation of the work-hardened area, with complete loss of the desirable residual stress gradient.

2.15 Grinding

2.15.1 There are some processes that are capable of developing high localised surface temperatures which are often difficult to detect and occasionally are responsible for a failure in service. Grinding can be one of these processes.

2.15.2 The rapid quenching of the material immediately below the grinding wheel by the large mass of cold metal can produce cracks or ‘check’. If actual cracking does not result, brittle, crack-prone, untempered martensite might result or, with lower temperatures, softened overtempered martensite. High strength steels (for which grinding is most often used) are particularly sensitive to grinding techniques.

Section 3: Fatigue Design Assessment

3.1 Fatigue Design Assessment procedure

3.1.1 As part of the ShipRight design, construction and lifetime ship care procedures, Lloyd’s Register has developed and introduced a multi-level Fatigue Design Assessment (FDA) procedure which permits the evaluation of the fatigue performance of hull structural details. It is applied in conjunction with Lloyd’s Register’s Structural Design Assessment (SDA) and Construction Monitoring (CM) procedures.

3.1.2 The ShipRight FDA notation will be assigned when an appraisal has been made of the fatigue performance of the hull structure in accordance with this procedure and found to comply with the requirement of 20 years fatigue life based on the 100A1 Fatigue Wave Environment (World-wide) trading pattern.

3.1.3 The ShipRight FDA plus notation will be assigned when an additional appraisal has been made of the fatigue performance of selected critical structural arrangements in accordance with this procedure and found to comply with a level of fatigue performance higher than that specified for ShipRight FDA.

3.1.4 The ShipRight FDA notation is a mandatory requirement for to all new oil tankers and bulk carriers over 190 metres in length and new designs where the type, size and structural configuration demand in order to obtain the necessary confidence level in the configuration and details of the structure.

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1 Applicable for new oil tankers from 28th January 1995.
2 Applicable for new bulk carriers from 26th January 1996.
3.1.5 Except as indicated in 3.1.4, the FDA procedure can be applied on a voluntary basis to enhance the level of confidence in the fatigue performance of the hull structure. Where the FDA procedure is applied on a voluntary basis, depending on the level of fatigue performance requested, ships complying with the requirements of this procedure will, at the Owner’s request, be assigned the notation ShipRight FDA or ShipRight FDA plus.

3.1.6 The notations, ShipRight FDA and ShipRight FDA plus, will be placed in column 4 against the ship entry in Lloyd’s Register’s Register of Ships, see Pt 1, Ch 2.2 of Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships).

3.1.7 For all structural details in critical areas as identified in the ShipRight FDA Structural Detail Design Guide and by the ShipRight Structural Design Assessment, a Fatigue Design Assessment is to be performed.

3.1.8 In applying the Fatigue Design Assessment procedure, Lloyd’s Register requires the Shipbuilder to consider three possible levels of assessment as follows:

(a) Level One. The proposed joint configurations at critical areas are compared with the structural design configurations specified in the Structural Detail Design Guide, which can offer an improved fatigue life performance.

(b) Level Two. This is an efficient spectral direct calculation procedure based on simplified structural models which utilises Lloyd’s Register’s PC-Windows based software. This procedure is intended for the analysis of secondary stiffener connections.

(c) Level Three. This is a full spectral direct calculation procedure based on first principle computational methods, such as hydrodynamic load and ship motion analysis and finite element analysis. It is intended for the assessment of primary structural details.

3.1.9 A summary of the requirements for ShipRight FDA and ShipRight FDA plus notations for new ships is outlined in Table 1.3.1.

3.1.10 Where a ShipRight FDA notation is requested, the FDA level one minimum detail design improvement specified in this Structural Detail Design Guide is to be complied with for all primary structural connections. For alternative arrangement of primary structural connections, special consideration will be given by Lloyd’s Register for the need to apply a FDA level three assessment.

3.1.11 Where the ShipRight FDA notation is applied on a voluntary basis, an equivalence to the minimum design improvement stipulated in this Guide will be specially considered where appropriate.

3.1.12 For the assignment of ShipRight FDA and ShipRight FDA plus notations, in addition to the requirements indicated in Table 1.3.1, the scantling requirements in the Rules for Ships are to be complied with.

3.1.13 For containerships, except as indicated in 3.1.3, the FDA procedure is optional. The assessment of the FDA descriptive note requires the fatigue performance of the following structural details to be investigated:

(a) Connection of side and bottom shell longitudinal stiffeners to transverse structure.

(b) Connection of longitudinal stiffeners to transverse primary structure in way of partial decks or stringers.

(c) Connection of cross-deck box structure to side structure including hatchway corners at upper deck and hatch coaming top.

(d) Hatchway corners at the engine room front and integration of superstructure into the side coaming if applicable.

3.1.14 Lloyd’s Register derived the FDA 100A1 Fatigue Wave Environment (World-wide) trading patterns for specific ship types using the world-wide trading statistics. These trading patterns, which comprises a collective of trading routes, are used as a basis of the spectral fatigue direct calculation procedure in the Level Two and Level Three assessments. The FDA Fatigue Wave Environment (World-wide) 100A1 trading pattern is summarised in Tables 1.3.2, 1.3.3 and 1.3.4 for crude oil tankers, product oil tankers and bulk carriers respectively.

3.1.15 The FDA direct calculation procedures are applicable to structural details within the cargo space region, which are subjected to the action of low frequency wave-induced loads. The assessment of the fatigue performance of structural details subjected to cyclic loading caused by propeller or any other mechanical/hydraulically-induced vibrations is not covered by the procedures.
## Table 1.3.1  A summary of the requirements for ShipRight FDA and ShipRight FDA plus notations for new ships

<table>
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<tr>
<th>FEATURE</th>
<th>FDA</th>
<th>FDA plus</th>
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<tr>
<td><strong>Notation</strong></td>
<td>ShipRight FDA in column 4 of the Register Book whether applied on a voluntary or mandatory basis</td>
<td>ShipRight FDA plus in column 4 of the Register Book is applied on a voluntary basis</td>
</tr>
<tr>
<td><strong>Structural Details</strong></td>
<td>Assessment of fatigue performance, in association with criteria (1) below, requires: &lt;br&gt; (a) Application of FDA Level 1 Structural Detail Design Guide for all primary structural connections.&lt;br&gt; (b) Application of FDA Level 2 to all longitudinal end connections at deck, shell and longitudinal bulkheads. The FDA Level 1 Structural Detail Design Guide may be used for guidance, in conjunction with FDA Level 2, in achieving the acceptance criteria.&lt;br&gt; (c) Application of FDA Level 3 to novel structural connections at the discretion of the Plan Approval office.</td>
<td>In addition to the requirements for FDA, assessment of a higher fatigue performance, in association with the criteria in (1) and (2) below, requires: &lt;br&gt; (a) Application of FDA Level 2 to all longitudinal end connections at deck, shell and longitudinal bulkhead&lt;br&gt; (b) Application of FDA Level 3 to a selection of primary secondary structural connections. The selection process of such connections is made jointly between the Plan Approval office and the Owner.</td>
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<tr>
<td><strong>Service Life/Trading Pattern</strong></td>
<td>For (b) and (c) above: &lt;br&gt; (1) Not less than 20 years fatigue life using the 100A1 Fatigue Life Environment (World-wide) trading pattern for the relevant ship type and size.</td>
<td>For (a) and (b) above: &lt;br&gt; (1) Not less than 25 years fatigue life using the 100A1 Fatigue Wave Environment (World-wide) trading pattern for the relevant ship type and size; and&lt;br&gt; (2) Where an Owner’s specified trading pattern(s) is used, not less than 20 years fatigue life for that specified trading pattern(s). Note: Both (1) and (2) represent minimum requirements to obtain the FDA plus notation. Actual required fatigue life and trading pattern(s) are to be agreed between the Builder and Owner.</td>
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<tr>
<td><strong>Datasheet</strong></td>
<td>A datasheet containing the precise technical conditions of the fatigue assessment is to be made available to Owners via ClassDirect Live, or in hard copy form, at the Owner’s request.</td>
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<td><strong>Pre-Contract Consultation</strong></td>
<td>· It is important that the Builder, in conjunction with Lloyd’s Register, consults with the Owner in order to clarify the Owner’s requirements in respect of FDA notation, trading pattern and service life at the earliest possible opportunity in the pre-contract process.</td>
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### Table 1.3.2 100A1 fatigue wave environment (world-wide) trading patterns for crude oil tankers

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<th>Ship Type/Group</th>
<th>Exporting area</th>
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### General Introduction

#### Table 1.3.3 100A1 fatigue wave environment (world-wide) trading patterns for product oil tankers

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### Table 1.3.4 100A1 fatigue wave environment (world-wide) trading patterns for bulk carriers

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<th>Time %</th>
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<td>2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S. Africa (Richard’s Bay)</td>
<td>Far East (Taiwan)</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S. Africa (Richard’s Bay)</td>
<td>W. Europe (Rotterdam)</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Baltimore)</td>
<td>Far East (Taiwan)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>USA (Baltimore)</td>
<td>W. Europe (Rotterdam)</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td><strong>Grain 35%</strong></td>
<td>Canada (Vancouver)</td>
<td>Far East (Taiwan) via Panama</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latin America (Rosario, Argentina)</td>
<td>Japan (Yokohama)</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Charleston)</td>
<td>W. Europe (Rotterdam)</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Charleston)</td>
<td>W. Europe (Rotterdam)</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Charleston)</td>
<td>W. Africa (Lagos)</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (San Francisco)</td>
<td>Far East (Taiwan)</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td><strong>Handy bulk carrier 5000 - 50 000 dwt</strong></td>
<td>Iron Ore 16%</td>
<td>Australia (Walcott)</td>
<td>Japan (Yokohama)</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Canada (Sept Isles)</td>
<td>USA (New Orleans)</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latin America (Puerto Ordaiz)</td>
<td>W. Europe (Rotterdam)</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latin America (San Nicolas, Peru)</td>
<td>Far East (Taiwan)</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latin America (Tubarao)</td>
<td>Japan (Yokohama)</td>
<td>5.7</td>
</tr>
<tr>
<td><strong>Coal 29%</strong></td>
<td>Australia (Newcastle)</td>
<td>Japan (Yokohama)</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>China (Qinghuangdao)</td>
<td>Japan (Yokohama)</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L. America (Maracaibo, Venezuela)</td>
<td>W. Europe (Rotterdam)</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S. Africa (Richard’s Bay)</td>
<td>W. Europe (Rotterdam)</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Baltimore)</td>
<td>Japan (Yokohama)</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td><strong>Grain 36%</strong></td>
<td>Australia (Newcastle)</td>
<td>Far East (Taiwan)</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Charleston)</td>
<td>W. Europe (Rotterdam)</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (Charleston)</td>
<td>Latin America (Santos, Brazil)</td>
<td>15.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA (San Francisco)</td>
<td>Japan (Yokohama)</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td><strong>Bauxite 10%</strong></td>
<td>Australia (Haypoint)</td>
<td>USA (Los Angeles)</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latin America (Tubarao)</td>
<td>USA (Baltimore)</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latin America (Tubarao, Brazil)</td>
<td>W. Europe (Rotterdam)</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td><strong>Phosphate Rock 9%</strong></td>
<td>N. Africa (Casablanca, Morocco)</td>
<td>Latin America (Rosario, Argentina)</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N. Africa (Casablanca, Morocco)</td>
<td>Asia (Bombay, India)</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red Sea (Port Sudan)</td>
<td>S. Asia (Jakarta, Indonesia)</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
The current FDA Level 2 software can only accommodate up to three different loading conditions. Where a FDA Level 2 assessment is required for Handy size bulk carriers, RDD London is to be consulted.
3.1.16 For ships fitted with hatch covers, as the interaction between the hatch covers and the supporting hull structure in a seaway is a complex process subjected to uncertainties associated with the modelling of the interacting components, it is difficult to provide a realistic and rational quantitative assessment of the fatigue performance at these locations. These locations are not considered within the scope of application of the FDA procedure. In general, a qualitative assessment based on the FDA Level One Structural Detail Design Guide recommended detail design improvements is considered appropriate.

3.2 Basis of Fatigue Direct Calculation Procedure

3.2.1 A structural arrangement may contain an array of potential fatigue crack initiation sites. Regions identified as containing the highest stress fluctuations and/or severe stress concentrations would normally be assessed first.

3.2.2 The fatigue design assessment should use the best estimate of the stresses resulting from the best estimate of the applied loads.

3.2.3 It is necessary to establish the extent to which fatigue is likely to control the design taking into consideration:
(a) An accurate prediction of the complete service loading patterns throughout the design life.
(b) The elastic response of the structure under these loading patterns.
(c) The detail design, methods of manufacture and degree of quality control which may have a major influence on fatigue strength, and should be defined more precisely than for statically controlled members. This can have a significant influence on design and construction cost.

3.2.4 Traditionally, fatigue design assessment procedure relies on determining the maximum lifetime stress range, and the expected number of stress cycles during the life of the structural detail. These two parameters represent the intercept on the axes of the stress spectrum. A suitable distribution function has then to be chosen to represent the lifetime stress spectrum. Finally, the selection of a suitable S-N fatigue strength curve, from a fatigue design code permits calculation of fatigue damage on the assumption of the Palmgren-Miner linear cumulative fatigue damage law.

3.2.5 In order to evaluate fatigue lives accurately, it is necessary to establish, as close to reality as possible, the long-term distribution of the stress range taking into consideration all pertinent stress variations which can be expected during the life of the structure.

3.2.6 A spectral fatigue assessment procedure is adopted in which the stress ranges and associated number of cycles are determined based on a simulation of the ship voyages throughout the entire ship’s life, using the anticipated ship’s operational profiles, global wave statistical data and mathematical models of the ship.

3.2.7 The specification of design fatigue life should take account of the joints accessibility to inspection and proposed degree of inspection in addition to the consequence of failure.

3.2.8 High cycle fatigue assessment is to be based upon a period of time which is equal to the planned life of the structure.

3.2.9 High cycle related stresses will occur with variable amplitudes of a random nature. The listing of cycles in descending order of amplitude results in the development of a stress spectrum. For each calculation it may be necessary to simplify this spectrum into bands. The stress amplitudes and cycles are to be evaluated from a long-term distribution determined by the structure’s deemed service life.

3.2.10 Fatigue damage assessment must begin by assuming a typical loading sequence and establishment of the number of cycles expected at each stress level during the structure’s service life. For each potential crack location the long-term distribution of relevant stress ranges is to be established and the calculated fatigue life estimated by consideration of cumulative damage. Although fatigue damage is initially slow it increases rapidly towards the end of the structural detail’s fatigue life. A linear relationship between fatigue damage and the number of cycles is often assumed. This is given by Palmgren-Miner’s Law.

3.2.11 The cumulative damage factor, \( D \), according to Palmgren-Miner’s Law is given as:
\[
D = \sum_{i=1}^{k} \frac{n_i}{N_i}
\]
where 
- \( k \) = number of stress range components
- \( n_i \) = expected number of stress cycles in the design spectrum which are assumed to occur for the various stress ranges \( S_i \) corresponding to \( N_i \)
- \( N_i \) = permissible number of stress cycles for each \( S_i \) according to the selected S-N curve.
3.2.12 To satisfy the acceptance criteria, the value of the accumulative damage factor, $D$, has to be less than 1.0.

3.2.13 A diagrammatic illustration of the calculation procedures for the level two and three assessment is given in Fig. 1.3.1.

3.3 Level One Assessment: Structural Detail Design Guide

3.3.1 The Structural Detail Design Guide is based on the extensive knowledge database compiled from the detail design expertise held by Lloyd’s Register’s plan approval and field Surveyors, and it has also been supplemented by analytical, numerical and experimental research work. This has allowed the fatigue performance requirement and the practical considerations necessary for the manufacture of structural details to be taken into account.

3.3.2 The primary purpose of the Guide is to promote good detail design at an early stage in the structural design process by giving consideration to the following aspects:

- Application of fatigue design principles and analysis of fatigue performance.
- Construction tolerances and other practical considerations.
- In-service experience and fatigue performance.

3.3.3 The Guide provides a convenient approach to the design of ship structural details against fatigue by providing guidance for the following items:

- Identification of critical areas within the ship structure for a given ship type.
- Identification of the stress hot spot locations for each of the critical structural details.
- Provision of a set of alternative improved fatigue life configurations from which an appropriate solution can be selected.
- Recommendations on geometrical configurations, scantlings, welding requirements and construction tolerances.

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Fig. 1.3.1
Spectral fatigue analysis procedure (Level two and level three assessment)
3.3.4 Where several configurations are offered for a given structural detail, these are graded in terms of their relative fatigue life performance. Methods of improving fatigue life, such as weld toe grinding, weld dressing, etc., are also described.

3.3.5 The development of the Guide is an on-going process with regular updates to reflect the trends in fatigue life performance as obtained from service experience, as well as evolution and feedback from design and construction practices. The findings from Lloyd’s Register’s ongoing research, including structural detail finite element studies and experimental fatigue testing programme, are also incorporated in the Guide.

3.4 Level Two Assessment: Integrated Simplified Spectral Fatigue Analysis

3.4.1 The Level 2 Assessment utilises an Integrated Spectral Fatigue Analysis procedure which is a first-principles direct calculation procedure. The supporting FDA software is currently applicable to:
- double hull tankers hull longitudinal end-connections;
- bulk carriers hull longitudinal end-connections.

3.4.2 The direct calculation computational procedure is described as follows:
(a) The structural detail fatigue strength characteristics, represented by an appropriate S-N curve, are automatically assigned by the FDA software S-N Curve Expert, using a parametric formulation of the geometrical stress concentration factor derived from systematic finite element analyses of ship structural details.
(b) The wave-induced loads and motions in regular waves are determined from parametric formulations derived from the regression analysis of wave-induced loads and motions in regular waves which have been computed using first-principles methods such as Strip Theory. The procedure allows the determination of the amplitude and the associated phase angle of the global and local loads, and the motions for any ship loading condition, ship speed, wave frequency, and ship heading.
(c) The structural response is determined from first-principles methods using a combination of finite element beam models and analytical procedures. The structural response at each hot-spot location is computed in terms of the influence coefficients associated with each load component applied to the structural member, and the relevant geometrical stress concentration factor. The procedure allows the response of the primary structure to be included in the structural response model.
(d) The short-term total stress response in irregular waves is computed from the structural response influence coefficients, the regular wave load amplitudes and phase angles, and the wave energy spectrum. The stress range is obtained by combining the structural response arising from each load component taking into account the relative phase difference between each structural load component. Where non-linear and/or non-harmonic behaviour of the load component exists, a special time domain simulation method is applied to obtain the resulting stress range.
(e) For every sea state under consideration, the fatigue damage rate and stress reversal frequency are calculated from the short-term stress response statistics and the fatigue strength characteristics of the structural detail.
(f) A voyage simulation is performed for the FDA 100A1 trading pattern for the given ship type, see 3.1.10, to determine the 100A1 Fatigue Wave Environment. Sea-keeping criteria are used in order to simulate the operational procedure.
(g) The accumulated long-term fatigue damage is computed from each individual sea-state contribution using the probability matrix of sea-state occurrence defined by the computed FDA 100A1 trading pattern, the associated short-term fatigue damage rate and stress reversal frequency.
(h) In addition to the 100A1 Fatigue Wave Environment, Owner defined trading pattern can also be specified.
(i) The fatigue performance results are provided in the following formats:
- A deterministic accumulated fatigue damage for a given service life at 97.5 per cent probability of survival.
- A probability of failure for a given number of service years determined from a reliability fatigue model.
3.5 Level Three Assessment: First-Principles Spectral Fatigue Analysis

3.5.1 The FDA Level 3 Assessment is a first-principles direct calculation Spectral Fatigue Analysis procedure applicable to any structural details.

3.5.2 The concept of the FDA Level 3 Assessment is the same as that of FDA Level 2 Assessment except that:

- the ship motions and loads are determined using a first-principles direct calculation procedure of wave-induced loads and motions; and
- the structural response is determined using a top-down finite element analysis procedure, utilising a global finite element model of the ship and local 3-D finite element model of the structural details for a large number of discrete wave-induced load cases.

3.5.3 The concepts and analysis methods used in the FDA Level 3 Assessment are given in LR’s ShipRight Fatigue Design Assessment Procedure - FDA Level 3 Guidance on direct calculations.
Guidance for Designers

Section 1: General

Section 2: Fatigue life improvement methods

1.1 Definition

1.1.1 Critical areas can be defined as locations at which, due to stress concentrations, alignment/discontinuity and corrosion, will have a higher probability of failure during the life of the ship than the surrounding structures. Critical locations are defined as the specific locations within the critical area that can be prone to fatigue damage for which design improvements are provided.

1.2 General

1.2.1 In order to assist the designer and provide the data necessary to perform a fatigue design assessment, Lloyd’s Register has developed an extensive database of structural detail design aspects.

1.2.2 Utilising the results from detailed finite element analyses for an extensive range of structural details, it has been possible to examine a variety of configurations for each detail thereby enabling a grading to be made of their relative fatigue performance.

1.2.3 The outcome from some of this work has been incorporated in this guide. This guide is intended to provide a conservative approach to improving the fatigue life performance of structural details and is applied in conjunction with either the FDA level two or level three assessment procedures.

1.2.4 The designer may use this Guide to improve the detail design arrangements to provide a higher fatigue performance configuration in the case that a fatigue design assessment reveals an unacceptable fatigue life for the original design.

1.2.5 It is intended that the detail design database will be extended to incorporate further detail arrangements, to reflect; in-service experience of fatigue performance, design and construction practices, as well as any significant data made available from research studies.

1.2.6 Additionally, guidance is provided to the designer for other methods to improve the fatigue life performance of the structural detail.

1.3 Application

1.3.1 The detail design improvements provided in this guide are applicable to all grades of steel. This is because the enhancement to fatigue life is achieved by the proposed changes in geometry of the structural details to reduce stress concentrations and improved construction requirements which will ensure a satisfactory performance throughout the design lifetime of the structural detail under the expected stress variations.
Section 2: Fatigue life improvement methods

2.1 General

2.1.1 In general, the presence of a weld in a structural component represents a possible weakness with regard to both brittle fracture and fatigue. The low fatigue life of welded details can be considered as a limiting factor for the design of more efficient structures. Particularly, since the fatigue strength of welded materials does not increase with the yield strength.

2.1.2 The improvement of the fatigue life of a welded structural detail can be achieved in a number of ways during design and production:

(a) Design Stage:
- By adopting a good detail design configuration (e.g. by the provision of soft connections), the geometrical stress concentration factor due to the geometrical discontinuities may be reduced to a satisfactory level.
- By increasing the local scantlings, in particular those of the plate in which the potential crack sites are located, so as to reduce the local hot spot stresses.
- By modifying the structural load path and/or reducing the magnitude of the structural load with the provision of additional load-carrying members.

(b) Fabrication Stage:
- By improving the fatigue life of the detail by using a fabrication stage improvement method as listed in 2.4.1.
- Lloyd’s Register strongly promotes design stage methods for the fatigue strength improvement of ship structural details. Fabrication stage improvement methods should only be considered as remedial measures, and subjected to strict quality control procedures. The operational environment and inspection regime should be considered as these factors can reduce the effectiveness of the improvement over time. Adequate protection against corrosion is recommended, for example, a suitable coating.
- The calculated fatigue life of any welded structural detail at the design stage, prior to applying any fabrication stage improvement methods, must not be less than 20 years for all trading routes considered.

