Guidance Notes for the Classification of Special Service Craft

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GUIDANCE NOTES ON DESIGN DETAILS

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Section

1 **Introduction**

2 **Fatigue – General considerations**

Section 1 Introduction

1.1 Purpose of the Guidance Notes

1.1.1 With the advent of novel and high speed craft types the need for good structural detail has never been more important. Most structural failures that occur in the service life of a craft result from fatigue. A considerable amount of published data exists for more conventional steel vessels, however, little or no such data exists for the novel or high speed craft constructed from aluminium alloy or composite materials. Lloyd's Register (hereinafter referred to as LR) has amassed considerable knowledge in respect of structural detail which has demonstrated satisfactory service experience in resisting structural failure from fatigue. The details contained within these Guidance Notes are therefore provided to assist Builders and designers in identifying a minimum level of design detail which has provided acceptable levels of resistance to structural failure arising from fatigue.

1.1.2 It is not intended that the details contained within these Guidance Notes are the only solution to a particular structural design. Alternative structural details that have demonstrated satisfactory service experience will be acceptable.

1.2 General

1.2.1 Quality of detail design is fundamental if the craft's envisaged design life is to be attained. Experience over the past two decades, when structural concepts were revolutionised and aspects such as speed greatly increased, clearly indicated that areas of detail design became more prone to fatigue cracking with the traditional structural arrangements for details being used at that time.

1.2.2 Service experience has shown 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.

1.2.3 In general, the problems associated with aspects of detail design are those relating to fatigue ageing and failure.

1.2.4 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, where upon the structure fails. Fatigue accounts for a large percentage of all service failures.

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

1.2.6 Fatigue cracks generally initiate at high stress locations such as structural discontinuities, weld toes, matting in connections, 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 craft repairs, it is essential that fatigue is given more detailed consideration in the design of the structure.

1.2.7 Fatigue ageing of structural components is an accumulative process which is largely due to the environment and the loads experienced. An important realisation is that it is inevitable and where stress concentrations are present in association with significant magnitudes of stress variation then fatigue cracking will, in general, 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 selecting of the type and grade of material.
(d) The standard of workmanship in the craft construction.
(e) Corrosion rates and magnitudes (metallic structures).
(f) Erosion rates and magnitudes (composite structures).

1.2.8 Since the fatigue properties of higher tensile strength metallic materials are, in general, similar to those of the basic grade materials, the higher allowable 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 strength materials are incorporated and hence higher stress levels are accepted, then structural details, which would have been acceptable in mild steel structure manufactured from the basic grade material, might not be adequate.

1.2.9 The occurrence of cracking in craft is of prime concern from both a safety and maintenance point of view. Experience has shown that fatigue cracks in craft 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 Basis of the Guidance Notes

2.1.1 In assessing fatigue performance, the effect of cyclic loading should be taken into consideration. The types of cyclic loading experienced in service, will, in general, depend upon the size, type and speed of the craft. Cyclic wave induced loads created by the passage of waves along the craft sides and the associated local structural response create the highest risk for fatigue damage and cracking for large craft whereas, the major consideration for small high speed craft will relate to impact considerations, hard spots and discontinuities in the structure, etc.

2.1.2 Loading associated with bottom structures, in terms of hull girder response and local pressure variation, are heavily influenced by the length of waves and their direction in relation to the craft length and draught. Similarly, the deck structure is exposed to hull girder loads in response to relatively longer waves and cargo local loads arising from craft responses. Alternatively, these can be associated with structural discontinuities and slamming in shorter waves.

2.1.3 Deck and bottom longitudinal structure require attention to detail design and structural continuity to reduce the effects of stress concentration. Depending on the type of craft, the side shell structure may be exposed to dynamic loading from the internal pressure head from storage of consumables or cargo, in association with wave induced pressure variations, resulting in high cycle local bending stresses applied to the longitudinals and connection details at the transverse bulkhead stiffeners. This may transfer moments resulting in further increased stresses in the side longitudinals.

2.1.4 Every stress concentration and welded joint is a potential source of fatigue cracking and the design, taking note of symmetry, should reflect this. To ensure the structural integrity of the stiffening members particular attention should be given to the detail design. This document provides initial design guidance on fatigue and includes recommendations for the improvement of welded joint fatigue strength, or the bonded joint fatigue strength in the case of composite structures.

2.1.5 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 craft component the allowable stresses should be in accordance with the requirements of LR's *Rules and Regulations for the Classification of Special Service Craft* (hereinafter referred to as the Rules for Special Service Craft).

2.4 Design loads

2.4.1 Applied design loads must take into consideration the appropriate environmental and dynamic conditions. Such loads are indicated in Part 5 of the Rules for Special Service Craft.