1.3.2 In areas where mild steel may be used, a number of the suggested detail improvements may not be necessary due to the lower stress ranges that these details are likely to experience. However, in areas where higher tensile steel (HTS) is specified, the operating stresses will generally be higher. Therefore, the detail improvements suggested may be more critical in order to meet the fatigue design criteria. In many cases certain improvements may be mandatory.

1.3.3 Alternative structural arrangements may be acceptable, provided it can be demonstrated through a level two or a level three assessment, that a satisfactory fatigue life performance will be maintained throughout the design lifespan. In addition, the structural arrangements, where specified, and scantlings are to satisfy Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships) and, where applicable, the relevant ShipRight Structural Design Assessment (SDA) Procedures.

1.3.4 Where suggested values are indicated regarding geometries or scantlings, these are given as guidance only.
Guidance for Designers

2.2 Significant variables affecting fatigue strength improvement methods

2.2.1 The significant variables affecting the fatigue strength of ship structural details are:
- The notch geometry at the weld toe region is normally the most fatigue critical area in welded structures. Welded joints inherently contain a number of defects, most of which are so sharp that they start growing as fatigue cracks when the structure is subjected to dynamic loads, thus bypassing the crack initiation stage of the fatigue life.
- The fatigue crack is most likely to initiate and propagate in the Heat Affected Zone (HAZ) region, since local metallurgical changes may affect the local fatigue properties of the material. Defects are usually concentrated in this area.
- Residual stresses are set up in and near the weld due to the contraction of the weld metal during the cooling phase. These local residual stresses due to welding may reach yield stress magnitude, and affect the fatigue properties in a similar manner to externally imposed loads. Tensile residual stresses tend to reduce the fatigue strength, while compressive residual stresses may improve the fatigue strength. Attention to residual stresses is not only limited to the welding process, residual stresses may arise due to the restraints applied to the prefabricated units, the forcing of the prefabricated units during assembly, or uneven thermal expansion creating long range residual stresses acting over large areas. These long range residual stresses tend not to be relaxed by the occurrence of peak loads resulting in the so-called shakedown process, or local treatment of the structural detail. However, they are generally of a smaller magnitude compared to welding residual stresses.

2.3 Design stage fatigue strength improvement methods

2.3.1 It is clear that the most efficient method to improve the fatigue strength of welded structural details is at the design stage. To this effect, there are four factors presented in paragraphs 2.3.2 to 2.3.5, which need to be specially considered to improve the fatigue strength of ship structural details:
- Nominal stress levels.
- Stress concentrations due to the structural detail geometry.
- Weld geometry and construction tolerances.
- Residual stresses and construction procedures.

2.3.2 Nominal stress levels:
- The most efficient way to improve fatigue strength and reduce hot spot stresses for a given structural detail is to increase the local scantlings to reduce the nominal stress levels. In general, higher tensile steel structural details require closer attention in terms of detail design compared to a mild steel equivalent structural detail by virtue of the higher stress levels and the constant fatigue strength for weld material of various yield strengths.
- The advantages and disadvantages of this fatigue strength improvement method are summarised in Table 2.3.1.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce stress level</td>
<td>Increase steel weight</td>
</tr>
<tr>
<td>Increase static strength</td>
<td></td>
</tr>
<tr>
<td>Potentially decrease number of structural components and/or complexity required over that for a higher tensile steel structural detail</td>
<td></td>
</tr>
</tbody>
</table>

For plate free edge where the required fatigue design life cannot be achieved practically after consideration of all design options, fabrication improvement may be applied provided that the calculated fatigue life at the design stage, excluding the fabrication improvement, is not less than 17 years for all trading routes considered.

For fabrication stage improvement methods which are not addressed in this document, the quantitative improvement in the fatigue life should be considered based on existing experimental data.

The quantitative improvement in the fatigue life by the application of any fabrication stage improvement methods are to be agreed with Lloyd’s Register.

Where a fabrication stage improvement method is planned at the design stage, it is to be specially considered by Lloyd’s Register and subjected to enhanced survey procedures to ensure that a consistent level of fatigue strength improvement is achieved.

The use of improvement methods should be considered in association with the Construction Monitoring (CM) procedure to ensure that the benefits to be gained by the use of the improvement method are achieved. Adequate inspections are to be carried out. All details of fabrication stage improvements applied are to be recorded in the CM Plan.
2.3.3 Geometrical stress concentration:
- The adoption of a good detail design configuration by the provision of soft connections reduces stress concentration factors due to geometric discontinuities. Typical detail design improvements for the critical areas are provided in Chapters 4, 5 and 6 of this guide for double hull tankers, bulk carriers and containerships respectively. These detail design improvements have been developed from the consolidation of in-service experience, finite element analysis and the experimental fatigue testing of small specimens and large models of ship structures.
- The advantages and disadvantages of the geometrical stress concentration reduction fatigue improvement methods are summarised in Table 2.3.2.

Table 2.3.2 Geometrical stress concentration reduction

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Reduce hot spot stress level by reducing the local geometrical stress concentration.</td>
<td>- May increase steel weight if additional material is required.</td>
</tr>
<tr>
<td>- Effective fatigue strength improvement technique.</td>
<td>- Requires good workmanship where soft toe/heel connections are required.</td>
</tr>
<tr>
<td>- May provide additional structural redundancy.</td>
<td></td>
</tr>
</tbody>
</table>

2.3.4 Weld geometry and construction tolerances:
- At the design stage, special attention may be given to achieve favourable geometry and smooth transitions at the weld toe. This is to minimise secondary stress concentrations which may arise during fit-up and fabrication misalignment. Since the weld notch stress concentration is a direct function of the weld flank angle and the weld toe radius, critical structural details may be specified with an enhanced weld procedure and construction tolerances.
- The advantages and disadvantages of the weld geometry and construction tolerance fatigue improvement methods are summarised in Table 2.3.3.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The improvement may be introduced at the design stage.</td>
<td>- Improvement can be subject to large scatter if not controlled under QA survey conditions.</td>
</tr>
<tr>
<td>- The improvement is performed in the welding process itself.</td>
<td>- Special care should be taken to avoid failure from the weld root (e.g. by applying fuller weld penetration).</td>
</tr>
<tr>
<td>- Subject to well defined inspection plan.</td>
<td></td>
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</tbody>
</table>

2.3.5 Residual stresses and construction procedures:
- The reduction of residual stresses through the adoption of appropriate welding procedures and an appropriate sequence of manufacture for prefabrication units does not constitute a fatigue strength improvement procedure in itself. Nevertheless, careful planning should be considered at the design stage to ensure that detrimental effects will not be introduced during the construction process.

2.4 Fabrication stage fatigue strength improvement methods

2.4.1 Two basic methods to improve the fatigue strength at the fabrication stage are:
(a) Weld geometry control and defect removal methods:
   - Machining method, i.e. grinding.
   - Remelting method, i.e. dressing.
   - Weld profile control, i.e. enhanced workmanship.
(b) Residual stress improvement methods:
   - Peening methods.
   - Thermal stress relief.

2.4.2 The recommendations on weld improvement methods given in this guide are based on IIW Recommendations on Post Weld Improvement of Steel and Aluminium Structures, P. J. Haagensen and S J. Maddox, XIII-2200r1-07, 2007. The following limitations apply:
- The recommendations given do not apply to low-cycle fatigue conditions (i.e. when \( N \leq 5 \times 10^4 \), where \( N \) is the number of cycles to failure).
- Unless otherwise specifically stated, the recommendations apply to the improvement of welded joints with steel plate thicknesses from 6 to 50 mm.
Guidance for Designers

Chapter 2

Section 2

The improvement methods are applied to the weld toe. Thus, they are intended to increase the fatigue life of the weld from the viewpoint of a potential fatigue failure arising at the weld toe. The possibility of failure initiation at other locations must always be considered. For instance, if the failure origin is merely shifted from the weld toe to the root then there may be no significant improvement in the overall fatigue life of the joint. It is emphasised that in general cases improvements to the occurrence of fatigue cracking at the weld root cannot be expected from treatment applied to weld toe. When weld improvements are planned, full penetration welds are to be used to eliminate the possibility of cracking at the weld root. A brief description of each method and the degree of improvement which can be achieved are reviewed in paragraphs 2.4.3 to 2.4.6.

2.4.3 Machining methods

- The removal of corners of free plate edges by means of machining or cutting can improve the fatigue strength of the parent material for plate thickness under 66 mm. Fatigue test results have confirmed that there is no improvement due to machining of the corners for plates with thicknesses of 66 mm and above. The extent of machining is recommended to be not less than one tenth of the thickness of the plate, see Fig. 2.4.1. All visible signs of drag lines should be removed by grinding or machining.

- The weld may be machined using a mechanical grinding method to produce a favourable shape to reduce stress concentrations and remove defects at the weld toe, see Fig. 2.4.2. In order to remove defects such as intrusions, undercuts and cold laps, the material in way of the weld toe should be removed to a depth of 0,5 to 1,0 mm below any undercut. The total depth of the grinding is not to be greater than the lesser of 2 mm or 7 per cent the local thickness of the machined plate. Any undercut not complying with this requirement is to be repaired by an approved method.

- In larger multi-pass welded joints, the high notch stresses in the toe region can extend up to the weld face. Inter-bead toes may also be crack initiation sites. To eliminate this possibility, weld treatment must also be applied to inter-bead toes within a region extending up the weld face by a distance (w) of at least half the leg length L, as illustrated in Fig. 2.4.3. Note that the burr radius has to be scaled to the plate thickness and to the grinding depth. For butt weld joints all inter-bead toes are to be eliminated by grinding.

- The weld throat and leg thickness after grinding must comply with the Rule requirements or any increased weld sizes as indicated on the approved drawings.

- The inspection procedure must include a check on the weld toe radius, the depth of grinding, and confirmation that the weld toe undercut has been removed completely.

- Corrosion pitting of the ground metal surface virtually eliminates the benefit of grinding. Therefore, the ground surface must be adequately protected against corrosion, e.g. by means of a suitable paint system.

- The amount of fatigue life improvement depends on the machining process used and can only be applied in high cycle fatigue conditions.

- The advantages and disadvantages of machining methods for fatigue improvements are summarised in Table 2.4.1.

- The fatigue strength improvement factors that can be achieved by machining are provided in Table 2.4.5. See Ch 2.1.2 for conditions of application.

NOTE

All visible signs of drag lines should be removed from the flame cut edge by grinding or machining. Any flame cut edges are to be subsequently machined or ground smooth.

Fig. 2.4.1

Removal of plate corners
Table 2.4.1 Fatigue improvement methods by machining

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe disc</td>
<td>• Relatively simple and easy to perform&lt;br&gt;• Equipment readily available&lt;br&gt;• Relatively fast&lt;br&gt;• Simple inspection criteria, e.g. 0.5 - 1 mm below plate surface</td>
<td>• Restricted applicability due to tool size&lt;br&gt;• Risk of over-grinding&lt;br&gt;• Reduced control</td>
</tr>
<tr>
<td>grinding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toe burr</td>
<td>• Relatively simple and easy to perform&lt;br&gt;• Wide application&lt;br&gt;• Equipment readily available&lt;br&gt;• Good, repeatable benefits&lt;br&gt;• Simple inspection criteria, i.e. 0.5 - 1 mm below plate surface</td>
<td>• Relatively slow&lt;br&gt;• Grinding chippings</td>
</tr>
<tr>
<td>grinding</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4.4 Weld toe remelting methods

- Remelting the weld toe region (i.e. dressing), generally gives large improvements in fatigue strength since a smooth transition between the plate and the weld metal can be achieved and non-metallic intrusions are melted and removed. TIG weld dressing may be used, provided adequate surface preparation has been completed prior to dressing and the stop/start points are at a location removed from the higher stressed areas. The degree of fatigue life improvement depends on the dressing process used and can be applied in the high cycle fatigue region. Plasma weld dressing generally provides a greater improvement to the fatigue life compared to TIG dressing due to a wider weld pool.
- The advantages and disadvantages of this method of fatigue strength improvement are summarised in Table 2.4.2.
- The improvement factors on fatigue strength that can be achieved by weld toe remelting method are provided in Table 2.4.5. See Ch 2.2.1.2 for conditions of application.
- In larger multi-pass welded joints, the high notch stresses in the toe region can extend up on the weld face, and inter-bead toes may also be crack initiation sites. To eliminate this possibility, the inter-bead toes within a region extending up the weld face by a distance \( w \) of at least half the leg length, \( L \), as illustrated in Fig. 2.4.3, must be treated by a suitable method or removed by grinding. If grinding is adopted to remove the inter-bead toes, the weld throat thickness after grinding must

![Diagram of weld toe remelting methods](image-url)
comply with the Rule requirements or the increased throat thickness as indicated on the approved drawings.

Table 2.4.2  Weld toe remelting methods

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIG dressing</td>
<td>● Good potential for automation &lt;br&gt;● Considered as part of welding process &lt;br&gt;● Large improvements in fatigue strength are possible</td>
<td>● Special workmanship requirement  &lt;br&gt;● Equipment not readily available &lt;br&gt;● Risk of local HAZ hardening &lt;br&gt;● Restricted applicability &lt;br&gt;● Careful cleaning of the weld and plate is necessary</td>
</tr>
<tr>
<td>Plasma dressing</td>
<td>● Good potential for automation &lt;br&gt;● Considered as part of welding process &lt;br&gt;● Provides somewhat larger improvement in fatigue strength than TIG dressing</td>
<td></td>
</tr>
</tbody>
</table>

2.4.5  Weld profile control

● It is considered that instead of employing costly post-weld improvement methods, attention is to be given to achieving favourable geometry and smooth transitions at the weld toe initially. Since the weld notch stress concentration is a direct function of the weld flank angle and the weld toe radius, the weld procedure is to be such that a weld flank angle with a maximum mean value of 50 degrees, or less is specified on the approved drawings and should be achieved together with a weld toe radius with a mean value of 0.5 mm. Careful control of the single pass weld bead may be achieved by applying a secondary weld pass at the toe of the weld to reduce the weld stress concentration factor as shown in Fig. 2.4.4.

● Where the reduction in stress concentration factor due to additional weld bead or extended weld toe (i.e. longer weld leg length) is taken into account in a fatigue assessment to estimate the quantitative improvement in fatigue strength, the weld leg length is not to be taken as greater than half the thickness of the plate where the weld toe is located.

● Another method to improve the weld profile is by means of profiling. This method produces a smooth concave weld shape as shown in Fig. 2.4.5. Full burr grinding is one method that can be used for removing undercut and other weld defects from the weld toe and improving the weld profile. The achieved weld profile is to be of a smooth concave shape. The weld throat thickness after profiling must comply with the Rule requirements or any increased throat thickness as indicated on the approved drawings. Weld flank angles of less than 30° should be achieved at the toe(s) prior to any toe burr grinding being carried out.

● Weld profile control methods are effective in improving the fatigue strength of structural details under high cycle fatigue conditions. The advantages and disadvantages of the weld profile methods of fatigue strength improvements are summarised in Table 2.4.3.

● The improvement factor on fatigue strength that can be achieved by applying full burr grinding is provided in Table 2.4.5. See Ch 2.2.1.2 for conditions of application.
### Guidance for Designers

#### Table 2.4.3 Weld profile control

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional weld bead.</td>
<td>The improvement may be introduced at the design stage.</td>
<td>Improvement can be subject to large scatter if not controlled under QA survey conditions.</td>
</tr>
<tr>
<td>Full burr grinding (weld profiling, see Fig. 2.4.5).</td>
<td>The improvement is achieved through the welding process itself.</td>
<td>Risk of removing too much material and reducing the weld throat thickness.</td>
</tr>
<tr>
<td></td>
<td>Subject to well defined inspection plan, and hence higher reliability.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large improvements in fatigue strength are possible.</td>
<td></td>
</tr>
</tbody>
</table>

#### 2.4.6 Residual stress methods

- Due to the presence of high tensile residual stresses in as-welded joints, applied stresses become fully tensile within the welded area, even if the applied stress cycles are partly compressive. Thus, as-welded components are insensitive to the mean stress of the applied stress range. Residual stress relief or the introduction of beneficial compressive residual stresses can therefore be used to improve the fatigue strength. However, the degree of improvement is strongly dependent on the mean stress of the applied load cycles. Significant improvements due to stress relief are possible only if the applied stress cycles are at least partly compressive.

- Residual stress methods have the effect of ‘clamping’ the weld toe in compression, the result is that an applied tensile stress must first overcome the compressive residual stress before it becomes damaging. Thus, the applied stress range is less damaging. As with all weld improvement methods, residual stress methods can only be used on welded joints that are most likely to fail at the weld toe. Techniques used to introduce compressive residual stress include hammer, needle, shot and ultrasonic peening. In each case, compressive residual stresses are induced by mechanical plastic deformation of the weld toe region. Compressive residual stresses then arise as a result of the constraint imposed by the surrounding elastic material.

- Peening methods are effective in improving the fatigue strength of structural details under high cycle fatigue conditions. The recommendations are only applicable to connections with main plate thickness of at least 4 mm. The amount of improvement in fatigue strength depends on the peening process used.

#### 2.4.7 Table 2.4.5 provides the improvement factors on fatigue strength that can be achieved in a corrosion free condition.

#### 2.4.8 Where a fabrication stage improvement method is used as a means to achieve the required design fatigue life of a structural detail, the improved fatigue life is to be calculated in accordance with Table 2.4.6.
### Table 2.4.4 Residual stress methods

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer and needle peening</td>
<td>• Large improvements in fatigue strength are possible</td>
<td>• Special workmanship requirement</td>
</tr>
<tr>
<td></td>
<td>• Larger areas could be treated with needle peening rather than with hammer peening</td>
<td>• Reduced control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Equipment not readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restricted applicability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Careful cleaning of the weld and plate is necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Risk of cold lap defects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Produce noise and vibration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hammer peening requires small diameter tool (6 – 12 mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Both methods require at least four passes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual inspection is not always sufficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sensitive to applied mean stress – no benefit if the applied stress is tensile with a stress ratio of more than 0.5 or with maximum applied stress above 80 per cent of the yield stress of the material</td>
</tr>
<tr>
<td>Shot peening</td>
<td>• Large improvements in fatigue strength are possible</td>
<td>• Special workmanship requirement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Equipment not readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restricted applicability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Careful cleaning of the weld and plate is necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Produce noise and vibration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Requires high intensity and at least four passes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual inspection is not always sufficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sensitive to applied mean stress – no benefit if the applied stress is tensile with a stress ratio of more than 0.5 or with maximum applied stress above 80 per cent of the yield stress of the material</td>
</tr>
<tr>
<td>Ultrasonic peening (UP) and Ultrasonic Impact Treatment (UIT), see Note</td>
<td>• Large improvements in fatigue strength are possible</td>
<td>• Special workmanship requirement</td>
</tr>
<tr>
<td></td>
<td>• Produces no noise</td>
<td>• Equipment not readily available</td>
</tr>
<tr>
<td></td>
<td>• Tools are compact</td>
<td>• Careful cleaning of the weld and plate is necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sensitive to applied mean stress – no benefit if the applied stress is tensile with a stress ratio of more than 0.5 or with maximum applied stress above 80 per cent of the yield stress of the material</td>
</tr>
</tbody>
</table>

**NOTE**
Currently treatment is only accepted using UIT equipment supplied by Applied Ultrasonics Inc. (USA) or UP equipment supplied by Integrity Testing Laboratory (Canada). Other types of equipment may be considered based on scientifically verified research confirming the effects of the process to enhance fatigue life by the magnitudes seen for UP and UIT. Operators are to be trained to a programme acceptable to Lloyd’s Register.
## Table 2.4.5  Fatigue strength improvement factors

<table>
<thead>
<tr>
<th>Method</th>
<th>Improvement factor on fatigue life, ( f_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld toes (see Notes 1 to 7)</td>
<td></td>
</tr>
<tr>
<td>Disc toe grinding</td>
<td>1.1</td>
</tr>
<tr>
<td>Burr toe grinding</td>
<td>2.0</td>
</tr>
<tr>
<td>TIG and plasma dressing</td>
<td>2.0</td>
</tr>
<tr>
<td>Full burr grinding (toe burr grinding with smooth concave weld profile, see Fig. 2.4.5)</td>
<td>3.0</td>
</tr>
<tr>
<td>Hammer peening</td>
<td>1.3</td>
</tr>
<tr>
<td>Controlled shot peening</td>
<td>2.0</td>
</tr>
<tr>
<td>Ultrasonic peening (UP) and Ultrasonic Impact Treatment (UIT), see Note 7</td>
<td>2.5 minimum yield stress &lt; 315 N/mm²</td>
</tr>
<tr>
<td></td>
<td>3.5 minimum yield stress ≥ 315 N/mm²</td>
</tr>
<tr>
<td>Free edge of parent material (see Notes 2, 4 and 8)</td>
<td></td>
</tr>
<tr>
<td>Removal of plate corners, see Note 8</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Obtain by linear interpolation</td>
<td>66 mm &gt; ( t &gt; 22 ) mm</td>
</tr>
</tbody>
</table>

### NOTES

1. Fatigue strength improvement factors may only be applied to as-welded transverse butt welds, as-welded T and cruciform welds and as-welded longitudinal attachment welds, see ShipRight Fatigue Design Assessment Level 3 Procedure, Table 7.2.1 in Chapter 7.
2. See Ch 2.2.1.2 for conditions of application of fabrication stage fatigue strength improvement methods.
3. When a factor improvement factor of above 1.6 is applied to the weld toes, full penetration welds are to be used to eliminate the possibility of cracking at the weld root. For a lower improvement factor, partial penetration welds in accordance with the Rules for Ships may be used. See 2.4.2.
4. In way of areas prone to mechanical damage, fatigue improvement may only be granted if these are adequately protected.
5. No improvement factor should result in a fatigue life longer than that calculated using the S-N curve given in Table 2.4.7.
6. Treatment of inter-bead toes will be necessary for large multi-pass welds. See 2.4.3, 2.4.4 and 2.4.6.
7. UP and UIT may only be used on single pass electro-gas butt welds for plate thickness in the range from 50 mm to 80 mm.
8. Improved factors may be applied in addition to the improved free edge S-N curves given in Table 7.1.1 in Chapter 7 of ShipRight Fatigue Design Assessment Level 3 procedure.
Guidance for Designers

Table 2.4.6  Fatigue life improvement by fabrication improvement methods

The improved fatigue life by applying the fabrication improvement methods listed in Table 2.4.5 are to be obtained as follows:

\[
FL_{\text{improved}} = f_L \cdot \left( f_L - f_L_{\text{corr}} \right) \cdot FL_{\text{air}} + T_c \quad \text{for } T_c < f_L \cdot FL_{\text{air}}
\]

\[
FL_{\text{improved}} = f_L \cdot FL_{\text{air}} \quad \text{for } T_c \geq f_L \cdot FL_{\text{air}}
\]

Symbols

- \( FL_{\text{improved}} \) fatigue life after the application of the fabrication stage improvement
- \( FL_{\text{air}} \) fatigue life in air, calculated using the design S-N curves in air specified in Lloyd’s Register, ShipRight Fatigue Design Assessment – Level 3 Procedure, Ch 7.1. The acceptable value of \( FL_{\text{air}} \) is to be such that \( FL_{\text{corrected}} \) is not less than 20
- \( FL_{\text{corrected}} \) fatigue life before the application of the fabrication stage improvement, corrected for the effect due to the operational environment where applicable:
  - \( FL_{\text{corrected}} = T_c + f_L \cdot (FL_{\text{air}} - T_c) \quad \text{for } FL_{\text{air}} > T_c \)
  - \( FL_{\text{corrected}} = FL_{\text{air}} \quad \text{for } FL_{\text{air}} \leq T_c \)
- \( f_L \) fatigue life improvement factor as given in Table 2.4.5
- \( f_{L_{\text{corr}}} \) fatigue life improvement factor in a corrosive environment,
  - \( f_{L_{\text{corr}}} = (1 + (f_L - 1) \cdot f_{ic}) \)
  - \( f_{ic} = 0.5 \) for the peening improvement methods listed in Table 2.4.5
  - \( f_{ic} = 1 \) for other improvement methods listed in Table 2.4.5,
  - \( f_{ic} = 1 \) for dry space
- \( T_c \) effective life of the applied coating,
  - \( T_c = 0 \), if no coating is applied
- \( f \) fatigue life reduction factor for operational environment, see Lloyd’s Register’s, ShipRight Fatigue Design Assessment – Level 3 Procedure, Table 7.2.1 in Ch 7.1

Table 2.4.7  Parameters for upper limit S-N curves

| Material | Steel grade | Log \( (K_{fmd}) \) | \( m^2 \) | \( m^2 \) | Stress range \( \Delta S_{N} \) N/mm\(^2\) at \( 10^7 \) cycles | Standard deviation of log \( N \) |
|----------|-------------|-----------------|---|---|-----------------|----------------
|          | Mean | Design | \( N \leq 10^7 \) | \( N > 10^7 \) | Mean | Design |
| Non-welded material, see Note | A and D for all yield stress E and EH27 | 17,72 | 17,32 | 5 | 9 | 139,42 | 115,96 | 0,2 |
| | EH32 and FH32 | 17,84 | 17,44 | 5 | 9 | 147,28 | 122,50 | 0,2 |
| | EH36 and FH36 | 17,98 | 17,58 | 5 | 9 | 156,69 | 130,33 | 0,2 |
| | EH40 and FH40 | 18,03 | 17,63 | 5 | 9 | 160,33 | 133,35 | 0,2 |
| Welded material, see Note | All grades | 12,99 | 12,59 | 3 | 5 | 99,37 | 73,10 | 0,2 |

NOTE
For use in determining the maximum permitted fatigue life improvement factor, see Table 2.4.5, Note 4.
2.5 Summary of fatigue strength improvement methods

2.5.1 In summary, Fig. 2.5.1 provides a typical flow diagram which may be used in the design process of ship structural details to prevent fatigue damage.

![Flow diagram](image_url)

*Fig. 2.5.1*

Design process to prevent fatigue damage
Section 1: Introduction

Section 2: Construction tolerances

Section 3: Defect correction procedures

1.1 General

1.1.1 The fatigue life of structural details can be adversely affected by a variety of imperfections. The most common type of imperfections are:
   (a) misalignment of structural members, poor fit-up;
   (b) welding defects;
   (c) material defects;
   (d) poor manufacture and fabrication procedures resulting in stress concentrations; and
   (e) unfairness of plating.

1.1.2 The actual influence on fatigue life will depend on the number, location and size of such imperfections.

1.1.3 Where design calculations highlight regions of stress concentration then experience clearly indicates that such regions will have a higher probability of failure during the life of the ship than surrounding structures. Hence in such locations there is a need to introduce standards that will reduce or eliminate the number or type of imperfections present.

1.1.4 Basic requirements concerning welding and structural details are given in Pt 3, Ch 10 of Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships). The individual standards employed by Shipbuilders are normally based on individual National Standards (e.g. JSQS), and these supplement the Rule requirements.

1.1.5 Construction and erection criteria in accordance with such standards must inevitably be taken into account in the fatigue life calculation for any structural detail. Whilst it may be anticipated that such criteria may in general, in association with an acceptable detail arrangement, provide for adequate fatigue life, there may well be instances where there is a specific need to introduce construction tolerances that are more rigorous.

1.1.6 In applying the ShipRight Fatigue Design Assessment (FDA) procedure, Lloyd’s Register requires the Shipbuilder to submit details of the intended construction tolerances. Manufacture of the structural details for specified critical areas must then be carried out in accordance with the Rules for Ships and the approved construction tolerances and associated non-destructive examination through the ShipRight Construction Monitoring (CM) procedure.

1.1.7 The Lloyd’s Register Surveyors, in applying the CM procedure, will be required to confirm that the work is carried out in accordance with the approved construction tolerances. Where the approved tolerances are exceeded then corrective action to the satisfaction of the Surveyor will be required. Details of the construction tolerances and defect correction procedures to be applied are generally indicated in the following Sections of this Chapter. Detailed requirements will be agreed between Lloyd’s Register and the Shipbuilder for each ship being considered for the CM notation as part of the ShipRight procedures.
2.3.3 In considering critical locations and their construction standards, it also has to be borne in mind that ship construction is a traditional process with alignment standards based on heel lines. In addition, therefore, to establishing the more critical joints in terms of fatigue life, consideration of the thicknesses to be employed in these joints should be a fundamental factor. If the heel line principle is maintained at the toes of, for example, primary member end brackets, where increased thicknesses are employed, the arrangements will in reality, be out of line, even though perfect alignment is attained to the standard, see Fig. 3.2.1(a). If, however, a median line principle is employed at this local area, a level of improved alignment could be more easily attained. From Lloyd’s Register’s point of view the various thicknesses of plating at structural joints, particularly the higher stress joints, is an important consideration. In this respect the gradient of load through the through-thickness loaded plate is to be controlled to a maximum of one in three, see Fig. 3.2.1(b).

2.3.4 Whenever possible the plate thicknesses, \( t_1 \) and \( t_2 \), (see Fig. 3.2.1) are to be kept as close as possible in order to minimise the potential difficulties associated with a median line alignment.

2.3.5 The alignment of secondary stiffening and associated brackets is also important. Recommendations are made in 2.3.6 and 2.3.7, and illustrated in Fig. 3.2.2.

2.3.6 For asymmetrical sections (inverted rolled angles, bulb plates, fabricated sections), the stiffener or bracket connection to the flange of the secondary stiffening member is to follow the construction standard illustrated in Fig. 3.2.3.

2.3.7 The weld toe is to be clear of the edge of the longitudinal in order to avoid the creation of a notch at the edge of the longitudinal/weld bead interface. Where insufficient space exists to achieve the Rule leg length, then a partial penetration welding procedure is to be adopted to achieve the Rule throat.

2.3.8 Overhang of the weld bead beyond the edge of the longitudinal should be avoided. In cases where weld bead overhang exists, it is to be ground off to form a smooth weld profile at the toe/heel of stiffener and the brackets identified as critical locations.
2.3.9 Where the standard offset distance is impractical in order to achieve proper alignment of the bracket/stiffener with the supporting members, e.g. bracket connection of bottom and inner bottom longitudinals at the end of a partial girder; a deep penetration weld procedure with edge preparation will be incorporated in order to achieve sufficient weld area. In such cases, the welding is likely to cut the edge of the longitudinal at the toe of bracket and the weld flank angle will tend to be higher. Where this occurs, the weld is to be ground to form a smooth profile between the bracket and longitudinal to remove any notches.

2.3.10 The fatigue life predictions obtained utilising the ShipRight FDA Level 2 software take into account the construction standard defined in Fig. 3.2.3.

2.3.11 It is essential that the shipbuilder adheres to this construction standard as the stress gradient varies significantly across the flange of the secondary stiffening member due to the warping behaviour of asymmetrical sections.

2.4 Prefabrication

2.4.1 Throughout the preparation of material and assembly of prefabrication units, the workmanship is to be inspected in order to ensure that correct procedures are being followed. By attention in the early stages of construction, undesirable procedures and faulty workmanship can be avoided, or their consequences minimised, and when the existence of such defects is noticed prompt and suitable measures are to be taken for rectification.
2.4.2 Examination of structure will normally be carried out during the prefabrication of units, and liaison between the Lloyd’s Register Surveyor and the Shipbuilder’s drawing offices and quality control departments will ensure that attention is also given to details which may not have been included on approved plans (air and drainage holes, etc.) during early material preparation stages.

2.4.3 It should be borne in mind that visual examination of welds and plating of a finished structure does not necessarily ensure a complete and satisfactory survey. Procedures are to be such as to ensure that adequate inspection is made of joint preparation before welding. Attention is drawn to the guidance on welding and structural details in Pt 3, Ch 10 of the Rules for Ships. Regular examination by the Lloyd’s Register Surveyor, in conjunction with the Shipbuilder, of non-destructive examination and other Quality records provides a check on the quality of welding operations and any decline in standards is to be investigated, including additional tests as considered desirable.

2.4.4 It is essential that a good standard of cleaning be achieved for these inspections. Welding slag is to be removed and rusting of weld deposits is to be removed by wire brushing.
2.5 Assembly of units

2.5.1 The Shipbuilder and the Lloyd’s Register Surveyors must ensure by regular and systematic examination that the control exercised up to the stage of block assembly is maintained by the efficient erection of blocks at the berth. It is particularly necessary at this point to ensure that fit-up, alignment, adjustment and welding of blocks is in accordance with the approved plans and building standards. Attention is to be given to the sequence of erection and of welding.

2.5.2 With the assembly of large blocks careful attention should be paid to the areas in way of lifting lugs, see Pt 3, Ch 10.5.6.3 of the Rules for Ships. It is not unusual to find small cracks in the vicinity of the weld area after removal of lugs. Where lugs are removed the dressing of the plate must be thorough and magnetic crack detection of the finished surface is good practice. Repair of any cracks found must be carried out by skilled welders under strict control.

2.5.3 Any unusual incidents during construction, such as fracturing of plates, are to be noted and brought to the attention of the Lloyd’s Register Surveyor. It will be necessary to have full information on the circumstances affecting such cases, such as position and extent of the fracture relative to adjacent structure and welds, atmospheric temperature, details of joints, precise stage and sequence of welding, type of electrode used, whether or not pre-heating was used, grades of steel involved and any other factors considered to have had a possible influence. Test details of affected plates and proposals for remedial measures are also to be made available. Where doubt exists in establishing the source of such incidents, the assistance of Lloyd’s Register’s staff at Headquarters, is to be sought.

2.6 Welding type definitions

2.6.1 Where deep penetration welding is required, a bevel plate edge preparation with a root less than or equal to one third of the plate thickness is to be applied. A double bevel plate edge preparation is preferred to a single edge preparation.

2.6.2 A deep penetration weld may be used in lieu of a full penetration weld providing the root of the double bevel plate edge preparation is less than or equal to 3 mm.

Section 3: Defect correction procedures

3.1 Inspection and testing

3.1.1 The fabrication specification is to include the extent of visual inspection and non-destructive examination along with details of the techniques and the appropriate acceptance criteria.

3.1.2 All non-destructive examination is to be carried out in accordance with written procedures, see also Pt 3, Ch 10 of the Rules for Ships.

3.1.3 Quality control levels for weld flaws found by radiographs, ultrasonic testing and magnetic particle inspection are to be approved by Lloyd’s Register and is to be imposed during fabrication as a means of quality control.

3.1.4 Welded joints critical to the integrity of the structure should be subjected to 100 per cent volumetric and/or, where applicable, surface examination during construction. This non-destructive examination is to be carried out prior to delivery, after the completion of welding. Any repairs resulting from the testing are be re-examined.

3.1.5 Any necessary repairs and corrective actions are to be carried out to the satisfaction of the Lloyd’s Register Surveyor and in accordance with an agreed procedure.
Double Hull Oil Tankers

Section 1: Identification of critical areas
Section 2: Structural details

1.1 General

1.1.1 Lloyd’s Register has applied direct calculation procedures in the structural appraisal and approval of new buildings and in various investigations on double hull tankers. Through these procedures and the wealth of information collected on the Lloyd’s Register fleet database, a number of locations have been identified where good design, workmanship and alignment during construction are particularly important. These are usually locations where high stress variations can be experienced during the lifetime of the ship. These are referred to as critical locations and are highlighted in this Chapter.

1.1.2 In order to give clear reference, Section 1 of this Chapter identifies the critical areas together with the nomenclature used to describe the various structural elements of the tanker midship section and transverse bulkheads, see Figs. 4.1.1 and 4.1.2.

1.1.3 In Section 2, the structural detail design improvements that can be applied to increase the fatigue life of the structural components are provided. These detail improvements are intended to give the designer guidance for meeting the design criteria for structural detail components, see Ch 1,3,2.5.

1.1.4 The application of 2 and 3-dimensional finite element analyses techniques to the hull structure enables the global and local capabilities of the hull structure to withstand static and dynamic loadings to be assessed. Such analyses will enable those high stress locations and joints within the cargo area of double hull oil tankers to be readily identified. Such locations will then, by their very nature, be at risk to fatigue damage unless appropriate measures are taken at the design stage and subsequently during construction.

1.1.5 Extensive experience in the application of finite element techniques to existing oil tankers and new double hull oil tankers, together with construction and ‘in-service’ experience of the performance of existing ship structures, already provide an awareness of those critical locations which merit particular attention either due to stress or alignment difficulties.

1.2 Critical areas

1.2.1 Stress concentrations occur in the primary structures of all oil tankers and are identified during the design process by such means as finite element calculations. The designer will modify the detail to alleviate the stress concentration either by re-design or increase in scantlings. However, even after modification that area will still, in general, be exposed throughout the life of the ship to stresses higher than in surrounding areas.
Fig. 4.1.1

Typical midship section nomenclature
Typical transverse bulkhead nomenclature

- Deck
- End bracket
- Vertical stringer
- Inner bottom longitudinal
- Inner bottom
- Tripping brackets
- Section X
- Section Y
- Transverse bulkhead in wing cargo tank
- Vertical stiffeners in centre cargo tank
- Transverse bulkhead plating in way of transverse bulkhead
- Transverse bulkhead plating in wing ballast tank
- Horizontal stringer
- Inner hull longitudinal bulkhead
- Transverse bulkhead
- End bracket
- Buttress
- Face plate
- Bottom shell
- Horizontal stringer
- Longitudinal bulkhead
- Deck
### Table 4.1.1 Locations where correct alignment during construction is important and where high stress variations can be experienced during the lifetime of the ship

<table>
<thead>
<tr>
<th>Double hull tanker type</th>
<th>General location</th>
<th>Items susceptible to higher stress levels and misalignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Typical small tankers (See Figs. 4.1.3 and 4.1.4)</td>
<td>Transverse section (Mid-hold)</td>
<td>Intersection of end brackets of transverse framing and primary webs with inner bottom plating and longitudinal bulkhead.</td>
</tr>
<tr>
<td></td>
<td>Transverse bulkhead (Vertically corrugated)</td>
<td>Connections of corrugations to inner bottom. Connections of corrugations to deck. Connections of deck longitudinals to corrugations.</td>
</tr>
<tr>
<td></td>
<td>Transverse bulkhead (Horizontally corrugated)</td>
<td>Connections of corrugations to longitudinal bulkhead and inner hull. Connection of inner bottom and bottom shell longitudinals to floors in way of lower stool.</td>
</tr>
<tr>
<td>2. Typical larger tankers up to Suezmax size with none or one longitudinal bulkhead (See Figs. 4.1.5, 4.1.6 and 4.1.7)</td>
<td>Transverse section (Mid-hold)</td>
<td>Intersection of inner bottom and lower hopper sloping plate. Intersection of longitudinal bulkhead (inner hull) with lower hopper sloping plate. Side web lower panels above lower hopper especially in way of openings. Connection of deck transverse end bracket to longitudinal bulkhead or topside tank sloping plating. Connection of topside tank sloping plating to longitudinal bulkhead. Side shell longitudinal connections to side web plating particularly in region between ballast and load waterlines. Where centreline longitudinal bulkhead fitted, toes of vertical web brackets to inner bottom, and toes of brackets from deck transverse to bulkheads.</td>
</tr>
<tr>
<td></td>
<td>Transverse bulkhead (Vertically corrugated)</td>
<td>Connection of lower stool to inner bottom plating. Connection of lower stool to lower shelf plate. Connection of vertical corrugations to lower stool plate. Connection of vertical corrugations to upper stool plate. Connection of longitudinal deck girder system to upper stool. Connection of upper and lower shelf plates to side structure.</td>
</tr>
<tr>
<td></td>
<td>Transverse bulkhead (Plane)</td>
<td>Connection of vertical stiffening to inner bottom. Connection of vertical stiffening to horizontal stringers. Connection of horizontal stringers to side girders. Connection of inner bottom and bottom shell longitudinals to floors in way of lower stool.</td>
</tr>
<tr>
<td>3. Typical VLCCs with two longitudinal bulkheads in cargo tanks (See Figs. 4.1.8 and 4.1.9)</td>
<td>Transverse section (Mid-hold)</td>
<td>Intersection of inner bottom and lower hopper sloping plating. Double bottom floor panels at hopper and longitudinal bulkhead. Intersection of inner hull at side with lower hopper sloping plating. Side web lower panels above lower hopper especially in way of openings. Longitudinal bulkhead vertical transverse end bracket connection to inner bottom. Primary bottom bracket web toe connections to inner bottom and longitudinal bulkhead. Connections of wing cargo tank cross tie to inner hull at side. Connection of deck transverse end bracket to inner hull at side and longitudinal bulkhead. Bottom and inner bottom longitudinal connections to double bottom floor pillar stiffeners. Side longitudinal connections to side webs particularly in region between ballast and load waterlines.</td>
</tr>
<tr>
<td></td>
<td>Transverse bulkhead (Plane)</td>
<td>Connection of horizontal stringers to longitudinal bulkhead and inner hull at side. Connection of vertical stiffening to horizontal girders and inner bottom. Connection of side shell and inner hull longitudinals to transverse bulkhead in double side. Connection of inner bottom and bottom shell longitudinals to floor in way of transverse bulkhead.</td>
</tr>
</tbody>
</table>
1.2.2 At the design appraisal stage, a plan of the primary structure can be prepared indicating these regions, and consideration can then be given, by the production team, into the appropriate methods of construction and the tolerances to be applied in order to remain within the assigned design parameters.

1.2.3 In order to give an example of areas where these stress concentrations could be expected, the following sections give general information for double hull tankers. Examples of critical areas are shown in Figs. 4.1.3 to 4.1.9 indicating locations prone to stress concentrations and misalignment.

1.2.4 For the purposes of this guide the terms Aframax and Suezmax refer to tankers in the range 90 000 – 100 000 tonnes dwt and 130 000 – 150 000 tonnes dwt respectively.
1.3 Misalignment during construction

1.3.1 The very nature of shipbuilding requires the assembly of a multitude of structural components into blocks within an assembly shop and then the erection of these blocks within a building dock or on a building berth. The welded interface between structural components in sub-assembly areas can be reasonably controlled; however, the welded connections between large prefabricated blocks in the building dock or on the building berth cannot be so easily controlled due to the sheer size of the blocks being handled.
1.3.2 The most critical type of joint is the welded cruciform joint where it is subjected to high magnitudes of tensile stress normal to the table member of the joint. In double hull tanker designs, the double side and double bottom construction lends itself to the block construction. The interfaces between these blocks and those formed by the primary transverse structure may lie in areas of high stress. Critical cruciform joints are also found within the prefabricated blocks and also require close attention to alignment, but this is more easily achieved.

1.3.3 It can readily be seen that the combination of stress concentration and misalignment is to be avoided if the fatigue strength is to be satisfactory during the service life of the ship.

1.4 Fatigue considerations

1.4.1 The side shell area between load and ballast waterlines is subjected to the highest cyclic loading throughout the ship’s life due to the passage of waves along the side of the ship.

1.4.2 The fatigue fractures in side longitudinal endconnections of higher tensile steel construction in certain single hull VLCC’s has been well documented, and constructional details in way of these connections, designed to increase fatigue life, are now incorporated by many shipyards as standard. It is, therefore, important that due consideration be given to this detail at the design stage to reduce the risk of fatigue cracking during service.

1.4.3 Design improvements are detailed herein for the critical areas, see Section 2. The level two FDA procedure, or if appropriate the level three assessment, may be applied to more accurately assess the fatigue life of end connections prior to considering detail design improvements.
Critical areas in typical transverse bulkheads of double hull VLCC

Fig. 4.1.9
Section 2:  Structural details

2.1  Detail design improvement

2.1.1  For the purposes of this Guide, the double hull oil tanker structural locations have been divided into thirteen separate areas, referred to as Critical Areas, see Table 4.2.1. Each Critical Area contains a number of examples of the locations which may be prone to fatigue damage, referred to as Critical Locations, for which detail design improvements are provided.

2.1.2  A summary of the data presented is given in Table 4.2.1 whilst the full detail improvements are given in Figures 1.1 to 13.1, as contained in this Section.

2.1.3  Generally, where alternative structural detail design improvements are provided, the details are shown in an ascending order of improved fatigue strength. Therefore, when used in conjunction with a level two or a level three assessment, the designer may select which design improvement is the optimum for the design criteria.

2.1.4  Where asymmetrical sections are shown, the same requirements apply to bulb plate stiffeners and flat bars.

2.1.5  By virtue of the low fatigue capability of lapped connections, they are not permitted in association with the FDA notation or descriptive note.

2.2  Minimum detail design improvement

2.2.1  Where a FDA notation is requested, the FDA level one minimum detail design improvement specified in this guide is to be complied with for all primary structural connections. For alternative arrangement of primary structural connections, special consideration will be given by Lloyd’s Register for the need to apply a level three assessment.

2.2.2  A FDA Level 2 assessment is to be carried out to all longitudinal end connections at deck, shell and longitudinal bulkheads. The Structural Detail Design Guide may be used for guidance, in conjunction with FDA Level 2, in achieving the acceptance criteria.

2.2.3  Where only one detail design improvement is proposed, it is to be selected as the structural detail minimum recommendation.