2.4.2 Realistic assessment of the fatigue loading is crucial to the estimation of fatigue life. Little or no published data for loading exists for the types of craft covered by the Rules for Special Service Craft. LR is conducting research in this field, the results of which will form the basis of Rules for Special Service Craft requirements in the future.

2.5 Stress concentrations

2.5.1 The design, fabrication and construction of all structural details should be based on procedures and processes to minimise stress concentrations.

2.5.2 Fatigue strength is seriously reduced by the introduction of a stress raiser such as a notch, of the method of termination of stiffeners and brackets, etc., or a 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 processing 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, etc., as appropriate to the construction material.

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,
(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.

2.5.5 Values of the stress concentration factor 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 should be avoided as they can induce local stress concentrations and reductions of fatigue life.

2.7 Vibration

2.7.1 If possible, precautions should 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 panel 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 associated with the four way connection of plate or stiffeners, may be separated into two distinct types depending on whether or not the fillet weld transmits direct load i.e. non-load carrying or load carrying cruciform joints. 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.

2.8.5 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.

2.8.6 Tee joints, since they represent a semi-cruciform joint in a three way connection of plates or stiffeners, 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.

2.8.7 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 Manufacture, Testing and Certification of Materials* (hereinafter referred as the Rules for Materials).

2.8.8 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.

2.8.9 The most common sites for potential fatigue cracks therefore are:

(a) Toes and roots of fusion welds.
(b) Machined corners.
(c) Drilled holes, cut-outs or other openings.

2.8.10 The main conditions affecting fatigue performance are:

(a) High ratios of dynamic to static loads.
(b) Loading frequency.
(c) Material selection.
(d) Welding.
(e) Complexity of joint detail.
(f) Environment.

2.8.11 For craft operating for long periods in low air temperatures, or high temperatures for composites, 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 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft for steel and aluminium alloy craft respectively.

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 5×10^8 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 should 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 detailed 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, in general, with increasing thickness.

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 As an example 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 must 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’. High strength steels (for which grinding is most often used) are particularly sensitive to grinding techniques.

Guidance for Designers for Steel/Aluminium Construction

Section

1 **Introduction**

2 **Fatigue strength improvement methods**

Section 1 Introduction

1.1 Definition

1.1.1 **Critical areas** can be defined as locations that, by reason of stress concentration, alignment/discontinuity and corrosion will have a higher probability of failure during the life of the craft 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 to minimise fatigue failures, LR has developed an extensive database on 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 condensed into these Guidance Notes. It is intended as a conservative approach to improving the fatigue life performance of structural details.

1.2.4 The designer may therefore, using these Guidance Notes, readily upgrade the detail design arrangements to provide a higher fatigue performance configuration.

1.2.5 It is intended that the detail design database given in Chapter 4 will be extended to incorporate further detail arrangements, to reflect in-service experience of their fatigue performance, design and construction practice, as well as any significant data made available from research studies.

1.2.6 In addition, guidance is provided to the designer and Builder on other methods to improve the fatigue life performance of the structural detail such as detail geometry, construction tolerances, welding sequence, weld defect, weld dressing, etc.

1.3 Application

1.3.1 The detail design improvements provided in these Guidance Notes are applicable to all grades of steel, commonly used aluminium alloys and composite structures. This is because the fatigue life improvement will be achieved through the suggested change of **geometry** which will reduce the stress concentrations and the **improved construction** requirements which will improve the performance throughout the design lifetime of the structural detail under the expected stress variations.

1.3.2 In areas where **mild steel** and basic grade aluminium may be used a number of the suggested detail improvements may not be necessary due to the lower stress ranges that the details are designed to experience. However, in areas where **higher tensile steel** (HTS) or higher strength grade aluminium are used, the operating stresses will generally be higher. Therefore the detail improvements suggested may become necessary in order to meet the fatigue strength of the structure.

1.3.3 **Alternative structural arrangements** will, in general, be acceptable provided it can be demonstrated, that a satisfactory fatigue life performance will be maintained throughout the design life span. In addition the structural arrangements and scantlings are to satisfy the Rules for Special Service Craft.

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

Section 2 Fatigue strength improvement methods

2.1 General

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

2.1.2 Upgrading of the fatigue life of a structural detail can be achieved in a number of ways as follows:

Design Stage

- By adopting good detail design configuration, i.e., by the provision of soft connections, the geometrical stress concentration factor due to the geometrical discontinuity 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, to reduce the local hot spot stresses.
- By modifying the structural load path and/or reducing the structural load level by the provision of additional load carrying members.

Fabrication Stage

- By improving the fatigue life of the detail by using an improvement method.

2.1.3 It is LR's intention to promote the Design Stage method for fatigue strength improvement of a craft's structural details. Fabrication stage improvement methods should only be considered as remedial measures, and subjected to strict quality control procedures. Where a fabrication stage improvement method is planned at the design stage, it is to be specially considered by LR to ensure that a satisfactory level of fatigue strength improvement is achieved.