2.2.4  The structural detail improvements given in this design guide are mainly concerned with methods for improving fatigue performance. The designer’s attention is, therefore, drawn to the Rules for Ships, the requirements of which must be satisfied at all times.
### Table 4.2.1 Summary of critical structural details and design improvements

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Critical Area</th>
<th>Example No.</th>
<th>Example title</th>
<th>Figure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connection of side shell and side longitudinal bulkhead longitudinals to transverse webs in double side tanks</td>
<td>1</td>
<td>Asymmetrical higher tensile steel side longitudinals to transverse web flat-bar stiffeners</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Symmetrical higher tensile steel side longitudinals to transverse web flat-bar stiffeners</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Asymmetrical higher tensile steel side longitudinals to transverse web with parallel vertical stiffeners</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Symmetrical higher tensile steel side longitudinals to transverse web with parallel vertical stiffeners</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Higher tensile steel side longitudinals to tripping brackets in way of hopper transverse ring in hopper side tank</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>Connection of bottom shell and inner bottom longitudinals to floors in double bottom tanks</td>
<td>1</td>
<td>Asymmetrical higher tensile steel bottom longitudinals to floor flat-bar stiffeners</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>Connection of side shell and side longitudinal bulkhead longitudinals to transverse bulkheads</td>
<td>1</td>
<td>Higher tensile steel side longitudinals to deep tank bulkhead horizontal stiffeners</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Higher tensile steel side longitudinals to transverse webs in line with oiltight or non-oiltight transverse bulkheads</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>Connection of shell and inner bottom longitudinals to transverse bulkheads</td>
<td>1</td>
<td>Plane oiltight transverse bulkheads. Higher tensile steel bottom shell and inner bottom longitudinals to watertight floor stiffeners</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Corrugated transverse oiltight bulkheads supported by horizontal girders. Higher tensile steel bottom shell and inner bottom longitudinals to watertight floor stiffeners</td>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
<td>Connection of double bottom girders to transverse bulkheads</td>
<td>1</td>
<td>High tensile steel double bottom girders to vertical brackets on plane transverse oiltight bulkheads</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Higher tensile steel girders to vertical webs on vertically corrugated transverse oiltight bulkheads</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Higher tensile steel girders to vertical stiffener end brackets on plane transverse oiltight bulkheads</td>
<td>5.3</td>
</tr>
<tr>
<td>6</td>
<td>Connection of side stringers in double side tanks to transverse bulkheads</td>
<td>1</td>
<td>Higher tensile steel stringers to horizontal girders on plane transverse oiltight bulkheads</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Higher tensile steel stringers to horizontal girders on corrugated transverse oiltight bulkheads</td>
<td>6.2</td>
</tr>
<tr>
<td>7</td>
<td>Connections of floors in double bottom tanks to hopper tanks</td>
<td>1</td>
<td>Hopper corner connections employing welded inner bottom and hopper sloping plating</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Hopper corner connections employing knuckled inner bottom plating</td>
<td>7.2</td>
</tr>
<tr>
<td>8</td>
<td>Connections of transverse webs in side tanks to hopper tanks</td>
<td>1</td>
<td>Hopper corner connections employing welded side longitudinal bulkhead and hopper sloping plating</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Hopper corner connections employing knuckled side longitudinal bulkhead plating</td>
<td>8.2</td>
</tr>
<tr>
<td>9</td>
<td>Connection of cross-ties to transverse webs in double side tanks</td>
<td>1</td>
<td>Cross-ties in wing cargo tanks</td>
<td>9.1</td>
</tr>
<tr>
<td>10</td>
<td>Connection of open primary transverse structures end brackets to floors in double bottom tanks</td>
<td>1</td>
<td>Vertical webs and brackets on inner longitudinal bulkhead to floors – cross-ties in wing cargo tanks</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Vertical webs and brackets on inner longitudinal bulkhead to floors – cross-ties in centre cargo tanks</td>
<td>10.2</td>
</tr>
<tr>
<td>11</td>
<td>Connection of deck transverse end brackets to transverse webs in double side tanks</td>
<td>1</td>
<td>Cross-ties in wing cargo tanks or centre cargo tanks</td>
<td>11.1</td>
</tr>
<tr>
<td>12</td>
<td>Connection of transverse swash bulkhead in wing cargo oil tanks to transverse webs in double side tanks</td>
<td>1</td>
<td>Cross-ties in centre cargo tanks</td>
<td>12.1</td>
</tr>
<tr>
<td>13</td>
<td>Connection of oiltight/non-oiltight centreline bulkhead to centreline girder in double bottom tanks</td>
<td>1</td>
<td>Plane centreline bulkhead</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Note: Figures in this guide are given to illustrate some methods of improving the fatigue life of ship structural details and are not to scale. Dimensions where given are in millimetres.
AREA 1: Connection of side shell and longitudinal bulkhead longitudinals to transverse webs in double side tanks
EXAMPLE No. 1: Asymmetrical face/higher tensile steel side longitudinal connection to transverse web flat-bar stiffener

CRITICAL AREAS

SIDE SHELL SIDE LONGITUDINAL BULKHEAD

CRITICAL LOCATIONS

Max. 15 mm
\[ r = 30 \text{ mm} \]
Max. 15 mm
\[ d = 180 - 300 \text{ mm} \]
Max. 15 mm
\[ t > d/18 \]
\[ r \geq 0.75d \]
\[ r \geq 0.75d \]
\[ d \geq 400 \text{ mm} \]
Min. 1.5d
Min. 300 mm

Minimum Detail Design Improvement
All longitudinals are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.

Critical Location Improvement
Asymmetrical higher tensile steel side longitudinal face plate connections at the heel and the toe of the web stiffeners. Connections between the base line and 0.8D above the base line.

Detail Design Improvement
Soft toe and heel detail or symmetrical soft toe brackets can be used to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

Building Tolerances
Ensure good alignment of the web stiffener, the backing bracket and the web of the side longitudinal.

Welding Requirements
Fillet welding having minimum weld factor of 0.44 (Connection of web stiffeners to face plates of side longitudinals. Backing brackets to face plates of side longitudinals). A wrap around weld, free of undercut or notches, around the heel and toe connections of stiffeners and backing bracket to the longitudinal face plate. See also Pt 3, Ch 10 of Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships).

FIGURE 1.1

DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS
AREA 1: Connection of side shell and side longitudinal bulkhead longituindals to transverse webs in double side tanks
EXAMPLE No. 2: Symmetrical higher tensile steel side longitudinals to transverse web flat-bar stiffeners

CRITICAL AREAS

(a) Soft heel detail improvement

Further detail improvement (soft toe and soft heel)

(b) Symmetrical soft toe and soft backing bracket improvement

Minimum Detail Design Improvement
- Two longitudinals above and four longitudinals below the load waterline are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.
- Four longitudinals above and four longitudinals below the ballast waterline are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.
- All other longitudinals are to be fitted with a soft toe and soft heel detail design improvement.

Critical Location
- Symmetrical higher tensile steel side longitudinal face bar connections at the heel of the web stiffeners. Connections between the base line and 0.8D above the base line.
- Soft heel detail can be used to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

Building Tolerances
- Ensure good alignment of the web stiffener, and the web of the side longitudinal.

Welding Requirements
- Fillet welding having minimum weld factor of 0.44 (Connection of web stiffeners to face plates of side longitudinals). A wrap around weld, free of undercut or notches, around the web stiffener heel and toe connections to the longitudinal face plate. See also Pt 3, Ch 10 of the Rules for Ships.

FIGURE 1.2
DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS
**Double Hull Oil Tankers**

**AREA 1:** Connection of side shell and side longitudinal bulkhead longitudinals to transverse webs in double side tanks

**EXAMPLE No. 3:** Asymmetrical higher tensile steel side longitudinals to transverse web with parallel stiffeners

### Critical Locations

**Section A-A (Anti-tripping stiffener)**

- Critical locations
- \( d = 180 \text{~} 300 \text{ mm} \)
- Area of stiffener in accordance with Rule requirements

**Critically loaded locations**

\[ r \geq 0.75d \]

\[ r \geq 0.75d \]

**Max. 15 mm**

**Side shell**

**Side longitudinal bulkhead**

**Stiffeners parallel to side shell and longitudinal bulkhead**

**Critical locations**

**Max. 15 mm**

**Max. 15 mm**

**Max. 75 mm**

**Max. 75 mm**

**SYM**

**OR Symmetrical soft toe brackets**

- \( r \geq 2.0d \) (min. 400 mm)

- \( r \geq 0.75d \)

- \( d \)

- \( X \geq 1.5d \)

- \( X \geq 0.5d \)

- \( d \)

**Note:**

Bracket thickness = Flat bar thickness = \( d/18 \) (minimum thickness = 12.0 mm)

### Critical Areas

**Detail Design Improvement**

- Soft toe and soft heel detail
- Critical locations
- \( r \geq 0.75d \)

**Max. 15 mm**

**Max. 15 mm**

**Max. 75 mm**

**Max. 75 mm**

**SYM 1.3**

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS**

**Minimum Detail**

**Design Improvement**

All longitudinals are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.

### Critical Location

Asymmetrical higher tensile steel side longitudinal face bar connections at the heel and the toe of the anti-tripping stiffeners. Connections between the base line and 0.8D above the base line.

### Detail Design Improvement

Stiffener soft toe and heel detail or symmetrical soft toe brackets can be used to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

### Building Tolerances

Ensure good alignment of the anti-tripping stiffener, the backing bracket and the web of the side longitudinal.

### Welding Requirements

Fillet welding having minimum weld factor of 0.44 (Connection of anti-tripping stiffeners to face plates of side longitudinals. Backing brackets connecting to face plates of side longitudinals). A wraparound weld, free of undercut or notches, around the web stiffener and backing bracket heel and toe connections to longitudinals. See also Pt 3, Ch 10 of the Rules for Ships.
Area 1: Connection of side shell and side longitudinal bulkhead longitudinals to transverse webs in double side tanks.

Example No. 4: Symmetrical higher tensile steel side longitudinals to transverse web flat-bar stiffeners.

### Critical Areas

#### Critical Locations

- Stiffeners parallel to side shell and longitudinal bulkhead
- Critical locations: $d = 180 - 300 \text{ mm}$
- Area of stiffener in accordance with Rule requirements

#### Detail Design Improvement

- Soft toe and soft heel detail
- Critical locations: $X \geq 0.5d$
- $r \geq 0.75d$
- $d = 75 \text{ mm}$

Or

- Symmetrical soft toe brackets
- Critical locations: $X \geq 1.5d$
- $r \geq 2.0d$ (min. 400 mm)
- $d = 75 \text{ mm}$

#### Design Improvement

All longitudinals are to be fitted with a soft toe and soft heel detail design improvement.

### Critical Location

Symmetrical higher tensile steel side longitudinal face plate connections at the heel and toe of the anti-tripping stiffeners. Connections between the base line and $0.8D$ above the base line.

### Detail Design Improvement

Soft toe and soft heel detail to reduce peak and range of resultant stresses arising from external hydrodynamic pressure and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

### Building Tolerances

Ensure good alignment of the anti-tripping stiffener, and the web of the side longitudinal

### Welding Requirements

Fillet welding having minimum weld factor of 0.44 (Connection of anti-tripping stiffeners to face plates of side longitudinals). A wraparound weld, free of undercut or notches, around the web stiffener heel and toe connections to longitudinals. See also Pt 3, Ch 10 of the Rules for Ships.

### FIGURE 1.4

**Detail Design Guidelines for Double Hull Tanker Structural Details**
### AREA 1: Connection of side shell and side longitudinal bulkhead longitudinals to transverse webs in double side tanks

### EXAMPLE No. 5: Higher tensile steel side longitudinals to tripping brackets in way of hopper transverse ring in hopper side tank

#### CRITICAL AREAS

<table>
<thead>
<tr>
<th>CRITICAL LOCATIONS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td>(a) Further detail improvement (soft toe and soft heel)</td>
</tr>
<tr>
<td><img src="image2" alt="Diagram" /></td>
<td>(b) Symmetrical soft toe and soft backing bracket improvement</td>
</tr>
</tbody>
</table>

#### Critical Location

- Higher tensile steel side shell longitudinal face plate connections at the toe and the heel of the tripping brackets. Connections between the base line and top of the hopper side tank.

#### Detail Design Improvement

- Soft toe and heel detail or soft toe backing bracket to reduce peak and range of resultant stresses arising from cyclic external pressure, and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

- Building Tolerances: Ensure good alignment of the tripping bracket, the backing bracket and the web of the side longitudinal.

- Welding Requirements: Fillet welding having minimum weld factor of 0.3 (Connection of tripping brackets to face plates of side shell longitudinals. Backing bracket connections to face plates of shell longitudinals). A wraparound weld, free of undercut or notches, around the heel and toe of the bracket connection to the longitudinal face plate. See also Pt 3, Ch 10 of the Rules for Ships.

---

**Minimum Detail Design Improvement**: All tripping brackets are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.

---

**Note**: Where depth of tripping bracket is less than 1200 mm the edge stiffener may be omitted provided the free edge has sufficient stability.

- Edge stiffener to stop away from abutting member at a distance of the order of 50 mm.
**AREA 2:** Connection of bottom shell and inner bottom longitudinals to floors in double bottom tanks

**EXAMPLE No. 1:** Asymmetrical higher tensile steel bottom longitudinals to floor flat-bar stiffeners

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**CRITICAL AREAS**

**DETAIL DESIGN IMPROVEMENT**

(a) Soft toe and soft heel detail improvement

(b) Symmetrical soft toe and soft backing bracket improvement

---

**MINIMUM DETAIL**

In way of the hopper tank, all bottom shell longitudinals are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.

In way of the double bottom, all bottom shell longitudinals are to be fitted with a soft toe and soft heel detail design improvement.

**CRITICAL LOCATIONS**

- **Critical locations**
  - $d' = 180 - 300 \text{ mm}$
  - $d > d'/18$
  - $r \geq 0.75d$
  - $r \geq 2.0d$
  - $r \geq 400 \text{ mm}$

**MODEL**

- **Figure 2.1**

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS**

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**CRITICAL LOCATION ASYMETRICAL HIGHER TENSILE STEEL BOTTOM SHELL LONGITUDINALS (E.G. INVERTED ANGLE) CONNECTIONS AT THE TOE AND THE HEEL OF THE FLOOR STIFFENERS.**

**ASYMETRICAL HIGHER TENSILE STEEL BOTTOM SHELL LONGITUDINALS TO FLOOR FLAT-BAR STIFFENERS.**

**SOFT TOE AND HEEL DETAIL OR SYMMETRICAL SOFT TOE BRACKETS TO REDUCE PEAK AND RANGE OF RESULTANT STRESSES ARISING FROM CYCLIC EXTERNAL PRESSURE AND HULL GIRDER LOADING. WHERE A SOFT HEEL DETAIL DESIGN IS ADOPTED, THE REDUCTION OF THE EFFECTIVE CROSS-SECTIONAL AREA OF THE WEB STIFFENER IN TRANSFERRING THE AXIAL LOADING SHOULD BE CONSIDERED IN THE APPLICATION OF THE RULE REQUIREMENTS.**
CRITICAL AREAS

AREA 3: Connection of side shell and side longitudinal bulkhead longitudinals to transverse bulkheads
EXAMPLE No. 1: Higher tensile steel side longitudinals to deep tank bulkhead horizontal stiffeners

CRITICAL LOCATIONS

Critical locations

SIDE SHELL Side longitudinal bulkhead

Transverse deep tank bulkhead in wing ballast tank

Transverse oiltight bulkhead in cargo tank

Symmetrical soft toe and backing bracket

Max 15 mm

$r \geq 2.0d$

(min 400 mm)

$X \geq 1.5d$

(min 300 mm)

$X \geq 1.0d$

$X \geq 1.5d$

Max 15 mm

$r \geq 1.5d$

Note:
Bracket material = Higher tensile steel
Bracket thickness = $d/22$
Minimum thickness = 12 mm

Minimum Detail Design Improvement
As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e. symmetrical soft toe brackets.

Critical Location
Higher tensile steel side longitudinal face plate connections at the toe of the end brackets and heel of the deep tank stiffeners. Connections between the upper turn of bilge and 0.8D above the base line.

Detail Design Improvement
Symmetrical soft toe, higher tensile steel brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading. Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

Building Tolerances
Ensure good alignment of the web of bulkhead horizontal stiffener, the soft toe brackets and the web of the side longitudinal.

Welding Requirements
Fillet welding having minimum weld factor of 0.34 (Connection of soft toe brackets to face plates of side longitudinals and to webs of horizontal stiffeners). A wraparound weld, free of undercut or notches, around the heel connections of bulkhead stiffener and the toe connection of brackets. See also Pt 3, Ch 10 of the Rules for Ships.

DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS

FIGURE 3.1
### AREA 3:

**Connection of side shell and side longitudinal bulkhead longitudinals to transverse bulkheads**

**EXAMPLE No. 2:**

Higher tensile steel side longitudinals to transverse webs in line with transverse oiltight or non-oiltight bulkheads

### CRITICAL AREAS

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side shell</td>
<td>Symmetrical soft toe and backing bracket</td>
</tr>
<tr>
<td>Side longitudinal bulkhead</td>
<td></td>
</tr>
<tr>
<td>Transverse web</td>
<td></td>
</tr>
<tr>
<td>Oiltight or non-oiltight bulkhead</td>
<td></td>
</tr>
</tbody>
</table>

### CRITICAL LOCATIONS

**Minimum Detail Design Improvement:**

As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e. symmetrical soft toe brackets.

**Critical Location:**

Higher tensile steel side longitudinal face plate connections at the toe and heel of the web stiffeners. Connections between the upper turn of bilge and 0.8D above the base line.

**Detail Design Improvement:**

Symmetrical soft toe, higher tensile steel brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading.

**Building Tolerances:**

Ensure good alignment of the stiffener, the backing bracket and the web of the side longitudinal.

**Welding Requirements:**

Fillet welding having minimum weld factor of 0.44 (Connection of web stiffeners to face plates of side longitudinals. Soft toe bracket connections to face plates of side longitudinals). A wraparound weld, free of undercut or notches, around the heel and toe of stiffener and bracket connections to longitudinal face plate. See also Pt 3, Ch 10 of the Rules for Ships.

### FIGURE 3.2

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS**
**Area 4**: Connection of bottom shell and inner bottom longitudinals to transverse bulkheads

**Example No. 1**: Plane transverse oiltight bulkheads. Higher tensile steel bottom shell and inner bottom longitudinals to watertight floor stiffeners

---

### Critical Areas

- **Critical Locations**

### Detailed Design Improvement

- Flanged bracket
- Critical locations
- Increased web depth and symmetrical soft toe brackets
- Critical locations
- Soft toe bracket with edge stiffener

---

**Minimum Detail**

As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e., increased depth of web stiffener and symmetrical soft toe and backing brackets.

**Critical Location**

- Higher tensile steel bottom shell and inner bottom longitudinal face plate connections at the toe of the end brackets and the heel of the watertight floor stiffeners.

**Detail Design Improvement**

- Increased web depth of the watertight floor stiffeners up to the depth of the oiltight bulkhead vertical stiffeners above and provision of higher tensile steel symmetrical soft toe brackets to reduce peak and resultant range arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder loading.

**Building Tolerances**

- Ensure good alignment of the floor stiffeners, the soft toe brackets and the web of the longitudinals.

**Welding Requirements**

- Fillet welding having minimum weld factor of 0.34 (Connection of soft toe brackets to face plates of bottom and inner bottom longitudinals and to face plates of watertight floor stiffeners). A wraparound weld, free of undercut or notches, around the floor stiffener heel and the heel and toe of bracket connections to longitudinals. See also Pt 3, Ch 10 of the Rules for Ships.

---

**Figure 4.1**

**Detail Design Guidelines for Double Hull Tanker Structural Details**

---

**Lloyd’s Register**
**AREA 4:**
Connection of bottom shell and inner bottom longitudinals to transverse bulkheads

**EXAMPLE No. 2:**
Corrugated transverse oiltight bulkheads supported by horizontal girders. Higher tensile steel bottom shell and inner bottom longitudinals to watertight floor stiffener

**CRITICAL AREAS**

**DETAILED DESIGN IMPROVEMENT**

Note: The detail design improvement as shown should only be applied to small tankers with a corrugation span of less than 6 metres

Increased depth of watertight floor stiffeners with transverse carlings and symmetrical soft toe brackets

**MINIMUM DETAIL**
As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e. increased depth of floor stiffener and symmetrical soft toe and backing brackets.

**CRITICAL LOCATIONS**

**MINIMUM DETAIL**
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**CRITICAL LOCATIONS**

**MINIMUM DETAIL**
As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e. increased depth of floor stiffener and symmetrical soft toe and backing brackets.

**CRITICAL LOCATIONS**

**MINIMUM DETAIL**
As a minimum, all longitudinals are to be fitted with the detail design improvement, i.e. increased depth of floor stiffener and symmetrical soft toe and backing brackets.
**Table of Contents**

**Critical Locations**
- Plane oiltight bulkhead
- Critical location
- Bottom shell

**Critical Areas**

**Connection of double bottom girders to transverse bulkheads**

**Example No. 1**
- Higher tensile steel; girders to vertical; brackets on plane transverse oiltight bulkheads

**Diagram with Details**

**Critical Location**
- Toe connections of vertical brackets to double bottom girders.

**Design Improvement**
- Soft toe detail with full penetration welding; or
- Parallel toe detail with deep penetration welding.

**Building Tolerances**
- Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and bottom girder web thickness should not exceed 1/3 of the inner bottom thickness.

**Welding Requirements**
- Deep penetration welding (Connection of bracket toes to inner bottom plating). Deep penetration welding or fillet welding having minimum weld factor of 0.44 (Connection of double bottom girder webs in way of bracket toes to inner bottom plating). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. A wraparound weld, free of undercut or notches, in way of bracket toe connections to the inner bottom plating. See also Pt 3, Ch 10 of the Rules for Ships.
### Chapter 4

**SECTION 2**

#### Lloyd's Register

<table>
<thead>
<tr>
<th>Area 5:</th>
<th>Connection of bottom girders in double bottom tanks to transverse bulkheads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example No. 2:</td>
<td>Higher tensile steel girders to vertical webs on vertically corrugated transverse oiltight bulkheads</td>
</tr>
</tbody>
</table>

#### Critical Areas

<table>
<thead>
<tr>
<th>Critical Locations</th>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracket Toes</td>
<td>Critical locations</td>
</tr>
<tr>
<td></td>
<td>Upper horizontal girder</td>
</tr>
<tr>
<td></td>
<td>Corrugated oiltight bulkhead</td>
</tr>
<tr>
<td></td>
<td>Lower horizontal girder</td>
</tr>
<tr>
<td></td>
<td>Inner bottom</td>
</tr>
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<td></td>
<td>Bottom shell</td>
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<tr>
<td></td>
<td>Critical locations</td>
</tr>
<tr>
<td></td>
<td>Taper 1 : 6 (approx.)</td>
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<tr>
<td></td>
<td>Deep penetration welding</td>
</tr>
<tr>
<td></td>
<td>root $R \leq \frac{1}{3}t$</td>
</tr>
<tr>
<td>Soft toe detail</td>
<td>$\theta \leq 15$</td>
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<tr>
<td></td>
<td>$f$</td>
</tr>
<tr>
<td></td>
<td>$\theta$</td>
</tr>
<tr>
<td>Or parallel toe detail</td>
<td>$\theta = 0$</td>
</tr>
<tr>
<td></td>
<td>Deep penetration welding</td>
</tr>
<tr>
<td></td>
<td>root $R \leq \frac{1}{3}t$</td>
</tr>
</tbody>
</table>

Minimum Detail

As a minimum, the detail design improvement is to be fitted with:
- Soft toe detail with full penetration welding; or
- Parallel toe detail with deep penetration welding.

Alternative arrangements will be considered.

#### Critical Location

**Design Improvement**

- Toe connections of vertical web end brackets to bottom girders in double bottom tanks.
- Soft toe or parallel toe detail to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder global loading.
- Enhanced good alignment standard. The nominal distance between the centres of bracket toe thickness and bottom girder web thickness should not exceed 1/3 of the inner bottom thickness.
- Deep penetration welding (Connection of bracket toes to inner bottom plating). Deep penetration welding or fillet welding having minimum weld factor of 0.44 (Double bottom girder webs in way of bracket toes to inner bottom plating). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. A wrap around weld, free of undercut or notches, around the bracket toes. See also Pt 3, Ch 10 of the Rules for Ships.
### AREA 5:
Connection of bottom girders in double bottom tanks to transverse bulkheads.

### EXAMPLE No. 3:
Higher tensile steel girders to vertical stiffener end brackets on plane transverse oiltight bulkheads.

### CRITICAL AREAS

<table>
<thead>
<tr>
<th><strong>CRITICAL LOCATIONS</strong></th>
<th><strong>DETAIL DESIGN IMPROVEMENT</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracket Toes</td>
<td></td>
</tr>
<tr>
<td>Critical locations</td>
<td></td>
</tr>
<tr>
<td>Plane oiltight bulkhead</td>
<td></td>
</tr>
<tr>
<td>Inner bottom</td>
<td></td>
</tr>
<tr>
<td>Bottom shell</td>
<td></td>
</tr>
</tbody>
</table>

### CRITICAL LOCATIONS

**Bracket Toes**

**Critical locations**

**Plane oiltight bulkhead**

**Inner bottom**

**Bottom shell**

### Minimum Detail Design Improvement

As a minimum, the detail design improvement is to be fitted, i.e. integral soft toe bracket.

### Critical Location

Toe connections of vertical stiffener end brackets to bottom girders in double bottom tanks and vertical stiffeners.

### Detail Design Improvement

Integral soft toe bracket to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder global loading.