2.2 Significant variables affecting fatigue strength improvement methods

2.2.1 The significant variables affecting the fatigue strength of a craft's structural details are reviewed:

- The geometrical notch at the weld toe region is normally the most fatigue critical area. 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 eliminating 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, and 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 small 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 which need to be specially considered to improve the fatigue strength of ship structural details as follows:

- Nominal stress level.
- Geometrical stress concentration due to the structural detail geometry.
- Weld geometry and construction tolerances.
- Residual stresses and construction procedure.

Each item outlined above is presented in the following Sections.

2.3.2 **Nominal stress level**. The most efficient way to improve fatigue strength is to increase the local scantling to reduce the nominal stress level, and hence the hot spot stress for a given structural detail. In general, structural details on higher tensile steel and aluminium require improvement in detail design over the mild steel and the base grade aluminium equivalent structural detail by virtue of the higher stress level and the constant fatigue strength for material of various yield strength. The advantages and disadvantages of this fatigue strength improvement method are summarised in Table 2.3.1.

Table 2.3.1 Nominal stress level

Advantages	Disadvantages
• Reduce stress level • Increase static strength • Potential decrease in number of structural components and/or complexity required over that for a structural detail in higher tensile strength material	• Increase structure weight

2.3.3 **Geometrical stress concentration**. The adoption of a good detail design configuration by the provision of soft connections reduces the geometrical stress concentration factor due to the geometrical discontinuity to a satisfactory level. Typical detail design improvements for the critical areas are provided in Chapters 4 and 5 of these Guidance Notes for steel/aluminium alloy and composite construction respectively. These detail design improvements have been developed from the consolidation of service experience and finite element analysis. The advantages and disadvantages of the subject fatigue improvement method are summarised in Table 2.3.2.

Table 2.3.2 Geometrical stress concentration

Advantages	Disadvantages
• Reduce hot spot stress level by reducing the local geometrical stress concentration • Most effective fatigue strength improvement technique • May provide additional structural redundancy	• May increase structural weight if additional pieces are required • Requires good workmanship where soft toe/heel are required

2.3.4 **Weld geometry and construction tolerances**. At the design stage, special attention may be given to achieving a favourable geometry and smooth transition at the weld toe, and minimising secondary stress concentration which may arise from the fit up and 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.

In view of the size and hull form of special service craft, additional considerations must, in general, be given to the accessibility for welding. This should include the selection of the depth, geometry and orientation of the stiffening members to provide the necessary access to carry out the required welding sequences, with the type and size of welding equipment available to the Builder.

The advantages and disadvantages of the subject fatigue improvement method are summarised in Table 2.3.3.

Table 2.3.3 Weld geometry and construction tolerances

Advantages	Disadvantages
• The improvement may be introduced at the design stage • The improvement is performed in the welding process itself • Subject to well defined inspection plan and hence higher reliability	• Improvement can be subject to large scatter if not controlled under QA survey conditions i.e., Fatigue Control Plan

2.3.5 **Residual stresses, and construction procedures**. The minimising of residual stresses through the adoption of appropriate welding procedures and sequences, the use of adequate unit size, and appropriate sequence of erection of the prefabrication unit do not constitute in themselves a fatigue strength improvement procedure. Nevertheless careful planning should be considered at the design stage to ensure that detrimental effects will not be introduced during the construction process.

Construction Tolerances and Defect Correction Procedures for Steel/Aluminium Construction

Section

1 **Introduction**

2 **Construction tolerances**

3 **Defect correction procedures**

Section 1 Introduction

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.
(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 craft 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 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft for steel and aluminium alloy craft respectively. The individual standards employed by Builders are normally based on individual national standards, e.g. British Standards, 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 The LR Surveyors 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 indicated in Pt 3, Ch 1 of the Rules for Special Service Craft.

Section 2 Construction tolerances

2.1 General

2.1.1 Construction tolerances are to comply with Pt 3, Ch 1 of the Rules for Special Service Craft. The additional guidance given in this Chapter should also be complied with where practicable.

2.2 Defects in steel/aluminium products

2.2.1 Where defects are found in materials after delivery to the Builder, any rectification should be agreed with the LR Surveyor and should generally be in accordance with Ch 3,1.11 or Ch 8,1.10 of the Rules for Materials and aluminium respectively.

2.2.2 If lamination is found during plate preparation the extent of the lamination should be ascertained by ultrasonic examination. Renewal of the affected material is normally recommended.

2.3 Construction standards

2.3.1 Construction standards (including preparation of material, joint alignment, type of welded joint, fit-up prior to welding, steps to be taken for rectification of defects, etc.) are to be agreed between LR and the Builder. Such standards will be recorded and kept on file by LR. In a number of countries national standards exist in respect of the acceptable shipbuilding standards.

2.3.2 In shipyards certified under the LR Quality Assurance Scheme, the standards will have received general approval as part of the certification procedures and their application to particular craft will be included in the quality plan submitted to LR for approval.

2.3.3 In considering critical locations and their construction standards it also has to be borne in mind that craft 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). It is therefore recommended, particularly for aluminium, that a median line principle is employed at this local area so that an improved alignment can be more easily attained. From LR'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 should be controlled to a maximum of one in three, *see* Fig. 3.2.1(b).

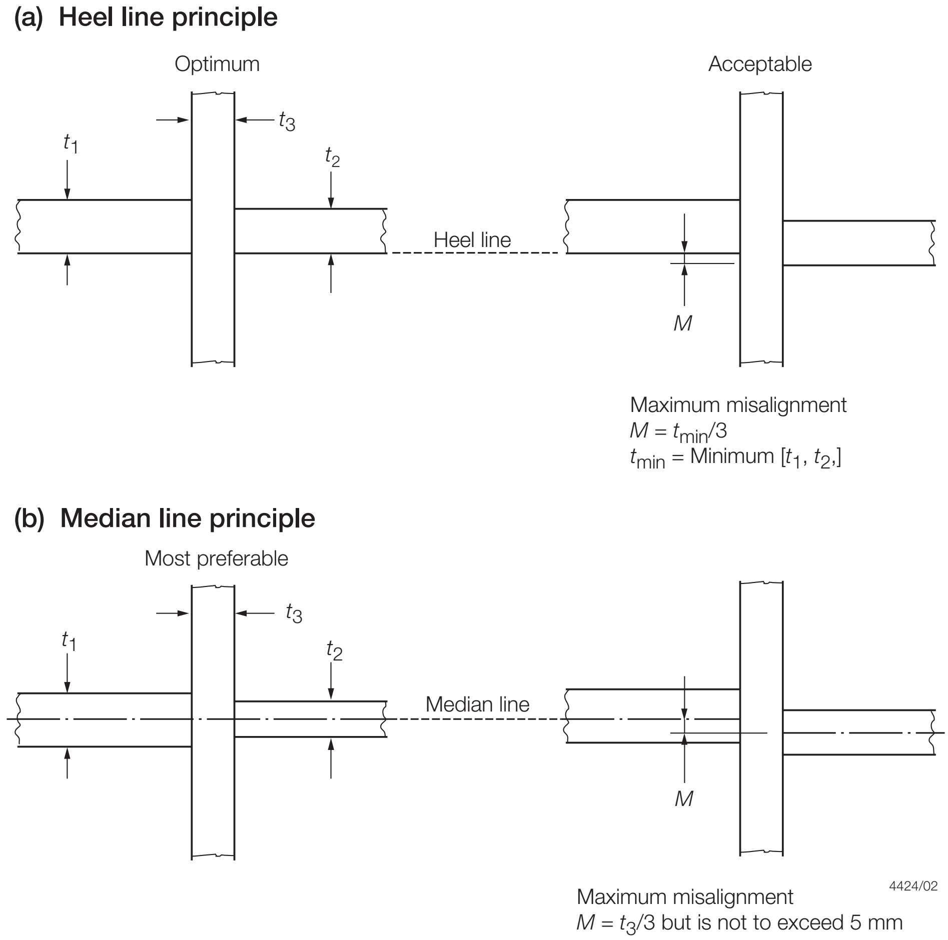


Fig. 3.2.1 Recommended alignment of primary members

2.3.4 In addition to cruciform joint misalignment, the alignment of secondary stiffening and associated brackets is also important. Recommendations are made in Fig. 3.2.1 and Fig. 3.2.2. Where centreline alignment is recommended the tolerance guideline in Fig. 3.2.2 should be followed.

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

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. 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 LR Surveyor and the Builder'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 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft for steel and aluminium alloy craft respectively. Regular examination by the LR Surveyor, in conjunction with the Builder, of non-destructive examination and other Quality records provides a check on the quality of welding operations and any decline in standards should 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. Special attention, as indicated in Pt 7, Ch 2,3.11.5 of the Rules for Special Service Craft, are to be applied for aluminium. For steel structures welding slag should be removed and rusting of weld deposits should be removed by wire brushing.