### Building Tolerances

Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and bottom girder web thickness should not exceed 1/3 of the inner bottom thickness.

### Welding Requirements

Fillet welding having minimum weld factor of 0.44 (Connection of end brackets to inner bottom plating). A wraparound weld, free of undercut or notches, around the bracket toe. A small scallop of suitable shape, which is to be closed by welding after completion of the continuous welding of bulkhead, is to be provided where scallop is eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 6: Connection of side stringers in double side tanks to transverse bulkheads
EXAMPLE No. 1: Higher tensile stringers to horizontal girders on plane oiltight transverse bulkheads

**CRITICAL AREAS**

<table>
<thead>
<tr>
<th>CRITICAL LOCATIONS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical location 1</td>
<td>Toe connection of horizontal girder end brackets to side stringers in double side tanks (LOCATION 1). Intersections of webs of horizontal girders and side stringers forming square corners (LOCATION 2). Toe of horizontal stringers to be fitted with soft toe detail with full penetration welding or parallel toe detail with deep penetration welding as shown in Area No.5, Example No.1 (LOCATION 2). Elimination of scallops in way of cruciform joint and fitting of a localised ‘D’ grade steel insert plate, with minimum thickness of 7 mm in addition to the Rule required thickness, to reduce the peak and range of resultant stresses arising from cyclic cargo inertia pressure and hull girder global loading. In addition, a soft toed backing bracket of suitable dimension is to be fitted (LOCATION 2).</td>
</tr>
<tr>
<td>Critical location 2</td>
<td>Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness (LOCATION 1 and LOCATION 2).</td>
</tr>
</tbody>
</table>

**Building Tolerances**

- Deep penetration welding (Connection of bracket toes in LOCATION 1). Fillet welding having minimum weld factor of 0.44 (Side stringer webs in way of bracket toes in LOCATION 1 and all connections in LOCATION 2). The extent of full penetration is to be of the order 2 - 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. A wraparound weld, free of undercut or notches, around the plate thickness. A small scallop of suitable shape, which is to be closed by welding after completion of the continuous welding of bulkhead, is to be provided where scallop is eliminated. See also Pt 3, Ch 10 of the Rules for Ships.

**Welding Requirements**

- As a minimum, the detail design improvement is to be fitted.

See also Pt 3, Ch 10 of the Rules for Ships.
Area 6: Connection of side girders in double bottom tanks to transverse bulkheads

Example No. 2: Higher tensile steel girders to horizontal webs on corrugated oiltight transverse bulkheads

Critical areas

Critical locations

Minimum detail improvement

As a minimum, the detail design improvement is to be fitted with:

- Soft toe detail with full penetration welding; or
- Parallel toe detail with deep penetration welding.

Alternative arrangements will be considered.

Critical location

Detail design improvement

Toe connections of horizontal girder end brackets to side stringers in double side tanks.

Improvement of bracket toe detail similar to those shown in Area No.5 Example No.1.

Building tolerances

Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and side stringer web thickness should not exceed 1/3 of side longitudinal bulkhead thickness.

Welding requirements

Deep penetration welding (Connection of bracket toes to side longitudinal bulkheads). Fillet welding having minimum weld factor of 0.44 (Side stringer webs in way of bracket toes to side longitudinal bulkheads). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Wraparound weld, free of undercut or notches, around the plate thickness.

See also Pt 3, Ch 10 of the Rules for Ships.

Detail design guidelines for double hull tanker structural details

Figure 6.2
AREA 7: Connections of floors in double bottom tanks to hopper tanks
EXAMPLE No. 1: Hopper corner connections employing welded inner bottom and hopper sloping plating

CRITICAL AREAS

SECTION 2

CRITICAL LOCATIONS

Notes:
’Z’ grade steel may be required in accordance with Pt 3, Ch 2.2 of the Rules for Ships.
Grinding need not be applied in the No.1 hold in which floor spans are reduced due to shape.
Grinding need not be applied for the knuckle joints at transverse bulkhead positions, or at the floor adjacent to the transverse bulkhead.

Minimum Detail As a minimum, the detail design improvement is to be fitted.
Design Improvement Further consideration will be given where hopper angle, $Q$, exceeds 50°.
The ground surface should be protected by a stripe coat of suitable paint composition where the lower hopper knuckle region of cargo oil tanks is not coated.

Critical Location Hopper sloping plating connections to inner bottom plating in way of floors. Floor connections to inner bottom plating and side girders in way of hopper corners.
Detail Design Improvement Elimination of scallops in way of hopper corners, extension of inner bottom plating to reduce level of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder loads.
Building Tolerances Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness.
Welding Requirements Deep penetration welding and weld dressing (hopper sloping plating to inner bottom plating). Deep penetration weld (connection of floors to inner bottom plating and to side girders, connection of hopper transverse webs to sloping plating, to inner bottom plating, connection of hopper transverse webs to sloping plating, to inner bottom plating and to side girders in way of hopper corners).

FIGURE 7.1 DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS
**Area 7:** Connections of floors in double bottom tanks to hopper tanks

**Example No. 2:** Hopper corner connections employing knuckled inner bottom plating

### Critical Areas

<table>
<thead>
<tr>
<th>View A</th>
<th>View A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper</td>
<td>View A</td>
</tr>
</tbody>
</table>

### Critical Locations

#### View A

- Critical location: 100 – 150 mm

#### View B

- Critical location: 100 – 150 mm

### Detail Design Improvement

- **Knuckle radius:** Not to be less than 5 x \( t \) or 100 mm, where \( t \) is the plate thickness.

- **Elimination of scallops:** Closer knuckle distance from side girder and additional longitudinal/transverse brackets.

#### Section A-A

- **Deep penetration welding:**

#### Section B-B

- **Transverse bracket**

#### Section C-C

- **Girder**
- **Longitudinal bracket**

### Minimum Detail Design Improvement
As a minimum, the detail design improvement is to be fitted.

### Critical Location
- Side girder connections to inner bottom plating in way of floors. Floor and hopper transverse web connections to inner bottom plating and to side girders in way of hopper corners.

### Detail Design Improvement
- Elimination of scallops in way of hopper corners, closer knuckle distance from side girders and additional transverse brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure, and hull girder global loading.

### Building Tolerances
- Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members (e.g. floor and hopper web plate and additional supporting brackets) should not exceed 1/3 of the table member thickness.

### Welding Requirements
- Deep penetration welding (Connection of side girders to inner bottom plating. Connection of floors to inner bottom plating and to side girders. Connection of hopper transverse webs to sloped inner bottom plating and to side girders in way of hopper corners). Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of side girders to inner bottom plating, are to be provided where scallops are eliminated.

See also Pt 3, Ch 10 of the Rules for Ships.
### AREA 8: Connection of transverse webs in double side tanks to hopper tanks

#### EXAMPLE No. 1: Hopper corner connections employing welded side longitudinal bulkhead and hopper sloping plating

#### CRITICAL AREAS

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>SIDE LONGITUDINAL BULKHEAD CONNECTIONS TO SIDE STRINGERS IN WAY OF TRANSVERSE WEBs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Location</td>
<td>Transverse webs to side longitudinal bulkhead and to side stringers in way of hopper corners. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of hopper sloping plating and side stringers to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.</td>
</tr>
</tbody>
</table>

#### DETAIL DESIGN IMPROVEMENT

- Elimination of scallops and addition of intermediate transverse brackets

#### Minimum Detail Design Improvement

As a minimum, the detail design improvement is to be fitted.

#### Critical Location

- Side longitudinal bulkhead connections to side stringers in way of transverse webs.

#### Detail Design Improvement

- Elimination of scallops in way of hopper corners and extension of side longitudinal bulkhead to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia pressure and hull girder global loading.

#### Building Tolerances

- Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness.

#### Welding Requirements

- Deep penetration welding (Connection of hopper sloping plating to side longitudinal bulkheads, Connection of side stringers to side longitudinal bulkhead. Connection of transverse webs to side longitudinal bulkhead and to side stringers. Connection of hopper transverse webs to sloping plating, to side longitudinal bulkhead and to side stringers in way of hopper corners). Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of hopper sloping plating and side stringers to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
### Critical Locations

- **Side longitudinal bulkhead**
- **Side stringer**
- **Transverse web**
- **Hopper transverse ring**
- **Knuckle line**

**Connections**
- Side stringer connections to side longitudinal bulkhead in way of transverse webs. Double side tank transverse web and hopper transverse web connections to side longitudinal bulkhead and to side stringers in way of hopper corners.

**Welding Requirements**
- Deep penetration welding (Connection of side stringers to side longitudinal bulkhead. Connection of double side tank transverse webs to side longitudinal bulkhead and to side stringers. Connection of hopper transverse webs to sloped side longitudinal bulkhead and to side stringers in way of hopper corners). Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of side stringers to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.

**Building Tolerances**
- Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness.

### Critical Areas

- **SECTION B-B**
- **Section C-C**

**Critical Design Improvements**

- Knuckle radius not to be less than 5 \( t \) or 100 mm, where \( t \) is the plate thickness.
- Elimination of scallops, closer knuckle distance from side girder and additional longitudinal/transverse brackets.

**Minimum Detail Design Improvement**

As a minimum, the detail design improvement is to be fitted.

---

**FIGURE 8.2**

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER**

**STRUCTURAL DETAILS**
### AREA 9: Connection of cross-ties to transverse webs in double side tanks

**EXAMPLE No. 1:** Cross-ties in wing cargo tanks

### CRITICAL AREAS

<table>
<thead>
<tr>
<th>CRITICAL LOCATIONS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side shell plating</td>
<td>Modification from lapped collars to slit-type collars, elimination of scallops and improvement of bracket toe details similar to those shown in Group No. 5 Example No. 1</td>
</tr>
<tr>
<td>Transverse web</td>
<td>Soft toe or parallel toe detail</td>
</tr>
<tr>
<td>Side longitudinal bulkhead</td>
<td>Silt-type collars or insert collars as per marked * example</td>
</tr>
<tr>
<td>Side stringer</td>
<td></td>
</tr>
<tr>
<td>Cross-tie</td>
<td></td>
</tr>
<tr>
<td>Hopper sloping plating</td>
<td></td>
</tr>
</tbody>
</table>

**Minimum Detail Design Improvement:**

As a minimum, the detail design improvement is to be fitted with:
- Soft toe detail with full penetration welding;
- Parallel toe detail with deep penetration welding, as per Figure 5.1.

**Critical Location Detail Design Improvement:**

- Toe connections of cross-tie end brackets to transverse webs in double side tanks.
- Silt type collars, elimination of scallops and soft toe or parallel toe detail to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and cargo inertia pressure.

**Building Tolerances:**

Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and transverse web thickness should not exceed 1/3 of the side longitudinal bulkhead thickness.

**Welding Requirements:**

Deep penetration welding (Connection of bracket toes to side longitudinal bulkhead). Fillet welding having minimum weld factor of 0.44 (Connection of transverse webs in way of bracket toes to side longitudinal bulkhead). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of longitudinal bulkhead stiffeners to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
### AREA 10: Connection of open primary transverse structures end brackets to floors in double bottom tanks

#### EXAMPLE No. 1: Vertical webs and brackets on inner longitudinal bulkhead to floors – Cross-ties in wing cargo tanks

#### CRITICAL AREAS:
- **Bottom shell**
- **Vertical web**
- **Inner longitudinal bulkhead**

#### CRITICAL LOCATIONS:
- **Critical locations**

#### DETAIL DESIGN IMPROVEMENT:
- **Critical locations**
- **Modification from lapped collars to slit-type collars, elimination of scallops and improvement of bracket toe details similar to those shown in Group No. 5 Example No. 1**
- **Soft toe or parallel toe detail**
- **No scallops**
- **Slit-type collars or insert collars as per marked + example**

### Minimum Detail Design Improvement

As a minimum, the detail design improvement is to be fitted with:
- Soft toe detail with full penetration welding; or
- Parallel toe detail with deep penetration welding, as per Figure 5.1.

### Critical Location Detail Design Improvement

- Toe connections of vertical web end brackets to floors in double bottom tanks.
- Slit type collars, elimination of scallops and soft toe or parallel toe detail to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and cargo inertia pressure.

### Building Tolerances

Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and transverse web thickness should not exceed 1/3 of the inner bottom plating thickness.

### Welding Requirements

Deep penetration welding (Connection of bracket toes to inner bottom plating). Fillet welding having minimum weld factor of 0.44 (Connection of floors in way of bracket toes to inner bottom plating). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of inner bottom longitudinals to inner bottom plating, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.

---

**FIGURE 10.1**

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS**
AREA 10: Connection of open primary transverse structures end brackets to floors in double bottom tanks
EXAMPLE No. 2: Vertical webs and brackets on inner longitudinal bulkhead to floors – Cross-ties in centre cargo tanks

CRITICAL AREAS

CRITICAL LOCATIONS

Minimum Detail Design Improvement
As a minimum, the detail design improvement is to be fitted with:
- Soft toe detail with full penetration welding;
- Parallel toe detail with deep penetration welding, as per Figure 5.1.

Critical Location Detail Design Improvement
Toe connections of vertical web end brackets to floors in double bottom tanks.
Silt type collars, elimination of scallops and soft toe or parallel toe detail to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressure and cargo inertia pressure.

Building Tolerances
Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and floor thickness should not exceed 1/3 of the inner bottom plating thickness.

Welding Requirements
Deep penetration welding (Connection of bracket toes to inner bottom plating). Fillet welding having minimum weld factor of 0.44 (Connection of floors in way of bracket toes to inner bottom plating). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of inner bottom longitudinals to inner bottom plating, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
Double Hull Oil Tankers

AREA 11: Connection of deck transverse end brackets to transverse webs in double side tanks
EXAMPLE No. 1: Cross-ties in wing cargo tanks or centre cargo tanks

CRITICAL AREAS

CRITICAL LOCATIONS

Critical Location Toe connections of deck transverse end brackets to transverse webs in double side tanks.

Detail Design Improvement
- Soft toe detail with full penetration welding; or
- Parallel toe detail with deep penetration welding, as per Figure 5.1.

Building Tolerances
Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and transverse web thickness should not exceed 1/3 of the side longitudinal bulkhead thickness.

Welding Requirements
Deep penetration welding (Connection of bracket toes to side longitudinal bulkhead). Fillet welding having minimum weld factor of 0.44 (Connection of transverse webs in way of bracket toes to side longitudinal bulkhead). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of longitudinal bulkhead stiffeners to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
## AREA 12: Connection of transverse swash bulkhead wing cargo oil tanks to transverse webs in double side tanks

**EXAMPLE No. 1:** Cross-ties in centre cargo tanks

### CRITICAL AREAS

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Toe connection of transverse swash bulkhead end brackets to transverse webs in double side tanks.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Location</td>
<td>Slit type collars, elimination of scallops and soft toe or parallel toe detail to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and cargo inertia pressure.</td>
</tr>
<tr>
<td>Building Tolerances</td>
<td>Enhanced alignment standard. The nominal distance between the centres of bracket toe thickness and transverse web thickness should not exceed 1/3 of the side longitudinal bulkhead thickness.</td>
</tr>
<tr>
<td>Welding Requirements</td>
<td>Deep penetration welding (Connection of bracket toes to side longitudinal bulkhead). Fillet welding having minimum weld factor of 0.44 (Connection of transverse webs in way of bracket toes to side longitudinal bulkhead). The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of longitudinal bulkhead stiffeners to longitudinal bulkhead, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.</td>
</tr>
</tbody>
</table>

---

**FIGURE 12.1**

**DETAIL DESIGN GUIDELINES FOR DOUBLE HULL TANKER STRUCTURAL DETAILS**
### AREA 13: Connection of oiltight/non-oiltight centreline bulkhead to double bottom centreline girder

**EXAMPLE No. 1:** Plane centreline bulkhead

#### CRITICAL AREAS

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical location 1</td>
<td>Similar to those shown in Group No.10, Examples No. 1 and 2</td>
</tr>
<tr>
<td>Critical location 2</td>
<td>Lowest strake of centreline bulkhead (abutting member)</td>
</tr>
</tbody>
</table>

#### CRITICAL LOCATIONS

![Diagram of critical locations](image)

#### VERTICAL WEB

- Critical location 1: Oiltight or non-oiltight bulkhead
- Critical location 2: Bottom shell

#### ACCESS OPENINGS

(in case of non-oiltight bulkhead)

#### MINIMUM DETAIL

- For critical location 1, as a minimum, the detail design improvement is to be fitted with:
  - Soft toe detail with full penetration welding;
  - Parallel toe detail with deep penetration welding, as per Figure 5.1.

#### TOE CONNECTIONS

- Connections of double bottom centre girder to inner bottom plating (LOCATION 2).

#### BUILDING TOLERANCES

- Enhanced alignment standard. The nominal distance between the centres of thickness of the two abutting members should not exceed 1/3 of the table member thickness (LOCATION 1 and LOCATION 2).

#### WELDING REQUIREMENTS

- Deep penetration welding (Connection of bracket toes in LOCATION 1 and where abutting member thickness ≥ 25 mm in LOCATION 1).
- Fillet welding having minimum weld factor of 0.44 (Connection of floors in way of bracket toes in LOCATION 1 and where abutting member thickness < 25 mm in LOCATION 2).

- The extent of full penetration is to be of the order 2 – 3 longitudinal spacings, or back to the first bracket web stiffener, or as agreed with the Plan Approval Surveyor. Small scallops of suitable shape, which are to be closed by welding after completion of the continuous welding of inner bottom longitudinals to inner bottom plating, are to be provided where scallops are eliminated. See also Pt 3, Ch 10 of the Rules for Ships.
Section 1: Identification of critical areas

1.1 General

1.1.1 For many years Lloyd’s Register has applied direct calculation procedures in the structural appraisal and approval of new buildings and in various investigations on bulk carriers in service. Through these procedures and the wealth of information collected on the Lloyd’s Register fleet database, a number of locations have been identified where good design, workmanship and alignment during construction are particularly important. These are usually locations where high stress variations can be experienced during the lifetime of the ship. These are referred to as critical locations and are highlighted in this Chapter.

1.1.2 In order to give clear reference Section 1 of this Chapter identifies the critical areas in typical bulk carriers together with the terminology and general nomenclature of the various structural components, see Figs. 5.1.1 to 5.1.3.

1.1.3 In Section 2 the structural detail design improvements that can be applied to increase the fatigue life of the structural components are provided. These detail improvements are intended to give the designer guidance for meeting the design criteria for structural detail components, see Ch 1,3.2.5.

1.2 Critical areas

1.2.1 Stress concentrations occur in the primary structures of all bulk carriers and are identified during the design process by such means as finite element calculations. The designer will modify the detail to alleviate the stress concentration either by redesign or increase in scantlings. However, even after modification that area will still, in general, be exposed throughout the life of the ship to stresses higher than in surrounding areas.

1.2.2 At the design appraisal stage, a plan of the primary structure can be prepared indicating these regions, and consideration can then be given, by the production team, to the appropriate methods of construction and the tolerances to be applied in order to remain within the assigned design parameters.

1.2.3 In order to give an example of areas where these stress concentrations could be expected, the following sections give general information for bulk carriers. Examples of critical areas are shown in Figs. 5.1.4 and 5.1.5 indicating locations prone to stress concentrations and misalignment.
Fig. 5.1.1

Typical cargo hold structural configuration for a single skin bulk carrier
Fig. 5.1.2
Nomenclature for typical transverse section in way of cargo hold
Fig. 5.1.3
Nomenclature for typical transverse bulkhead and alternative lower stool arrangements
Table 5.1.1 Locations where correct alignment during construction is important and where high stress variations can be experienced during the lifetime of the ship

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Critical areas</th>
<th>Example No.</th>
<th>Critical locations</th>
</tr>
</thead>
</table>
| 1        | Double bottom                   | 1                                                     | 1. Connections of the double bottom floor vertical stiffeners to the bottom shell longitudinals.  
                                                       |                                                  | 2. Connections of the double bottom floor vertical stiffeners to the inner bottom longitudinals.  |
| 2        | Hopper tank                     | 1                                                     | Connections near the welded knuckle formed by the intersection of inner bottom plating with double bottom girder and hopper sloping plate.  |
|          |                                  | 2                                                     | Connections near the radiused knuckle formed by the intersection of inner bottom plating with double bottom girder and hopper sloping plate.  |
| 3        | Hold frames                     | 1                                                     | Toe connections of hold frame lower and upper end brackets to the hopper and topside sloping plating.  |
| 4        | Topside tanks                   | 1                                                     | Connections of topside tank lower intermediate brackets above hold frame upper end brackets.  |
|          |                                  | 2                                                     | Connections of topside tank transverse web stiffeners to the side shell longitudinals.  |
|          |                                  | 3                                                     | Connections of the topside tank transverse web brackets to the side shell longitudinals.  |
|          |                                  | 4                                                     | Connections of the topside tank transverse web stiffeners to the topside tank sloping plate longitudinals.  |
|          |                                  | 5                                                     | Connections of the topside tank transverse web brackets to the topside tank sloping plate longitudinals.  |
| 5        | Deck outside line of openings   | 1                                                     | 1. Cut-outs in the deck transverse ring web for deck longitudinals.  
                                                       |                                                  | 2. Connections of the deck transverse web stiffeners to the upper deck longitudinals.  |
| 6        | Deck between hatches            | 1                                                     | 1. Deck plating in way of the hatch corners.  
                                                       |                                                  | 2. Connections of hatch end beam to topside tank transverse.  |
| 7        | Transverse bulkheads (Deep tank)| 1                                                     | Connections of double bottom floor vertical stiffeners to the bottom and inner bottom longitudinals below lower stool and connections of lower stool to the inner bottom plate.  |
|          |                                  | 2                                                     | Connections of bottom stools to the inner bottom plating in way of double bottom girders.  |
|          |                                  | 3                                                     | 1. Connection of bottom stool shelf plate to stool and corrugated transverse bulkheads.  
                                                       |                                                  | 2. Connections of shedder plates to corrugated transverse bulkhead.  |
|          |                                  | 4                                                     | Connections of corrugated bulkhead to the topside tank boundary plating, deck and upper stool.  |
Typical transverse bulkhead vertically corrugated with upper and lower stools and areas susceptible to higher stresses and misalignment

Fractures initiating at the connections of the stool sloping plating to the inner bottom

Fractures initiating at connections of stool/hopper sloping plating

Fractures initiating at the hopper knuckles

(Similar damages may occur at the upper connections of the bulkhead to the deck structure)

Typical fractures at the connection of transverse bulkhead structure
Section 2: Structural details

2.1 Detail design improvement

2.1.1 For the purposes of this Guide, the bulk carrier cargo area has been divided into seven areas, referred to as Critical Areas, see Table 5.2.1. Each Critical Area contains a number of examples of the locations which may be prone to fatigue damage, referred to as Critical Locations, for which detail design improvements are provided.

2.1.2 A summary of the data is presented in Table 5.2.1 whilst the full detail improvements are given in Figures 1.1 to 7.4, as contained in this Section.

2.1.3 Generally, where alternative structural detail design improvements are provided, the details are shown in an ascending order of improved fatigue strength. Therefore, when used in conjunction with a level two or a level three assessment, the designer may select which design improvement is the optimum for the design criteria.

2.1.4 Where asymmetrical sections are shown, the same requirements apply to bulb plate stiffeners and flat bars.

2.1.5 By virtue of the low fatigue capability of lapped connections, they are not permitted in association with the FDA notation or descriptive note.

2.2 Minimum detail design improvement

2.2.1 Where a FDA notation is requested, the FDA level one minimum detail design improvement specified in this guide is to be complied with for all primary structural connections. For alternative arrangement of primary structural connections, special consideration will be given by Lloyd’s Register for the need to apply a level three assessment.

2.2.2 A FDA Level 2 assessment is to be carried out to all longitudinal end connections at deck, shell and longitudinal bulkheads. The Structural Detail Design Guide may be used for guidance, in conjunction with FDA Level 2, in achieving the acceptance criteria.

2.2.3 Where only one detail design improvement is proposed, it is to be selected as the structural detail minimum recommendation.
### Table 5.2.1 Summary of critical structural details and design improvements

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Critical Areas</th>
<th>Example No.</th>
<th>Example title</th>
<th>Figure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Double bottom</td>
<td>1</td>
<td>Floor vertical flat bar stiffener connection to inner bottom and bottom shell longitudinals.</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>Hopper tank</td>
<td>1</td>
<td>Welded knuckle connection of hopper tank sloping plating to inner bottom plating.</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Radiused knuckle connection of hopper tank sloping plating to inner bottom plating.</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Transverse ring web, flat bar stiffener connection to longitudinal on sloping hopper plating, bottom shell and side shell plating.</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Transverse ring web, tripping bracket connection to longitudinal on hopper sloping plate, bottom shell and side shell plating.</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Upper intermediate brackets below hold side shell frame lower brackets.</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>Hold frames</td>
<td>1</td>
<td>Connection of side shell frames to hopper and topside tank plating.</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>Topside tank</td>
<td>1</td>
<td>Lower intermediate brackets above side shell frame upper bracket.</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Transverse ring web flat bar stiffener connection to longitudinal on side shell plating.</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Transverse ring web, tripping bracket connection to longitudinal on side shell plating.</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Transverse ring web, stiffener connection to longitudinals on topside tank sloping plating.</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Transverse ring web, tripping bracket connection to longitudinals on topside tank sloping plating.</td>
<td>4.5</td>
</tr>
<tr>
<td>5</td>
<td>Deck outside line of openings</td>
<td>1</td>
<td>Deck transverses, stiffener connection to longitudinals on upper deck.</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Deck transverses, tripping bracket connection to longitudinals on upper deck.</td>
<td>5.2</td>
</tr>
<tr>
<td>6</td>
<td>Deck between hatches</td>
<td>1</td>
<td>Hatch corners and hatch end beam connection to topside tank transverse web.</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Hatch coaming longitudinal end brackets.</td>
<td>6.2</td>
</tr>
<tr>
<td>7</td>
<td>Transverse bulkheads (Deep tank)</td>
<td>1</td>
<td>Connections of bottom shell and inner bottom longitudinals below lower stool.</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Connections of lower stool to inner bottom in way of double bottom girders.</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Connections in way of lower stool shell plate.</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Connections in way of upper boundaries of corrugated bulkheads.</td>
<td>7.4</td>
</tr>
</tbody>
</table>

**Note:** Figures in this Guide are given to illustrate some methods of improving the fatigue life of ship structural details and are not to scale. Dimensions where given are in millimetres.
Bulk Carriers

Chapter 5

SECTION 2

AREA 1: Double bottom
EXAMPLE No. 1: Floor vertical flat bar stiffener connection to inner bottom and bottom longitudinals.

CRITICAL AREAS

CRITICAL LOCATIONS

Longitudinal section

Transverse section A-A

DETAIL DESIGN IMPROVEMENT

(a) Soft heel detail improvement

Further detail improvement *

(b) Symmetrical soft toe and soft backing bracket improvement

Note:
Where higher tensile asymmetrical steel longitudinals are used and double bottom and topside tanks are interconnected a soft heel detail is required as a minimum improvement to the floor stiffener.
* To be confirmed by FDA2.

Minimum Detail Design Improvement

For interconnected double bottom and topside tanks and asymmetrical longitudinals:
- All longitudinals are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.
- All longitudinals are to be fitted with a soft toe and soft heel detail design improvement.

Critical Location

1. Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.
2. Heel and toe connection of the floor stiffeners to the inner bottom longitudinals.

Detail Design Improvement

1. Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket, can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder longitudinal loading.
2. Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket, can be used to reduce peak and range of resultant stresses from cyclic cargo inertia loads and hull girder global loading.

Building Tolerances

Ensure good alignment between longitudinal stiffener web and floor stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

Welding Requirements

Ensure start and stop of welding is as far away as practicable from the stiffener/bracket heel and toe. A wraparound weld, free of notches of undercut or notches around the heel and toe connections of the stiffener and backing bracket connection to longitudinal. See also Pt 3, Ch 10 of Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships).
**Chapter 5**

**SECTION 2**

**Bulk Carriers**

AREA 2: Hopper tank
EXAMPLE No. 1: Welded knuckle connection of hopper tank sloping plating to inner bottom plating

### CRITICAL AREAS

### DETAIL DESIGN IMPROVEMENT

**MINIMUM DETAIL DESIGN IMPROVEMENT**

- **Ballast holds:** No scallops or close scallops with collars; scarfing bracket; deep penetration weld between hopper, tanktop, girder connection; full penetration weld between floor/hopper web and inner bottom/hopper plate/girder; intermediate bracket if floor spacing greater than 2.5 m.
- **Dry holds:** Close scallops or scarfing bracket (if scallop retained on hopper side); deep penetration web between hopper, tanktop, girder connection; full penetration weld between floor/hopper web and inner bottom/hopper plate/girder.
- **An FDA Level 3 Assessment is to be carried out where the floor spacing is greater than 3.0 m.**

**CRITICAL LOCATIONS**

**MINIMUM DETAIL**

- Ballast holds: No scallops or close scallops with collars; scarfing bracket; deep penetration weld between hopper, tanktop, girder connection; full penetration weld between floor/hopper web and inner bottom/hopper plate/girder; intermediate bracket if floor spacing greater than 2.5 m.
- Dry holds: Close scallops or scarfing bracket (if scallop retained on hopper side); deep penetration web between hopper, tanktop, girder connection; full penetration weld between floor/hopper web and inner bottom/hopper plate/girder.
- An FDA Level 3 Assessment is to be carried out where the floor spacing is greater than 3.0 m.

**Building Tolerances:**

Ensure good alignment between floor and hopper transverse ring web and between sloping plating and hopper side girder. Maximum misalignment is to be not greater than (t/3) where t is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements:**

Full penetration welding to be applied to the connections in way of the knuckle as follows:
- floor/inner bottom
- hopper ring web/girder
- hopper/inner bottom
- floor/girder
- hopper ring web/hopper
- hopper/girder

See also Pt 3, Ch 10 and Pt 4, Ch 7,8 of the Rules for Ships.

**FIGURE 2.1**

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER**

**STRUCTURAL DETAILS**
AREA 2: Hopper tank
EXAMPLE No. 2: Radiused knuckle connection of hopper tank sloping plating to inner bottom plating.

CRITICAL AREAS

CRITICAL LOCATIONS

Longitudinal section

Critical locations

Only below WB holds

Floor

Hopper transverse web frames

Inner bottom

Outermost girder

B

A

Transverse section A-A

Critical location

Inner bottom

Longitudinal girder

Hopper transverse ring web frame

NOTE

Distance from side girder to centre of knuckle is to be as small as practicable, but not to exceed 70 mm.

Minimum Detail Design Improvement

- As a minimum, the structural detail is to be fitted with full penetration welds in way of all holds
- Ballast holds: Two intermediate brackets fitted at approximately 0.5 frame space from floor/hopper web.
- Dry holds: One intermediate bracket fitted at 0.5 floor space from floor/hopper web if floor spacing is equal to or greater than 2.5 m.
- An FDA Level 3 Assessment is to be carried out where the floor spacing is greater than 3.0 m.

Critical Location Detail Design Improvement

Connections near the knuckle formed by the intersection of inner bottom with hopper sloping plate. As per minimum detail design improvement above.

Building Tolerances

Ensure good alignment between double bottom floor and hopper transverse ring web. Maximum misalignment is to be not greater than (t/3) where t is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

Welding Requirements

Full penetration welding to be applied to the connections near the knuckle between inner bottom and transverse ring web. See also Pt 3, Ch 10 and Pt 4, Ch 7.8 of the Rules for Ships.

DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS

FIGURE 2.2
**AREA 2: Hopper tank**

**EXAMPLE No. 3:** Transverse ring web, flat bar stiffener connection to longitudinal on hopper sloping plate, bottom shell and side shell plating.

### CRITICAL AREAS

**DETAIL DESIGN IMPROVEMENT**

- **(a) Soft heel detail improvement**

- **Further detail improvement** *

- **(b) Symmetrical soft toe and soft backing bracket improvement**

### CRITICAL LOCATIONS

**Transverse section through hopper tank**

**Critical locations**

**Section A-A**

**Bottom shell**

Minimum Detail Design Improvement

As a minimum, the structural detail is to be fitted according to the structural configuration as follows:

- All longitudinals are to be fitted with a symmetrical soft toe and soft backing bracket detail design improvement.
- For interconnected double bottom and topside tanks and asymmetrical longitudinals:
  - All longitudinals are to be fitted with a symmetrical soft toe and soft heel detail design improvement.
- For interconnected double bottom and topside tanks and symmetrical longitudinals:
  - All longitudinals are to be fitted with soft heel detail design improvement.
- For non-interconnected double bottom and topside tanks and asymmetrical longitudinals:
  - All longitudinals are to be fitted with soft heel detail design improvement.
- For non-interconnected double bottom and topside tanks and symmetrical longitudinals:
  - All longitudinals are to be fitted with soft heel detail design improvement.

Critical Location

1. Heel and toe connection of the hopper tank transverse ring web stiffeners to the bottom shell and side shell longitudinals.
2. Heel and toe connection of the hopper tank transverse ring web stiffeners to the hopper sloping plate longitudinals.

Detail Design Improvement

1. Soft heel or soft toe and soft heel or symmetrical soft toe with backing bracket, can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading.
2. Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket, can be used to reduce peak and range of resultant stresses from cyclic cargo inertia loads and hull girder global loading.

Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

Building Tolerances

Ensure good alignment between longitudinal stiffener web, transverse ring web stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

Welding Requirements

Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap around weld, free of undercut or notches around the heel and toe connections of stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

* To be confirmed by FDA2.

### FIGURE 2.3

**DETAIl DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS**
**AREA 2:** Hopper tank  
**EXAMPLE No. 4:** Transverse ring web, tripping bracket connection to longitudinal on hopper sloping plate, bottom shell and side shell plating.

### CRITICAL AREAS

#### CRITICAL LOCATIONS

Transverse section through hopper tank

#### MINIMUM DETAIL DESIGN IMPROVEMENT

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Minimum Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Heel and toe connection of the hopper tank transverse ring web brackets to longitudinals on the hopper sloping plate, bottom shell and side shell plating.</td>
<td></td>
</tr>
<tr>
<td>2. Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.</td>
<td></td>
</tr>
<tr>
<td>3. Ensure good alignment between longitudinal stiffener web, transverse ring web tripping brackets and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.</td>
<td></td>
</tr>
<tr>
<td>4. Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap around weld, free from undercut and notches around the heel and toe connections of brackets. See also Pt 3, Ch 10 of the Rules for Ships.</td>
<td></td>
</tr>
</tbody>
</table>

### DESIGN IMPROVEMENT

- **Further detail improvement** (soft toe and soft heel)

### FIGURE 2.4

DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS

* To be confirmed by FDA2.
**Area 2: Hopper Tank**

**Example No. 5:** Upper intermediate brackets below hold side shell frame lower brackets.

**Critical Locations**

**Transverse Section through Hopper Tank**

**Critical Area Connection of hopper side upper intermediate brackets below side shell frame lower brackets.**

Where the frame lower brackets are not positioned directly above a ring web, supporting brackets are to be provided. In the design ensure that if a hopper tank stiffener is positioned below the end of the frame lower bracket, the stiffener cut-out is avoided or closed with a full collar.

Increasing the size of supporting brackets will reduce stress concentrations in the critical area.

**Building Tolerances**

Ensure good alignment between lower frame bracket and supporting bracket. Maximum misalignment is to be not greater than \( \frac{t}{3} \) where \( t \) is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements**

Ensure start and stop of welding is as far away as practicable from the unsupported edge corners in the supporting brackets. See also Pt 3, Ch 10 of the Rules for Ships.

**Minimum Detail Design Improvement**

As a minimum, the structural detail is to be fitted with:

- Detail improvement (a), if a longitudinal is fitted in way of the bracket toe; or
- Detail improvement (b), if a longitudinal is not fitted in way of the bracket toe.

**Figure 2.5**

**Detail Design Guidelines for Bulk Carrier Structural Details**
**Chapter 5**

**SECTION 2**

### Bulk Carriers

**AREA 3:** Hold frames

**EXAMPLE No. 1:** Connection of side shell frames to hopper and topside tank plating.

### CRITICAL AREAS

### DETAIL DESIGN IMPROVEMENT

**Transverse section through side shell**

- **Suggested:**
  - \( r = \frac{10t_w}{3} \)
  - \( x = \frac{2}{3} r \)
  - \( y = \frac{1}{2} r \)

- **Chamber 1:3**
  - 10 mm
  - Weld factor of 0.44
  - 15 - 25 mm

- **View X**
  - **Face plate**
  - **Taper 1:5**
  - **Chamfer 1:3**
  - **Ring web below hopper**
  - **Max taper 1:3**
    - Recommended 1:5 when HT steel is used
    - Suggested \( y = \frac{5t_w}{8} \)
    - \( y_{max} = 80 \text{ mm} \)

### CRITICAL LOCATIONS

**Minimum Detail**

**Design Improvement**

- As a minimum, the structural detail is to be fitted with:
  - A soft toe for a mild steel side shell frame; or
  - A tapered toe for high tensile steel side shell frame.

**Critical Location**

- Toe connection of side shell frame lower and upper brackets to the hopper and topside sloping plates.

**Detail Design Improvement**

- Ensure that a long enough leg length is used to allow adequate tapering down to the toe end of the frame end brackets. This will ensure a smooth change of section, which will reduce the peak and range of stresses resulting from side shell differential of pressures and relative rotation between hopper and topside tanks.

**Building Tolerances**

- Ensure good alignment between side shell frame lower and upper bracket and transverse ring webs or supporting brackets. Maximum misalignment is to be not greater than \((t/3)\) where \(t\) is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements**

- Use fillet welding with a weld factor of 0.44 and ensure start and stop of welding is as far away as practicable from the toe of the frame brackets. A wraparound weld, free from undercut and notches, around the toe of the end bracket connections to hopper plating. See also Pt 3, Ch 10 and Pt 4, Ch 7.6.2 of the Rules for Ships.

### NOTE

- Chamfer gradient may be increased for face plate thickness less than 25 mm.

---

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER**

**STRUCTURAL DETAILS**

**FIGURE 3.1**
**AREA 4: Topside tanks**

**EXAMPLE No. 1:** Lower intermediate brackets above hold side shell frame upper bracket.

### CRITICAL AREAS

#### Transverse section through topside tank

**Critical location**

**Frame upper bracket**

#### Critical locations

**Topside tank**

**Intermediate bracket**

**Frame upper bracket**

### DETAIL DESIGN IMPROVEMENT

#### (a) Detail improvement

- Recommended: fit a full collar at the intersection with the transverse ring webs (See Group 2, Example No. 5)

#### (b) Alternative detail improvement

- Recommended: no scallops

---

**Minimum Detail**

As a minimum, the structural detail is to be fitted with:

- Detail improvement (a), if a longitudinal is fitted in way of the side shell frame bracket toe; or
- Detail improvement (b), if a longitudinal is not fitted in way of the side shell frame bracket toe.

**Critical Location**

Connection of topside lower intermediate brackets above side shell frame upper bracket.

Where the frames upper brackets are not positioned directly below a topside ring web, supporting brackets are to be provided. In the design ensure that if a longitudinal stiffener in the topside tank is positioned directly above the end of the side shell frame upper bracket, the stiffener cut-out is avoided or closed with a full collar. Increasing the size of supporting brackets will reduce stress concentrations in the critical area.

**Building Tolerances**

Ensure good alignment between side shell frame upper bracket and supporting bracket. Maximum misalignment is to be not greater than \( \frac{t}{3} \) where \( t \) is the thinner of the web to be aligned and misalignment is the overhang of the thinnest thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements**

Ensure start and stop of welding is as far away as practicable from the unsupported edge corners in the supporting brackets. See also Pt 3, Ch 10 of the Rules for Ships.

---

**FIGURE 4.1**

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS**
## AREA 4: Example No. 2

### Transverse Ring Web

**Critical Locations**

Transverse section through topside tank

- **Deck**
- **Topside tank**
- **Side shell**

**Section A-A**

- **Critical locations**
- **Topside transverse ring web**

### Critical Areas

<table>
<thead>
<tr>
<th>Critical Locations</th>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topside tanks</td>
<td>(a) Soft heel improvement</td>
</tr>
<tr>
<td></td>
<td>(b) Symmetrical soft toe</td>
</tr>
<tr>
<td></td>
<td>and soft backing bracket</td>
</tr>
<tr>
<td></td>
<td>improvement</td>
</tr>
</tbody>
</table>

### Critical Locations

- **Note:** Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.

### Minimum Design Improvement

As a minimum, the structural detail is to be fitted with:

- For high tensile steel asymmetrical longitudinals, a symmetrical soft toe and soft backing bracket detail design improvement;
- For high tensile steel symmetrical longitudinals and mild steel asymmetrical longitudinals, a soft toe and soft heel detail design improvement;
- For mild steel symmetrical longitudinals, a soft heel detail design improvement.

### Critical Location

- Heel and toe connection of the topside tank transverse ring web stiffeners to the side shell longitudinals.

### Detail Design Improvement

- Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

### Building Tolerances

Ensure good alignment between longitudinal stiffener web, topside ring web stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

### Welding Requirements

Ensure start and stop of welding is as far away as practicable from the heel and toe. Awraparound weld free from undercut and notches, around the toe and heel connection of the stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.
### Critical Locations

**Transverse section through topside tank**

#### Critical Areas Design Improvement

<table>
<thead>
<tr>
<th>Area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Topside tanks</td>
</tr>
</tbody>
</table>

#### Example No. 3: Transverse ring web, tripping bracket connection to longitudinal on side shell plating.

#### Critical Locations

**Note:**

- Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.
- * To be confirmed by FDA2.

#### Minimum Design Improvement

As a minimum, the structural detail is to be fitted with:

- For high tensile steel asymmetrical longitudinals, a symmetrical soft toe and soft backing bracket detail design improvement;
- For high tensile steel symmetrical longitudinals and mild steel asymmetrical longitudinals, a soft toe and soft heel detail design improvement;
- For mild steel symmetrical longitudinals, a soft heel detail design improvement.

#### Critical Location

Heel and toe connection of the topside tank transverse ring web tripping brackets to the side shell longitudinals.

#### Detail Design Improvement

Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

#### Building Tolerances

Ensure good alignment between longitudinal stiffener web, topside transverse ring web bracket and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

#### Welding Requirements

Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap around weld, free from undercut and notches around the toe and heel connection of the stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

---

**FIGURE 4.3**

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS**
### AREA 4: Topside tanks
EXAMPLE No. 4: Transverse ring web, stiffener connection to longitudinals on topside tank sloping plating.

<table>
<thead>
<tr>
<th>CRITICAL AREAS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Locations</td>
<td></td>
</tr>
<tr>
<td>Transverse section through topside tank</td>
<td></td>
</tr>
<tr>
<td>Deck</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Section A-A</td>
<td></td>
</tr>
<tr>
<td>Critical locations</td>
<td></td>
</tr>
<tr>
<td>Topside transverse ring web</td>
<td></td>
</tr>
<tr>
<td>Topside tank sloping plating</td>
<td></td>
</tr>
</tbody>
</table>

**MINIMUM DETAIL**
As a minimum, the structural detail is to be fitted with:
- For high tensile steel asymmetrical longitudinals, a symmetrical soft toe and soft backing bracket detail design improvement;
- For high tensile steel symmetrical longitudinals and mild steel asymmetrical longitudinals, a soft toe and soft heel detail design improvement;
- For mild steel symmetrical longitudinals, a soft heel detail design improvement.

**CRITICAL LOCATION**
Heel and toe connection of the topside tank transverse ring web stiffeners to the topside tank sloping plate longitudinals.

**DETAIL DESIGN IMPROVEMENT**
Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

**BUILDING TOLERANCES**
Ensure good alignment between longitudinal stiffener web, topside ring web stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

**WELDING REQUIREMENTS**
Ensure start and stop of welding is as far away as practicable from the heel and toe. A wraparound weld free from undercut and notches, around the toe and heel connection of the stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

**APPLICATION**
Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.

* To be confirmed by FDA2.

---

**CRITICAL LOCATIONS**

Note: Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.

**FIGURE 4.4**
DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS
Minimum Detail Design Improvement

As a minimum, the structural detail is to be fitted with:
- For high tensile steel asymmetrical longitudinals, a symmetrical soft toe and soft backing bracket detail design improvement;
- For high tensile steel symmetrical longitudinals and mild steel asymmetrical longitudinals, a soft toe and soft heel detail design improvement;
- For mild steel symmetrical longitudinals, a soft heel detail design improvement.

Critical Location

Heel and toe connection of the topside tank transverse ring web tripping brackets to the topside tank sloping plate longitudinals.

Detail Design Improvement

Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

Building Tolerances

Ensure good alignment between longitudinal stiffener web, topside transverse ring web bracket and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

Welding Requirements

Ensure start and stop of welding is as far away as practicable from the heel and toe. A wraparound weld, free from undercut and notches around the toe and heel connection of the stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

Note:
Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.
### Critical Locations

**Transverse section through deck**

<table>
<thead>
<tr>
<th>Critical Locations</th>
<th>Deck</th>
<th>Topside Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical locations</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

**Section A-A**

- Deck longitudinal
- Topside transverse ring web

#### Minimum Detail Design Improvement

- As a minimum, the structural detail is to be fitted with:
  - For high tensile steel longitudinals, a symmetrical soft toe and soft heel detail design improvement;
  - For mild steel longitudinals, a soft toe and soft heel detail design improvement.

#### Critical Location

1. Cut-outs on the transverse ring web for deck longitudinals.
2. Heel and toe connection of the topside tank transverse ring web stiffeners to the upper deck longitudinals.

#### Detail Design Improvement

1. Lugs can be added to reduce stress concentration in the ring web cut-outs.
2. Soft toe and soft heel can be used to reduce peak and range of resultant stresses for cyclic hull girder global loading.

Where a soft heel detail design is adopted, the reduction of the effective cross-sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

#### Building Tolerances

Ensure good alignment between longitudinal stiffener and topside transverse ring web stiffener.

#### Welding Requirements

Ensure start and stop of welding is as far away as practicably possible from the heel and toe. A wraparound weld, free from undercut and notches, around the toe and heel connections of the stiffener to the longitudinal. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2. See also Pt 3, Ch 10 of the Rules for Ships.

---

### Critical Areas

#### Deck outside line of openings

**EXAMPLE No. 1:** Deck transverses, stiffener connection to longitudinals on upper deck

#### Detail Design Improvement

**(a) Soft heel detail improvement**

- max 15 mm
- $r = 30$ mm
- 75 mm

**(b) Soft toe and soft heel detail improvement**

- max 15 mm
- $R \geq 0.75d$
- $t > d/18$
- 75 mm

Note: These detail improvements to be used only if it is required following a level two or level three assessment.
Critical Locations

**Transverse section through topside tank**

- **Critical locations**
- **Topside tank**
- **Deck**
- **Section A-A**

**Critical Areas**

**Example No. 2:** Deck transverses, tripping bracket connection to longitudinals on upper deck.

**Detail Design Improvement**

1. **(a) Soft heel detail improvement**
   - Further detail improvement (soft toe and soft heel)
   - **Note:** Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.