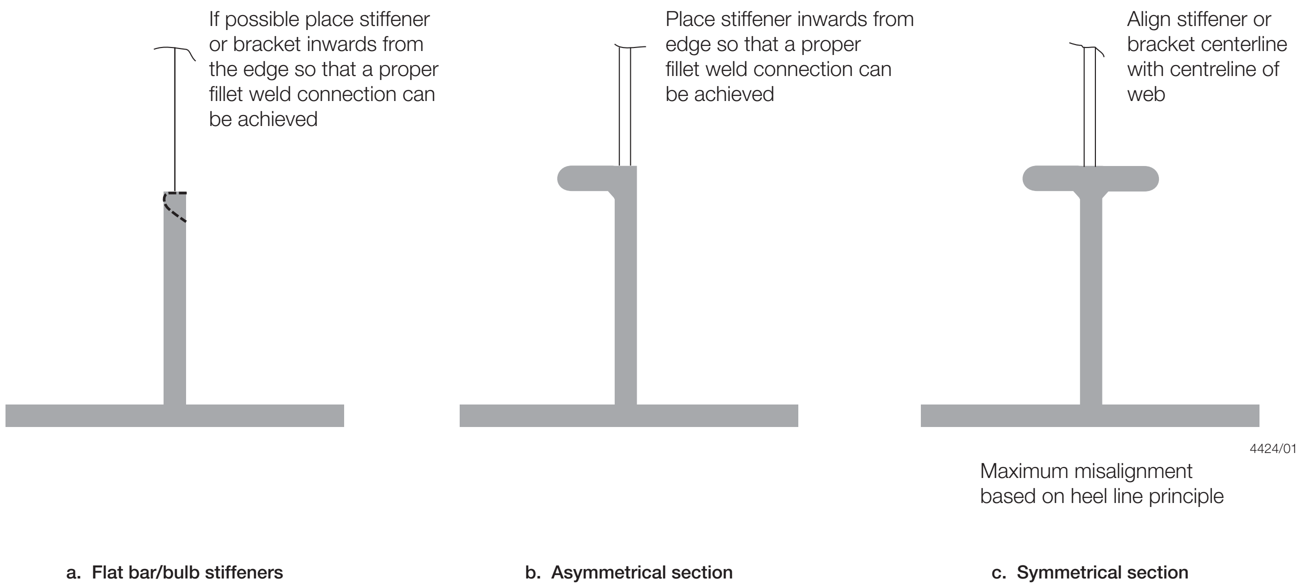


Fig. 3.2.2 Recommended alignment of secondary stiffening members

2.5 Assembly of units

2.5.1 The Builder and the LR 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. Particular attention should be given to length allowance for unwelded stiffening member alignment.

2.5.2 With the assembly of large blocks careful attention should be paid to the areas in way of lifting lugs. 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 examination by means of 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, should be noted and brought to the attention of the LR 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 filler wire used, whether or not pre-heating was used, grades of steel or aluminium alloy involved and any other factors considered to have had a possible influence. Test details of affected plates and proposals for remedial measures should also be made available. Where doubt exists in establishing the source of such incidents, the assistance of LR's staff at Headquarters, should be sought.

■ *Section 3* Defect correction procedures

3.1 Inspection and testing

3.1.1 The fabrication specification should state 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 should be in accordance with written procedures. (*See also* Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft for steel and aluminium craft respectively.)

3.1.3 Quality control levels for weld flaws found by radiographs, ultrasonic testing, magnetic particle and dye penetrant inspection, as appropriate, are to be approved by LR and shall 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 radiographic examination and/or, where applicable, surface examination during construction. This non-destructive examination should be carried out prior to delivery, after the completion of welding and prior to any coating which would adversely effect the type of non-destructive examination being undertaken. 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 LR Surveyor and in accordance with an agreed procedure.

Section

1 **Identification of critical areas**

2 **Structural details**

Section 1
Identification of critical areas

1.1 General

1.1.1 LR has applied direct calculation procedures in the structural appraisal and approval of new buildings and in various investigations on special service craft of both steel and aluminium alloy construction. Through these procedures and the wealth of information collected on the LR 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 craft. These are referred to to as **critical locations** and are highlighted in this Chapter.

1.1.2 This Chapter identifies the **critical areas** within various structural elements of the hull structure and transverse bulkheads.

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.

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 craft 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 'in service' experience of the performance of existing craft 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 both the primary and secondary structures of all craft 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 craft to stresses higher than in surrounding areas.

1.2.2 At the design appraisal stage, a plan of the structure should, where appropriate, be prepared indicating by the Builder or designer 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.

1.3 Misalignment during construction

1.3.1 The very nature of steel/aluminium construction 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.
The 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 craft.

1.4 Fatigue considerations

1.4.1 The bottom shell area of high speed craft is subjected to the highest cyclic loading throughout the life of such craft.

1.4.2 The fatigue fractures in bottom longitudinal end-connections of higher tensile steel and aluminium alloy has been well documented, and constructional details in way of these connections, designed to increase fatigue life, are now incorporated by many Builders 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 Detailed recommendations are given herein for the critical areas, *see* Section 2.

■ *Section 2* Structural details

2.1 Detail design improvement

2.1.1 For the purposes of these Guidance Notes, structural locations have been divided into three separate groups, with a series of examples of critical structural areas together with alternative associated detail design improvements.

2.1.2 A summary of the data presented is given in Table 4.2.1 whilst the full details are given in Figs. 1 to 29 as contained in this Section.

2.1.3 Generally, where alternative structural detail design improvements are provided, the details shown will provide improved fatigue strength.

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

Table 4.2.1

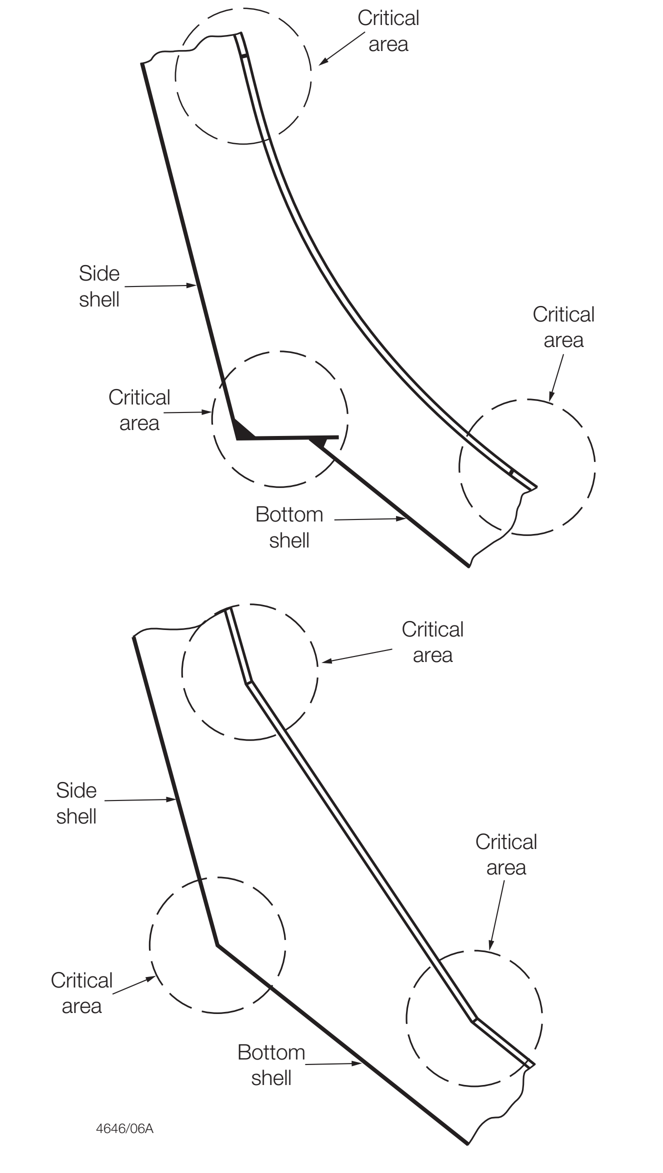
Group	Application	Area	Item	Fig. No
	High speed craft			
1		Hull structure	Chine to frame connection	1
		Hull structure	Chine and chine bar details (1)	2
		Hull structure	Chine and chine bar details (2)	3
		Hull internal structure	Frame to beam connection (radiused)	4
		Hull internal structure	Frame to beam connection (continuous bracket)	5
		Hull internal structure	Lug connections between secondary stiffeners and primary stiffener webs (1)	6
		Hull internal structure	Lug connections between secondary stiffeners and primary stiffener webs (2)	7
		Watertight/oiltight bulkheads	Shell longitudinals collared, brackets aligned	8
		Watertight/oiltight bulkheads	Shell longitudinal (fitted brackets)	9
		Watertight/oiltight bulkheads with boundary bar	Shell longitudinal (fitted brackets)	10
		Watertight/oiltight bulkheads	Collar inserts in way of secondary stiffening members	11
		Watertight/oiltight bulkheads	Collar inserts in way of primary stiffening members	12
		Cross-deck structure, multi-hulls	Inner side web frame to deck transverse connection	13
		Cross-deck structure	Deck transverse to watertight bulkhead connection	14
		Multi-hull structure	Cross-deck beam to bulkhead connection	15
	Low speed craft			
2		Hull internal structure	Floor to frame connection (bracketed)	16
		Hull internal structure	Frame to beam connection	17
		Watertight/oiltight bulkheads with boundary bar	Shell longitudinals (lapped brackets)	18
		Watertight/oiltight bulkheads	Shell longitudinals (lapped brackets)	19
		Watertight/oiltight bulkheads	Shell longitudinals collared, brackets lapped	20
		Cross-deck structure, multi-hulls	Connection between cross-deck beams and side hulls	21
	General detail			
3		Cross-deck structure, multi-hulls	Connection between cross-deck beams and side hulls	22
		Hull centreline structure	Bar and plate keels	23
		Hull centreline structure	Bar keels	24
		Hull centreline structure	Fabricated plate keel/skeg	25
		Hull centreline structure	Round bar and flat bar stems	26
		Hull centreline structure	Fabricated and plate stems	27
		Hull internal structure	Floors to frame connection (radiused)	28
		Hull internal structure	Web frame to tank boundary connection	29