2. **(b) Symmetrical soft toe and soft backing bracket improvement**
   - **Note:** Where higher tensile steel longitudinals are used on the side shell within 0.8D and the baseline a soft heel detail is required as a minimum improvement.

**Minimum Detail Design Improvement**

- As a minimum, the structural detail is to be fitted with:
  - For high tensile steel longitudinals, a symmetrical soft toe and soft backing bracket detail design improvement;
  - For mild steel longitudinals, a soft heel detail design improvement.

**Critical Location**

- Heel and toe connection of the topside tank transverse ring web tripping brackets to the deck longitudinals.

**Detail Design Improvement**

- Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading. Where a soft heel detail design is adopted, the reduction of the effective cross sectional area of the web stiffener in transferring the axial loading should be considered in the application of the Rule requirements.

**Building Tolerances**

- Ensure good alignment between longitudinal stiffener web, topside transverse ring web bracket and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Fig. 3.2.2.

**Welding Requirements**

- Ensure start and stop of welding is as far away as practicable from the heel and toe. A wraparound weld, free from undercut and notches around the toe and heel connection of the stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.
**Critical Location 1.** Deck plating in way of the hatch corners.

**Detail Design Improvement 1.** Use insert plates of enhanced steel grade and thickness. A radiused corner is to be provided to reduce stress concentration, see Figure above. Ensure gradual transition to thinner plating as far as practicably possible. Attention is drawn to Pt 4, Ch 7.4 of the Rules for Ships.

**Building Tolerances**

Ensure good alignment between hatch end beam and support in the topside tank. Maximum misalignment is to be not greater than \( t/3 \) where \( t \) is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements**

Ensure start and stop of welding is as far away as practicably possible from the toes of brackets or corners. A wraparound weld, free from undercut or notches, around the toe connection of the bracket to upper deck. See also Pt 3, Ch 10 of the Rules for Ships.

**Minimum Detail Design Improvement**

As a minimum, the detail design improvement is to be fitted. Radiused hatch corner insert is to be fitted for bulk carriers as described in Pt 4, Ch 7.4 of the Rules for Ships. For other bulk carriers, radiused hatch corner insert is recommended.
**Critical Areas**

**Detail Design Improvement**

### Critical Locations

#### Transverse section through hatch corner

- Hatch coaming transverse bracket with soft toe
- Deck between hatches
- Topside tank longitudinal boundary (Vertical strake)
- Longitudinal hatch coaming

#### Longitudinal Section A-A

- Hatch coaming longitudinal end brackets
- Critical location
- Deck between hatches
- Topside tank longitudinal boundary (Vertical strake)
- Topside ring web

#### Longitudinal Section B-B

- Hatch coaming longitudinal end brackets
- Deck between hatches
- Topside tank longitudinal boundary (Vertical strake)
- Symmetrical face flange

#### Longitudinal Section C-C

- Hatch coaming longitudinal end brackets
- Deck between hatches
- Topside tank longitudinal boundary (Vertical strake)
- Symmetrical face flange

### Minimum Detail Design Improvement

As a minimum, the detail design improvement (a) is to be fitted.

### Critical Location

Toe connection of longitudinal hatch coaming end bracket to the deck plating.

### Detail Design Improvement

Extend the longitudinal hatch coaming to approx 0.7Hc to provide an integral end bracket with soft toe for smooth transition of stresses from the deck. A symmetrical face flange can be used, see above improvement (b) with soft toe detail.

### Building Tolerances

Ensure good alignment between hatch coaming end bracket and supporting structure. Maximum misalignment is to be not greater than (t/3) where t is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.2.

### Welding Requirements

Use full penetration welding for a distance of 0.15Hc from the bracket toe end ensuring start and stop of welding is as far away as practicable from the toes of brackets or corners. A wraparound weld free from undercut or notches, around the toe connection of the bracket to the deck plating. See also Pt 3, Ch 10 and Ch 11.5 of the Rules for Ships.

**Note:**

Any piping holes are to be avoided in the end bracket as far as possible and, if any, suitable reinforcement is to be provided.

---

**AREA 6: Deck between hatches**

**EXAMPLE No. 2:** Hatch coaming longitudinal end brackets.

**FIGURE 6.2**

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS**
**AREA 7:** Transverse bulkheads (Deep tank)

**EXAMPLE No. 1:** Connections of bottom and inner bottom longitudinals below lower stool.

### CRITICAL AREAS

<table>
<thead>
<tr>
<th>Longitudinal section</th>
<th>Critical locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom shell</td>
<td>A</td>
</tr>
<tr>
<td>Inner bottom</td>
<td></td>
</tr>
<tr>
<td>Full collars</td>
<td></td>
</tr>
<tr>
<td>WT floor</td>
<td></td>
</tr>
<tr>
<td>Full collars</td>
<td></td>
</tr>
<tr>
<td>Critical locations</td>
<td></td>
</tr>
<tr>
<td>Section A-A</td>
<td>Sloping stool plate</td>
</tr>
<tr>
<td></td>
<td>Ring web</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CRITICAL LOCATIONS

**Minimum Detail Design Improvement**

As a minimum, the detail design improvement is to be fitted, i.e. symmetrical soft toe and backing bracket detail design.

### Detail Design Improvement

**Critical Location**

Connections of floor vertical stiffeners to the bottom and inner bottom longitudinals below lower stool and connections of lower stool to the inner bottom plate.

**Fitting of soft brackets will reduce peak and range of stresses in the vicinity near the connections of floor stiffeners to the bottom and inner bottom longitudinals and the connections of stool to inner bottom plate. Although the above improvements are intended for ballast holds, in some cases watertight bulkheads may require similar improvements if a level two or a level three assessment dictates it.**

**Building Tolerances**

Ensure good alignment between brackets and stiffener webs. Maximum misalignment is to be not greater than \( \frac{t}{3} \) where \( t \) is the thinner of the webs to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Figs. 3.2.1 and 3.2.2.

**Welding Requirements**

Use fillet welding with a weld factor of 0.44 between inner bottom and floors. Ensure start and stop of welding is as far away as practicable from the toes of brackets or corners. A wraparound weld, free of undercut and notches, around the toe connections of the stiffeners and backing brackets to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

### DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS

**Figure 7.1**
AREA 7: Transverse bulkheads (Deep tank)
EXAMPLE No. 2: Connections of lower stool to inner bottom in way of double bottom girders.

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT

---

Critical Location Connections of stools to the inner bottom plating in way of double bottom girders.

Critical Location Connections of stools to the inner bottom plating in way of double bottom girders.

Connection of lower stool to inner bottom in way of double bottom girders.

Connections of stools to the inner bottom plating in way of double bottom girders.

Avoiding the use of scallops on floors and lower stool ring webs near the intersection with the inner bottom, will reduce peak and range of stresses in the vicinity. Special consideration is to be given in order to minimise the number and size of manholes near the stool connections.

Avoiding the use of scallops and fitting of lugs in stiffener cut-outs on floors in line with stool plates will reduce peak and range of stresses in the vicinity. Provision of access openings in floors is to be avoided in the vicinity of double bottom girders. Particular attention is to be given to the design and positioning of bilge wells and suction intakes on the inner bottom plate.

Connections of stools to the inner bottom plating in way of double bottom girders.

Connections of stools to the inner bottom plating in way of double bottom girders.

Connections of stools to the inner bottom plating in way of double bottom girders.

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Connections of stools to the inner bottom plating in way of double bottom girders.

Connections of stools to the inner bottom plating in way of double bottom girders.
### Chapter 5

#### SECTION 2

**Area 7:** Transverse bulkheads (Deep tank)

**Example No. 3:** Connections in way of lower stool shelf plate.

### Critical Areas

<table>
<thead>
<tr>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced stress concentration in the corrugation corners.</td>
</tr>
<tr>
<td><strong>Diaphragm</strong></td>
</tr>
<tr>
<td><strong>Full penetration welding</strong></td>
</tr>
<tr>
<td><strong>Lower stool</strong></td>
</tr>
</tbody>
</table>

### Critical Locations

<table>
<thead>
<tr>
<th>Critical Location 1. Connections of lower stool shelf plate to lower stool and corrugated transverse bulkheads.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Location 2. Connections of shedder plates to corrugated transverse bulkhead.</td>
</tr>
</tbody>
</table>

### Detail Design Improvement

1. **Diaphragms** are to be fitted to the shelf plate in line with the face of the corrugation, to reduce the stress concentrations at the corrugation corners. This is achieved by the diaphragm plates as they provide a flexible base connection for the shedder plates. The minimum height of the diaphragm plate to be taken as half the corrugated bulkhead flange width.

2. To reduce stress concentrations at the crossing of the flat shedder plates the design can be modified by moving one shedder plate higher than the other. Alternatively, bracketed stiffener is to be fitted at the crossing points underneath the shedder plating facing a ballast hold.

### Building Tolerances

Ensure good alignment between lower stool sloping plates and corrugation faces as far as possible, see Ch 3, Fig. 3.2.1.

### Welding Requirements

Use full penetration welding at the connections of the bulkhead corrugations, diaphragm and the stool sloping plates to the lower stool shelf plate (recommended to be of grade ‘Z’ steel). Ensure start and stop of welding is as far away as practicable from the corners of the corrugations. See also Pt 3, Ch 10 of the Rules for Ships.

### Minimum Detail Design Improvement

1. Full penetration weld is to be incorporated at the connection of the corrugated bulkhead and stool wall plate to top plate of lower stool.

2. Where adjacent shedder plates cross, a bracketed stiffener is to be provided at the crossing point.

### Critical Locations

| Note: Similar improvements may be required for transverse watertight bulkheads. |

###エリア7:横断バッフル（深タンク）

**例3:** 下部所定板と下部の接続方法。

###重要箇所

| 重要箇所1. 下部所定板と下部および縦断バッフルとの接続。
| 重要箇所2. 降板の縦断バッフルとの接続。 |

###詳細設計改善

1. **ディアフラム**は、所定板に沿ってカーチャンの表面に配置され、コルクレーションの接続における応力集中的を低減する。ディアフラムプレートは、降板プレートを柔らかい基底接続として提供し得る。ディアフラムプレートの最小高さを、コルクレーションバッフルフランジ幅の半分とすること。 |

2. 平坦な降板プレートの交差点での応力集中のを軽減するための設計は、交差する1つの降板プレートを他より高くすることもできる。また、交差点下部の降板プレートに支柱の補助板を設けることもできる。 |

###建築許容度

所定板とコルクレーションの間での良好な対中を行なう。見解は、Ch 3, Fig. 3.2.1を参照。

###溶接要件

縦断バッフル、ディアフラム、および下部所定板との溶接にはフルペンetration溶接を使用する。降板の溶接箇所の角のから溶接をできるだけ遠ざける。 |

###最小詳細設計改善

1. 下部所定板と下部および縦断バッフルとの溶接を全溶接で行なう。

2. 相互に交差する降板プレートの交差点下部所定板に支柱の補助板を設ける。
### Chapter 5

**SECTION 2**

**Bulk Carriers**

**AREA 7:** Transverse bulkheads (Deep tank)

**EXAMPLE No. 4:** Connections in way of upper boundaries of corrugated bulkheads.

**CRITICAL AREAS**

**CRITICAL LOCATIONS**

![Diagram of Transverse section in way of transverse bulkhead]

**Minimum Detail Design Improvement**
As a minimum, the detail design improvement is to be fitted.

**Critical Location**
Connections of corrugated transverse bulkhead to the topside tank sloping plating and upper stool.

**Detail Design Improvement**
Diaphragm plates between corrugations can be used to increase attachment area of the transverse bulkhead thus reducing peak stresses. Further, a transverse web is to be provided in the topside tank in line with the face of the bulkhead corrugations to ensure that the loads are effectively dissipated.

**Building Tolerances**
Ensure good alignment between transverse web and the flange of corrugations. Maximum misalignment is to be not greater than \( \frac{t}{3} \) where \( t \) is the thinner of the plates to be aligned and misalignment is the overhang of the thinner thickness, see Ch 3, Fig. 3.2.1.

**Welding Requirements**
Use fillet welding with a weld factor of 0.44 for connections of transverse bulkhead to topside tank and upper stool shelf plating. Ensure start and stop of welding is as far away as practicable from the critical corners. See also Pt 3, Ch 10 of the Rules for Ships.

**FIGURE 7.4**

**DETAIL DESIGN GUIDELINES FOR BULK CARRIER STRUCTURAL DETAILS**
Section 1: Identification of critical areas

1. General

1.1.1 Using experience drawn from both analysis and service experience, a number of critical locations have been identified where good detail design, workmanship and alignment during construction are particularly important. These are generally locations where high stress variations can be experienced during the lifetime of the ship.

1.1.2 This Section defines the terminology and general nomenclature for the various structural components in a typical container ship and identifies the Critical Areas which may be prone to stress concentration and misalignment, see Figs. 6.1.1 to 6.1.9 and Table 6.1.1. The Critical Locations are defined as specific locations within the Critical Areas which are considered prone to fatigue, and where detail design improvement may have to be applied.

1.1.3 In Section 2, various design improvements for increasing the fatigue life of the structural details are provided. These are intended as guidance for the designer and may need to be verified by analytical or numerical means.

1.1.4 The design improvements provided in this Chapter are applicable for all grades of steel.

1.1.5 The arrangements and scantlings are to satisfy Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships) and, where applicable, the relevant ShipRight Structural Design Assessment (SDA) Procedure, Direct Calculations Guidance Notes.
Cross-deck structure
Upper deck
Under-deck passage
Side tanks

Continuous inboard hatch coaming and girder (if fitted)

Fig. 6.1.1
Typical large container ship and cargo hold configuration
Fig. 6.1.2

Nomenclature for typical transverse section in way of cargo hold and typical sections through forward cargo regions
Fig. 6.1.3

Nomenclature for typical structural members in cargo regions
Fig. 6.1.4
Nomenclature for typical watertight and non-watertight transverse bulkheads
Chapter 6
SECTION 1

Container Ships

Fig. 6.1.5
Critical Areas of deck region
Areas of high stress concentration

Areas susceptible to misalignment

Fig. 6.1.6
Critical Areas in cargo holds
Fig. 6.1.7
Critical Areas in cargo hold (tank top view)
Critical Areas

Hatch coaming beam brackets (stay brackets)

Watertight side web in line with watertight bulkhead

Upper deck

Hatch corner insert plate

Second deck and underdeck passage

Waterline

CL girder

Transverse side web

Fig. 6.1.8

Critical Areas in way of side tanks (side view)
Critical Areas

Fig. 6.1.9
Critical Areas in double bottom (underside view)
<table>
<thead>
<tr>
<th>Area No.</th>
<th>Critical Areas</th>
<th>Example No.</th>
<th>Critical Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Double bottom</td>
<td>1</td>
<td>Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.</td>
</tr>
<tr>
<td>2</td>
<td>Bilge tank</td>
<td>1</td>
<td>Heel and toe connection of the bilge tank transverse web stiffeners to the bottom, bilge and side shell longitudinals.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Heel and toe connection of the bilge tank transverse web brackets to the bottom, bilge and side shell plating longitudinals.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Side girder connections to inner bottom plating in way of floors. Floor and bilge transverse web connections to inner bottom plating and to side girders.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Side longitudinal bulkhead connections to bilge tanktop plate and transverse webs in way of corner.</td>
</tr>
<tr>
<td>3</td>
<td>Side tanks/underdeck passage</td>
<td>1</td>
<td>Heel and toe connections of horizontal flat bar stiffeners on transverse side webs to side shell longitudinals in side tanks. (Connections from the base line to just above the load water line will be the most critical.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Heel and toe connections of horizontal tripping brackets on transverse side webs to side shell longitudinals (connections from the base line to just above the load waterline will be the most critical).</td>
</tr>
<tr>
<td>4</td>
<td>Deck, hatch corners and between hatches</td>
<td>1</td>
<td>Deck plating in way of hatch corners.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>(a) Deck plating in way of the hatch corners near superstructure. Intersection of hatch coaming with superstructure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Toe connection of continuous coaming stay bracket to the deck plating and connection between transverse and longitudinal top of coamings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Connection of two adjacent hatches, especially at the vicinities of high local horizontal forces.</td>
</tr>
<tr>
<td>5</td>
<td>Hatch side coaming</td>
<td>1</td>
<td>Hatch cover supporting structure. Very high forces, due to container loads on the hatch cover. The loads have to be transferred into the longitudinal/transverse coamings via the bearing pads and the supporting brackets.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Interruption-rerouting of longitudinal stiffeners in way of openings in areas with high global bending stress, such as the top strake of longitudinal bulkhead.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Toe connection of the longitudinal hatch side coaming fore and aft termination.</td>
</tr>
<tr>
<td>6</td>
<td>Watertight and non-watertight bulkheads</td>
<td>1</td>
<td>Connections of hatch end beam and underside plate to the longitudinal bulkhead.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Connections of face plate of horizontal bulkhead stringers to the longitudinal bulkhead.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Connections of floor vertical stiffeners to the bottom and inner bottom longitudinals below bulkhead and connections of bulkhead bottom box to the inner bottom plate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Connections of bulkhead vertical web facce plates to the inner bottom structure and first walkway/stringer.</td>
</tr>
<tr>
<td>7</td>
<td>Intermediate decks in forward holds</td>
<td>1</td>
<td>Corner detail in way of stepped longitudinal bulkhead to intermediate deck connection.</td>
</tr>
</tbody>
</table>
Section 2: Structural details

2.1 Guidance for the designer

2.1.1 In order to assist designers in improving the fatigue performance of structural details, Lloyd’s Register has developed an extensive structural detail design database.

2.1.2 The results from detailed finite element analyses have enabled an assessment of the relative fatigue performance of different details.

2.1.3 This allows the designer to readily upgrade the detail design arrangements to provide an improved fatigue performance where required.

2.1.4 It is intended to incorporate additional arrangements in the detail design database to reflect the in-service experience, design and construction practice and new research findings.

2.1.5 In addition, Chapter 2 provides guidance on other methods to improve the fatigue performance, e.g. detail geometry, construction tolerances, weld requirements.

2.1.6 The design details and associated improvements indicated in this Section are utilized in the FDA procedures.

2.2 Detail design improvement

2.2.1 For the purposes of this Guide, the container ship cargo area has been divided into six groups referred to as Critical Areas, see Table 6.2.1. Each Critical Area contains a number of examples of the Critical Locations which may be prone to fatigue, for which detail design improvements are provided.

2.2.2 A summary of the data is presented in Table 6.2.1 whilst the full detail improvements are given in Figures 1.1 to 6.4, as contained in this Section.

2.2.3 Generally, where alternative structural detail design improvements are provided, the details are shown in an ascending order of improved fatigue strength. Therefore, when used in conjunction with a level two or a level three assessment, the designer may select which design improvement is the optimum for the design criteria.

2.2.4 The detail improvements recommended in this guidance are mainly concerned with methods for improving fatigue performance. The designer’s attention is, therefore, drawn to the Rules for Ships, the requirements of which must be satisfied at all times.
### Table 6.2.1 Summary of critical structural details and design improvements

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Critical Areas</th>
<th>Example No.</th>
<th>Example title</th>
<th>Figure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Double bottom</td>
<td>1</td>
<td>Floor vertical flat bar stiffener connection to bottom shell longitudinals</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Intersection of bottom shell longitudinals with floor, including offset stiffener for ships smaller than Panamax size</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>Bilge tank</td>
<td>1</td>
<td>Bilge tank transverse web, flat bar connections to shell longitudinals</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Bilge tank transverse webs, tripping bracket connection to shell longitudinals</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Bilge tank connection to double bottom</td>
<td>2.3(a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Longitudinal bulkhead connection to top of bilge tank</td>
<td>2.4(a)</td>
</tr>
<tr>
<td>3</td>
<td>Side tank / underdeck passage</td>
<td>1</td>
<td>Connection of side shell longitudinals to horizontal stiffeners on transverse side webs</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Connection of side shell longitudinals to horizontal tripping brackets on transverse side webs</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>Deck, hatch corners and between hatches</td>
<td>1</td>
<td>Deck plating in way of hatch corners of cargo region</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Connection of hatch side coaming to deckhouse side wall and deckhouse structure</td>
<td>4.2(a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Hatch coaming structure and transverse stay brackets</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Extension brackets between hatch end coamings at cross deck</td>
<td>4.4</td>
</tr>
<tr>
<td>5</td>
<td>Hatch side coaming</td>
<td>1</td>
<td>Details in way of hatch cover bearing pads and stoppers on longitudinal and transverse coamings</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Arrangements in way of openings in longitudinal coamings and top strake of the longitudinal bulkhead</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Termination of longitudinal hatch side coaming</td>
<td>5.3</td>
</tr>
<tr>
<td>6</td>
<td>Watertight and non-watertight bulkheads</td>
<td>1</td>
<td>Connection of hatch end beam to the longitudinal bulkhead, including 2nd deck transverse passageway</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Connection of bulkhead stringer (walkways) to the longitudinal bulkhead</td>
<td>6.2(a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Connections in the double bottom where both sides of bulkhead are supported</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Connections of vertical web face plates to inner bottom and first walkway/stringer</td>
<td>6.4</td>
</tr>
<tr>
<td>7</td>
<td>Intermediate decks to forward holds</td>
<td>1</td>
<td>Corner detail in way of stepped longitudinal bulkhead to intermediate deck connection.</td>
<td>7.1</td>
</tr>
</tbody>
</table>

**Note:** Figures in this Guide are given to illustrate some methods of improving the fatigue life of ship structural details and are not to scale. Dimensions where given are in millimetres.
**AREA 1:** Double bottom
**EXAMPLE No. 1:** Floor vertical flat bar stiffener connection to bottom and inner bottom longitudinals

<table>
<thead>
<tr>
<th>CRITICAL AREAS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**CRITICAL LOCATIONS**

**Longitudinal section**
- Inner bottom
- Floor
- Critical Locations
- Floor vertical stiffeners
- Bottom shell

**Transverse Section A-A**
- Inner bottom
- Longitudinal girder
- Floor
- Critical Locations
- Bottom shell

- **Critical Location**: Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.
- **Detail Design Improvement**: Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder longitudinal loading.
- **Building Tolerances**: Ensure good alignment between web of longitudinal, floor stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Figs. 3.2.2 and 3.2.3. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.
- **Welding**: Ensure start and stop of welding is as far away as practicable from the stiffener/bracket heel and toe. A wrap-around weld should be free of undercut and notches around the heel and toe connections of the stiffener and backing bracket connection to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.