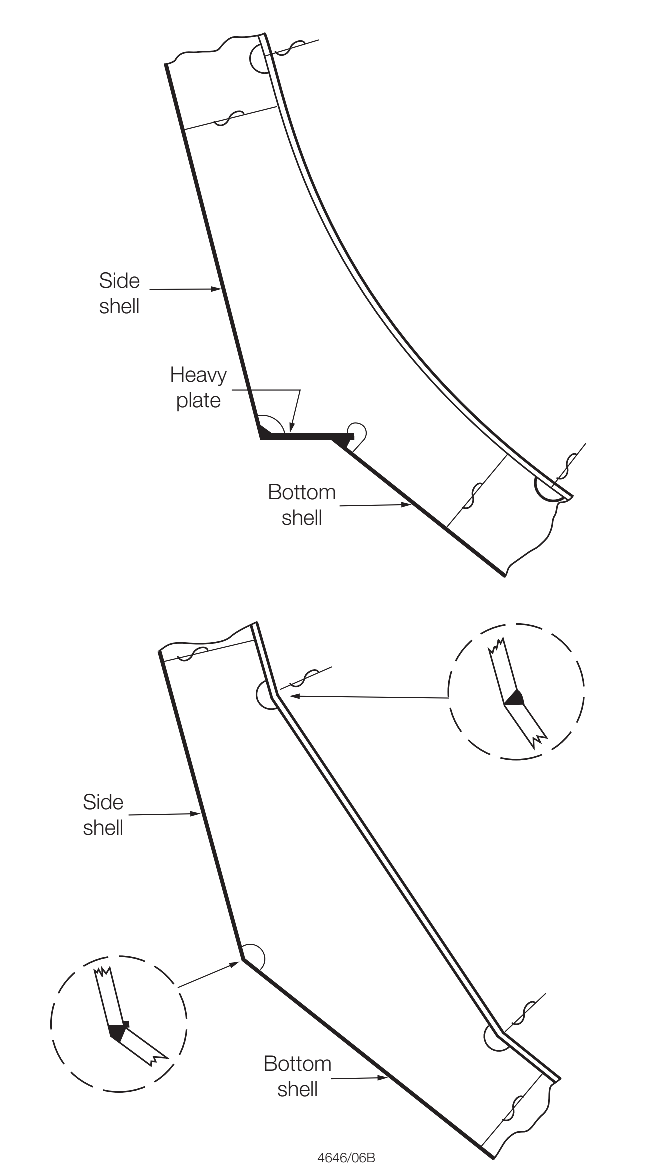
Detail Design Improvement for Steel/Aluminium Construction

AREA:	Hull structure
ITEM:	Chine to frame connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

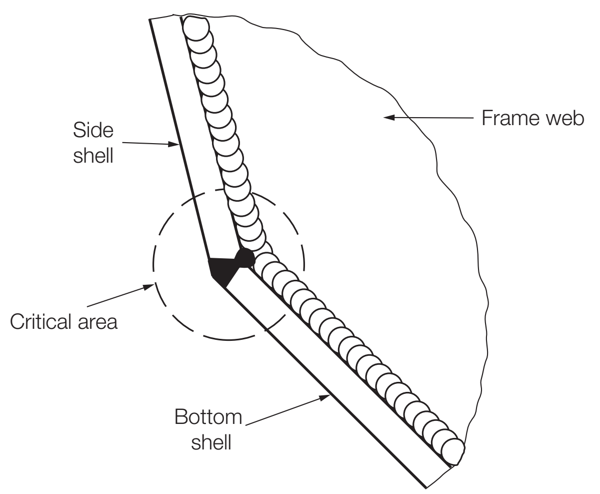
Failure Mechanism	Fatigue fractures from areas of tri-axial stress.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding between chine bars and shell plating is to be full penetration type. Butts in web plating and face flats are to be staggered.

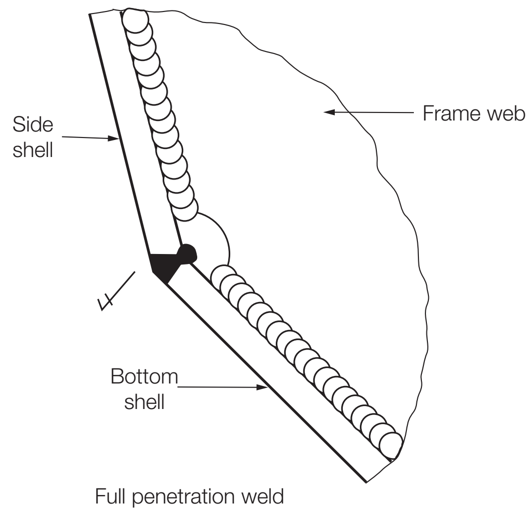
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	1