**FIGURE 1.1**
**DETAIL DESIGN GUIDELINES FOR CONTAINER SHIPS**
**STRUCTURAL DETAILS**
Example No. 2: Intersection of bottom and inner bottom longitudinals with floor, including offset stiffener

**Critical Locations**

- **Transverse Section A–A**: Critical Locations
- **Bottom shell**
- **Inner bottom**
- **Floor**

**Critical Areas**

- **A**: Inner bottom
- **B**: Bottom shell

**Detail Design Improvement**

- **Quality of wrap-around weld important**
- **Taper 1:3**
- **Toe height 10 ~ 15 mm**
- **50 mm max.**
- **25 ~ 50 mm**

**Critical Locations**

- **Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.**

**Detail Design Improvement**

- **Offset stiffener can be used to eliminate the stress concentration in the connection between the longitudinal and the floor stiffener. Scallop...**

**Building Tolerances**

- **Attention is drawn to Pt 3, Ch 10.5.2.14 of the Rules for Ships, dealing with collar plates and the distance between the offset stiffener and the cut-out of the longitudinal member.**

**Welding**

- **Special attention is to be drawn to the quality of the wraparound weld at the end of the offset stiffener and at the web/floor connection (most important). The wraparound...**

**Figure 1.2**

**Detail Design Guidelines for Container Ships**

**Structural Details**

---

**Transverse Section A–A**: Critical Locations

- **A**: Inner bottom
- **B**: Bottom shell

**Quality of wrap-around weld important**

- **Taper 1:3**
- **Toe height 10 ~ 15 mm**
- **50 mm max.**
- **25 ~ 50 mm**

**Critical Locations**

- **Heel and toe connection of the floor stiffeners to the bottom shell longitudinals.**

**Detail Design Improvement**

- **Offset stiffener can be used to eliminate the stress concentration in the connection between the longitudinal and the floor stiffener. Scallop...**

**Building Tolerances**

- **Attention is drawn to Pt 3, Ch 10.5.2.14 of the Rules for Ships, dealing with collar plates and the distance between the offset stiffener and the cut-out of the longitudinal member.**

**Welding**

- **Special attention is to be drawn to the quality of the wraparound weld at the end of the offset stiffener and at the web/floor connection (most important). The wraparound weld should be free of undercut and notches. See also Pt 3, Ch 10 of the Rules for Ships.**
**Area 2:** Bilge tank  
**Example No. 1:** Bilge tank transverse web, flat bar connections to shell longitudinals

### Critical Areas

### Detail Design Improvement

- **(a) Soft heel detail improvement**
  - Further detail improvement (soft toe and soft heel)

- **(b) Symmetrical soft toe and soft backing bracket improvement**

---

**Critical Location**: Heel and toe connection of the bilge tank transverse web stiffeners to the bottom, bilge and side shell longitudinals.

**Detail Design Improvement**: Soft heel or soft toe and soft heel or symmetrical soft toe with backing bracket can be used to reduce the peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading.

**Building Tolerances**: Ensure good alignment between web of longitudinal, transverse web stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Figs. 3.2.2 and 3.2.3. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.

**Welding**: Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap-around weld should be free of undercut or notches around the heel and toe connections of stiffener and bracket to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 2: Bilge tank
EXAMPLE No. 2: Bilge tank transverse web, tripping bracket connection to shell longitudinals

CRITICAL AREAS

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Heel and toe connection of the bilge tank transverse web brackets to the bottom, bilge and side shell longitudinals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail Design Improvement</td>
<td>Soft heel or soft toe and soft heel or symmetrical soft toe with soft backing bracket can be used to reduce the peak and range of resultant stresses from cyclic external hydrodynamic pressures and hull girder global loading.</td>
</tr>
<tr>
<td>Building Tolerances</td>
<td>Ensure good alignment between longitudinal stiffener web, transverse web tripping brackets and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Figs. 3.2.2. and 3.2.3.</td>
</tr>
<tr>
<td>Welding</td>
<td>Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap-around weld should be free from undercut and notches around the heel and toe connections of brackets. See also Pt 3, Ch 10 of the Rules for Ships.</td>
</tr>
</tbody>
</table>

CRITICAL LOCATIONS

Transverse section through bilge tank

- Critical Locations
- Section A-A
- Bottom shell

Critical Location

Further detail improvement (soft toe and soft heel)

(a) Soft heel detail improvement

(b) Symmetrical soft toe and soft backing bracket improvement

Welding

DETAIL DESIGN GUIDELINES FOR CONTAINER SHIPS
STRUCTURAL DETAILS

FIGURE 2.2
**Critical Locations**

Transverse section through bilge tank

- Longitudinal plate or bulkhead
- Bottom shell
- Section A-A

**Critical Locations**

- Inner bottom bulkhead
- Main transverse web
- Critical Location

**Critical Area 2: Bilge tank**

**Example No. 3: Bilge tank connection to double bottom**

**Critical Areas Design Improvement**

- Improvement at the lower 'hopper' knuckle
- Elimination or closure of scallops with full/flush collars
- Enhanced welding
- Inner bottom plate extended into the bilge tank

**Detail Improvement (Section A-A)**

- Scarfing bracket
- WT bulkhead
- Toe height 15 ~ 25 mm
- R > 400 mm

**Building Tolerances**

Ensure good alignment between inner bottom plate and backing brackets.

**Welding**

Small scallops of suitable shape are to be closed by welding after completion of the continuous welding of side girders to inner bottom plating. See also Pt 3, Ch 10 of the Rules for Ships. Enhanced fillet welding with weld factor 0.44 (Connection of side girders to inner bottom plating. Connection of floors to side girders. Connection of bilge transverse webs to side girders). Further improvement may be provided by applying deep penetration weld to midhold support of 20 feet container bay.

**See alternative example 2.3a**

**FIGURE 2.3(a)**

**Detail Design Guidelines for Container Ships**

**Structural Details**
### Critical Areas

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Side girder connections to inner bottom plating in way of floors. Floor and bilge transverse web connections to inner bottom plating and to side girders.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail Design Improvement</td>
<td>Elimination of scallops in way of bilge tank corners scarfing brackets in line with inner bottom extension to reduce the peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia and hull girder global loading.</td>
</tr>
<tr>
<td>Building Tolerances</td>
<td>Ensure good alignment between inner bottom plate and backing brackets.</td>
</tr>
<tr>
<td>Welding</td>
<td>Small scallops of suitable shape are to be closed by welding after completion of the continuous welding of side girders to inner bottom plating. See also Pt 3, Ch 10 of the Rules for Ships. Enhanced fillet welding with weld factor 0.44 (Connection of side girders to inner bottom plating. Connection of floors to side girders. Connection of bilge transverse webs to side girders). Further improvement may be provided by applying deep penetration weld to midhold support of 20 feet container bay.</td>
</tr>
</tbody>
</table>

### Detail Design Guidelines for Container Ships: Structural Details

**Figure 2.3(b)**
**Chapter 6**

**SECTION 2**

**Container Ships**

**Area 2:** Bilge tank

**Example No. 4:** Longitudinal bulkhead connection to top of bilge tank

<table>
<thead>
<tr>
<th>Critical Areas</th>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**Critical Locations**

**Transverse section through bilge tank**

<table>
<thead>
<tr>
<th>Critical Location</th>
<th>Detail Design Improvement</th>
<th>Building Tolerances</th>
<th>Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side longitudinal bulkhead connections to bilge tank top plate and transverse webs in way of corner.</td>
<td>Elimination of scallops in way of corners and enhanced support below side longitudinal bulkhead provided by increased stiffener below and supporting brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia loads and hull girder global loading.</td>
<td>Ensure good alignment between longitudinal bulkhead and backing bracket. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.</td>
<td>Scallop cut-outs in way are to be closed by collars after completion of the continuous welding of plating in the vicinity of knuckle. See also Pt 3, Ch 10 of the Rules for Ships. Enhanced fillet welding with weld factor 0.44 (connection of longitudinal bulkheads and backing bracket to bilge tank top plating). Further improvement may be provided by applying deep penetration weld to midhold support of 20 feet container bay.</td>
</tr>
</tbody>
</table>

**Figure 2.4(a)**

**Detail Design Guidelines for Container Ships**

**Structural Details**
AREA 2: Bilge tank
EXAMPLE No. 4a: Longitudinal bulkhead connection to top of bilge tank

**CRITICAL AREAS**

**DETAILED DESIGN IMPROVEMENT**

**Critical Location** Side longitudinal bulkhead connections to bilge tanktop plate and transverse webs in way of corner.

**Detail Design Improvement** Elimination of scallops in way of corners and enhanced support below side longitudinal bulkhead provided by increased stiffener below and supporting brackets to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure, cargo inertia loads and hull girder global loading.

**Building Tolerances** Alignment between longitudinal bulkhead and backing bracket is to comply with an approved standard. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.

**Welding** Scallop cut-outs in way are to be closed by collars after completion of the continuous welding of plating in the vicinity of knuckle. See also Pt 3, Ch 10 of the Rules for Ships. Enhanced fillet welding with weld factor 0,44 (connection of longitudinal bulkheads to bilge tank top plating). Consideration is drawn to the midhold connections between inner bottom and side longitudinal bulkhead. Further improvement may be provided by applying deep penetration weld to midhold support of 20 feet container bay.

**2055**
Critical Locations

Heel and toe connections of horizontal flat bar stiffeners on transverse webs to side shell longitudinals in side tanks. (Connections from the base line to just above the load waterline will be the most critical.)

Detail Design Improvement

Soft heel or soft toe and heel detail or symmetrical soft toe with soft backing bracket can be used to reduce the peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading.

Building Tolerances

Ensure good alignment between web of longitudinal transverse web stiffener and backing bracket, if fitted. For recommended stiffener and bracket alignment, see Ch 3, Figs. 3.2.2 and 3.2.3. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.

Welding

Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap-around weld should be free of undercut or notches around the heel and toe connections of stiffeners and backing bracket to the longitudinal face plate. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 3: Side tanks/underdeck passage
EXAMPLE No. 2: Connections of side shell longitudinals to horizontal tripping brackets on transverse webs

Critical Location Heel and toe connections of horizontal tripping brackets on transverse side webs to side shell longitudinals (connections from the base line to just above the load waterline will be the most critical).

Detail Design Improvement Soft heel or soft toe and heel detail or symmetrical soft toe with soft backing bracket can be used to reduce peak and range of resultant stresses arising from cyclic external hydrodynamic pressure and hull girder loading.

Building Tolerances Ensure good alignment of the tripping brackets, the backing bracket and the web of the side longitudinal. For recommended stiffener and bracket alignment, see Ch 3, Figs. 3.2.2 and 3.2.3.

Welding Ensure start and stop of welding is as far away as practicable from the heel and toe. A wrap-around weld should be free of undercut or notches around the heel and toe connections of stiffeners and backing bracket to the longitudinal face plate. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 4: Deck, hatch corners and between hatches
EXAMPLE No. 1: Deck plating in way of the hatch corners of cargo region

CRITICAL AREAS

Dt. 1. Example of detail design improvement

Detail design improvement, large radius deck corner insert plate

Critical Location
Deck plating in way of the hatch corners.

Detail Design Improvement
Use insert plates of enhanced steel grade and thickness. Ensure gradual transition to thinner plating as far as practicable. Attention is drawn to Pt 4, Ch 8.4 of the Rules for Ships.

Building Tolerances
Ensure good alignment between hatch end beam and support in the topside tank. Special attention is drawn to taper details of the insert plate. Insert plates may be avoided by modifying the corner detail to reduce stress levels and use EH grade plate.

Welding
Ensure start and stop of welding is as far away as practicable from the corners of the insert plate. Ensure weld profiles are ground smooth and free of notches after fit-up in way of insert plate free edges. Ensure that no weld attachments are subsequently made to ground edges. See also Pt 3, Ch 10 of the Rules for Ships.

FIGURE 4.1 DETAIL DESIGN GUIDELINES FOR CONTAINER SHIPS STRUCTURAL DETAILS
AREA 4: Deck, hatch corners and between hatches
EXAMPLE No. 2: Connection of hatch side coaming to deckhouse side wall and deckhouse structure

Critical Location 1. Deck plating in way of the hatch corners near superstructure.
2. Intersection of hatch coaming with superstructure.

Detail Design Improvement
Use insert plates of enhanced steel grade and thickness. A radiused corner is to be provided to reduce stress concentration. Ensure gradual transition or tapering to thinner plating as far as practicable. Attention is drawn to Pt 4, Ch 8.4 of the Rules for Ships. Grind edge smooth of the bracket to superstructure and use enhanced steel grade and thickness in superstructure side shell.

Building Tolerances
Ensure good alignment between main structure support members in the vicinity.

Welding
Ensure start and stop of welding is as far away as practicable from the toes of brackets or corners. A wraparound weld should be free from undercut or notches. See also Pt 3, Ch 10 of the Rules for Ships.
### Critical Locations

#### Critical Location 1
1. Deck plating in way of the hatch corners near superstructure.
2. Intersection of hatch coaming with superstructure.

#### Detail Design Improvement
Use insert plates of enhanced steel grade and thickness. A radiused corner is to be provided to reduce stress concentration. Ensure gradual transition or tapering to thinner plating as far as practicable. Attention is drawn to Pt 4, Ch 8.4 of the Rules for Ships. Grind edge smooth of the bracket to superstructure and use enhanced steel grade and thickness in superstructure side shell.

#### Building Tolerances
Ensure good alignment between main structure support members in the vicinity.

#### Welding
Ensure start and stop of welding is as far away as practicable from the toes of brackets or corners. A wraparound weld should be free from undercut or notches. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 4: Deck, hatch corners and between hatches
EXAMPLE No. 3: Hatch coaming structure and transverse stay brackets

CRITICAL AREAS

WT
BHD
WT
BHD

AREA 4: Deck, hatch corners and between hatches

EXAMPLE No. 3: Hatch coaming structure and transverse stay brackets

CRITICAL LOCATIONS

Critical Location
Toe connection of continuous coaming stay bracket to the deck plating and connection between transverse and longitudinal top of coamings.

Detail Design Improvement
1. Extend the hatch coaming, the transverse bulkheads and the transverse bracket to provide an integral soft toe for smooth transition of stresses into the deck.
2. A symmetrical face flange can be used, see above improvement (b) with soft toe.

Building Tolerances
Ensure good alignment between stay brackets and supporting structure. The heel line recommendation is sufficient, see Ch 3, Fig. 3.2.1.

Welding
Ensure start and stop of welding is as far away as practicable from the toes of brackets or corners. A wrap-around weld should be free from undercut or notches around the toe connection of the bracket to the deck plating. See also Pt 3, Ch 10 and Ch 11,5 of the Rules for Ships.
AREA 4: Deck, hatch corners and between hatches
EXAMPLE No. 4: Extension brackets between hatch end coamings at cross deck

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT

Critical Location
Connection of two adjacent hatches, especially at the vicinities of high local horizontal forces.

Detail Design Improvement
If it is not possible to fit a closed transverse hatch coaming, the web stiffening members should be well-rounded.

Building Tolerances
Attention is to be drawn to the alignment of the inboard web bracket to the underdeck (bulkhead) web stiffeners.

Welding
Ensure start and stop of welding is as far away as practicable from the toes or corners of the brackets. Transverse hatch coaming brackets should be free of notches.
AREA 5: Hatch side coaming
EXAMPLE No. 1: Details in way of hatch cover bearing pads and stoppers on longitudinal and transverse coamings

CRITICAL AREAS

CRITICAL LOCATIONS

Critical Location
Hatch cover supporting structure. Very high local forces, due to container loads on the hatch cover. The loads have to be transferred into the longitudinal/transverse coamings via the bearing pads and the supporting brackets.

Detail Design Improvement
Fit at least two well-rounded brackets under each bearing pad. The brackets should transfer loads either to the longitudinal/transverse stiffener on the vertical part of longitudinal/transverse coaming or to the structure below the deck. Use low-friction bearing materials to reduce horizontal forces in the surrounded structure of bearings. Stresses in the hatch coaming structure in way of the hatch cover supports are to be checked by detailed calculations. Every effort should be made to reduce eccentricities in the load path.

Building Tolerances
The position of the brackets should be within the length of the bearing pad. It is also possible to attach the bearing plate to the hatch cover and the bearing pad to the coaming. Similar supporting arrangements can be used for hatch cover positioning guides/stoppers.

Welding
The weld factor of the fillet welds of the brackets and stays should be not less than 0.34. The welds of the bearing plates should be dimensional according to the vertical and horizontal support reaction forces and on the longitudinal coaming at the end be increased with a weld flank angle of 30 degrees.
### AREA 5: Hatch side coaming

**EXAMPLE No. 2:** Arrangements in way of openings in longitudinal coamings and top strake of longitudinal bulkhead

<table>
<thead>
<tr>
<th>CRITICAL AREAS</th>
<th>DETAIL DESIGN IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**Critical Location Interruption-rerouting of longitudinal stiffeners in way of openings in areas with high global bending stress, such as top strake of the longitudinal bulkhead.**

**Detail Design Improvement:**
- Avoid interruptions, divert stiffener around the openings. Support the longitudinal stiffener with stiffenings. Weldings, as far as possible, should be outside of the stiffener’s knuckles and the longitudinal bulkhead insert plate. Fit insert plate around the opening in the longitudinal bulkhead.
- Building Tolerances: Misalignments at interruptions/connections of the longitudinal stiffeners should be as small as possible.
- Welding: Special consideration should be given to the butt weld of the longitudinal stiffeners and welding around the insert plate.

**FIGURE 5.2**

**DETAIL DESIGN GUIDELINES FOR CONTAINER SHIPS**

**STRUCTURAL DETAILS**
Critical Location: Toe connection of the longitudinal hatch side coaming fore and aft termination.

Detail Design Improvement: Continuous extended and radiused/reversed radiused coaming with soft toe termination to reduce the peak and range of resultant stresses arising from cyclic hull girder loading.

Building Tolerances: Ensure good alignment of termination plate with the underdeck longitudinal member (bulkhead or girder).

Welding: Ensure start and stop of welding is as far away as practicable from the toe. A wraparound weld should be free from undercut and notches around the toe. Use deep penetration welding at the toe termination. The deep penetration weld and the free edge of the coaming’s termination should be ground.
Area 6: Watertight and non-watertight bulkheads

Example No. 1: Connection of hatch end beam to the longitudinal bulkhead, including 2nd deck transverse passageway

Critical Areas

Detail Design Improvement

Modification/addition of collars, elimination of scallops and ensure alignment of horizontal web with hatch end beam underside plate.

Critical Locations

Critical Location

Connections of hatch end beam and underside plate to the inner side shell (longitudinal bulkhead).

Detail Design Improvement

Full collars, elimination of scallops and soft toe or parallel toe detail to reduce the peak and range of resultant stresses arising from global cyclic bending and torsion. Increase thickness of hatch end beams and transverse webs in way.

Building Tolerances

Enhanced alignment standard. Alignment between hatch end beam and side structure is to comply with an approved standard.

Welding

Enhanced fillet welds are to have a minimum weld factor of 0.44 (Connection of transverse webs in way of hatch end beam and underside plate to side longitudinal bulkhead). Scallops are to be closed after completion of continuous welding near the hatch end corner. See also Pt 3, Ch 10 of the Rules for Ships.
Area 6: Watertight and non-watertight bulkheads
Example No. 2: Connection of bulkhead stringer (walkways) to the longitudinal bulkhead

<table>
<thead>
<tr>
<th>Critical Locations</th>
<th>Detail Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side stringer</td>
<td>Separate Radiused Bracket Improvement</td>
</tr>
<tr>
<td>Side shell</td>
<td>Side (wing) tank</td>
</tr>
<tr>
<td>Side (wing) tank</td>
<td>Transverse side webs</td>
</tr>
<tr>
<td>Horizontal (walkway) stringer</td>
<td>Horizontal (walkway) stringer</td>
</tr>
<tr>
<td>Critical Locations</td>
<td>Integral Radiused Faceplate Improvement</td>
</tr>
<tr>
<td>Side stringer</td>
<td>Side (wing) tank</td>
</tr>
<tr>
<td>Side shell</td>
<td>Transverse side webs</td>
</tr>
<tr>
<td>Horizontal (walkway) stringer</td>
<td>Horizontal (walkway) stringer</td>
</tr>
<tr>
<td>Transverse side webs</td>
<td>Full collar</td>
</tr>
</tbody>
</table>

Critical Location: Connections of face plate of horizontal bulkhead stringers to the longitudinal bulkhead.

Detail Design Improvement: Symmetrical radiused or integral radiused brackets to reduce peak and the range of resultant stresses arising from cyclic cargo loading. Use full collars in longitudinal web plates if toes of face plates end close to longitudinal stiffener cut-outs. Further, side and inner shell longitudinals in way of bulkhead structure should be fitted with brackets.

Building Tolerances: Ensure good alignment of the side web and face plates of stringers and of horizontal side and bulkhead stringers.

Welding: Fillet welding having minimum weld factor of 0.34 (Connection of soft toe brackets to face plates of stringers and to longitudinal bulkhead). A wraparound weld should be free of undercut or notches around the toe connections of brackets. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 6: Watertight and non-watertight bulkheads
EXAMPLE No. 2a: Connection of bulkhead stringer (walkways) to the longitudinal bulkhead

**Critical Areas**

**Detail Design Improvement**

**Critical Locations**

**Critical Location**: Connections of face plate of horizontal bulkhead stringers to the longitudinal bulkhead.

**Detail Design Improvement**: Symmetrical radiused or integral radiused brackets to reduce peak and the range of resultant stresses arising from cyclic cargo loading. Use full collars in longitudinal web plates if toes of face plates end close to longitudinal stiffener cut-outs. Further, side and inner shell longitudinals in way of bulkhead structure should be fitted with brackets.

**Building Tolerances**: Ensure good alignment of the side web and face plates of stringers and of horizontal side and bulkhead stringers.

**Welding**: Fillet welding having minimum weld factor of 0.34 (Connection of soft toe brackets to face plates of stringers and to longitudinal bulkhead). A wraparound weld should be free of undercut or notches around the toe connections of brackets. See also Pt 3, Ch 10 of the Rules for Ships.

**Figure 6.2a**

**Detail Design Guidelines for Container Ships**

**Structural Details**
AREA 6: Watertight and non-watertight bulkheads
EXAMPLE No. 3: Connections in the double bottom where both sides of bulkhead are supported

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT

Critical Location
Connections of floor vertical stiffeners to the bottom and inner bottom longitudinals below bulkhead and connections of bulkhead bottom box to the inner bottom plate.

Detail Design Improvement
Fitting of soft brackets reduces peak and range of stresses in the vicinity near the connections of floor stiffeners to the bottom and inner bottom longitudinals and the connections of stool to inner bottom plate.

Building Tolerances
Ensure good alignment between brackets and stiffener webs, see Ch 3, Figs. 3.2.1, 3.2.2 and 3.2.3. If soft heel is used, the remaining cross-sectional area across the minimum width of the stiffener web is to be verified against the Rule requirements.

Welding
Use fillet welding with a weld factor of 0.44 between inner bottom and floors. Ensure start and stop of welding is as far away as practicable from the toes of brackets or corners. A wraparound weld should be free of undercut and notches around the toe connections of the stiffeners and backing brackets to longitudinal. See also Pt 3, Ch 10 of the Rules for Ships.
AREA 6: Watertight and non-watertight bulkheads
EXAMPLE No. 4: Connections of vertical web face plates to inner bottom and first walkway/stringer

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT

Critical Location
Connections of bulkhead vertical web face plates to the inner bottom structure and first walkway/stringer.

Detail Design Improvement
The face plate toes of the vertical webs should be terminated clear of a supporting stiffener. Gusset plate should be fitted at connection of horizontal and vertical webs.

Building Tolerances
Ensure good alignment of face plates and webs to floors or bulkheads below.

Welding
All rounded edges should be free of notches. A wraparound weld should be free of undercut and notches around the toe of the face plate. See also Pt 3, Ch 10 of the Rules for Ships. A minimum weld factor of 0.34 is to be adopted for the connection of web plate to inner bottom and 0.44 for the face plate to inner bottom.
AREA 7: Intermediate decks in forward holds
EXAMPLE No. 1: Corner detail in way of stepped longitudinal bulkhead to intermediate deck connection

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT

Minimum Detail Design Improvement
The corner detail design may vary with ship design, but in general, the radii at the corner are to be as large as practicable.

Further Detail Design Improvement
In addition to the above, it may be considered prudent to fit insert plates of 50% greater thickness than the surrounding plate and of enhanced material grade.

Welding
Welding in way of radii is to be avoided. See also Pt 3, Ch 10 of the Rules for Ships.