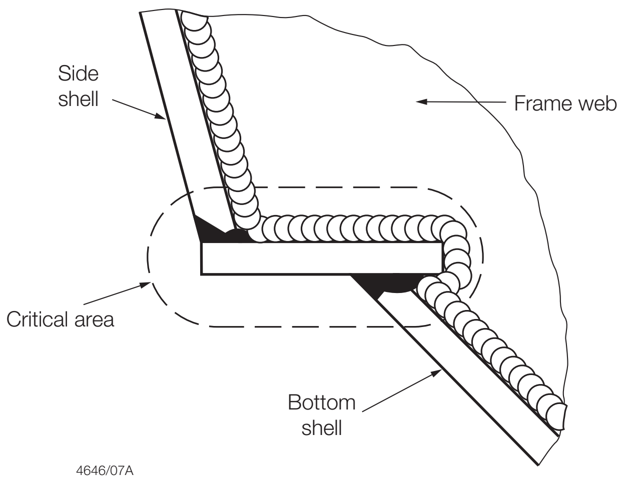
AREA:	Hull structure
ITEM:	Chine and chine bar details (1)

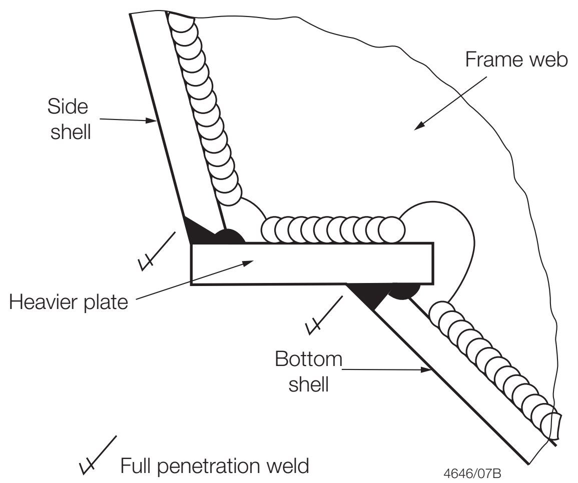
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









NOTES

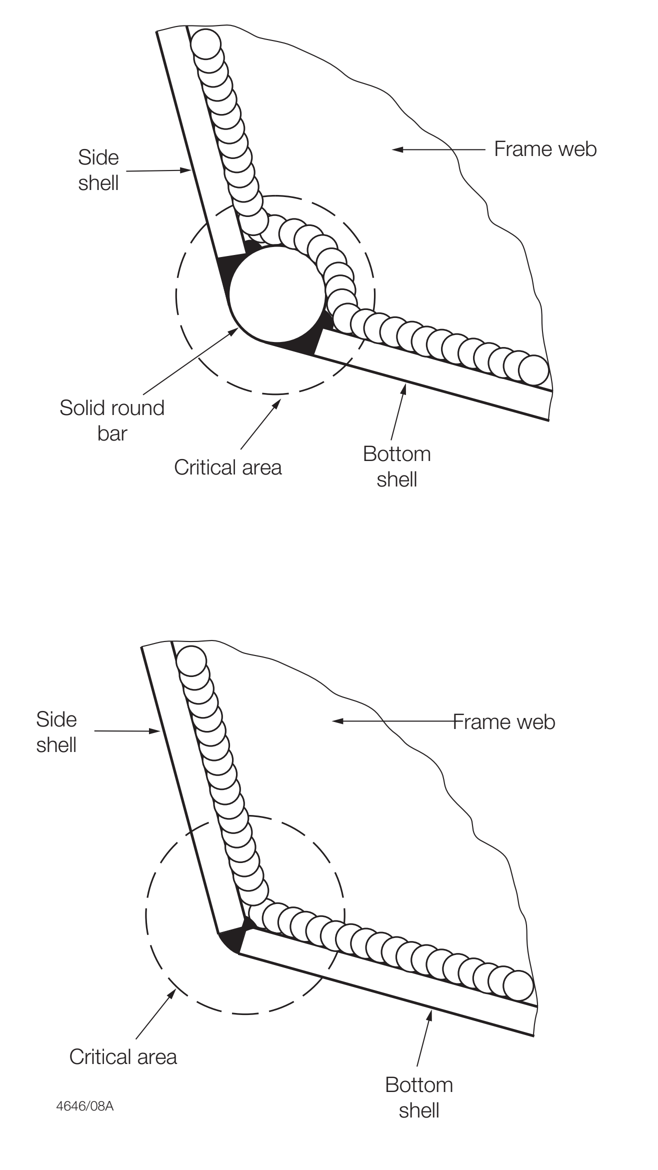
Failure Mechanism	Fatigue fractures from areas of tri-axial stress.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of shell plating and between chine bar and shell plating is to be full penetration type. Welds are to be returned around scallops.

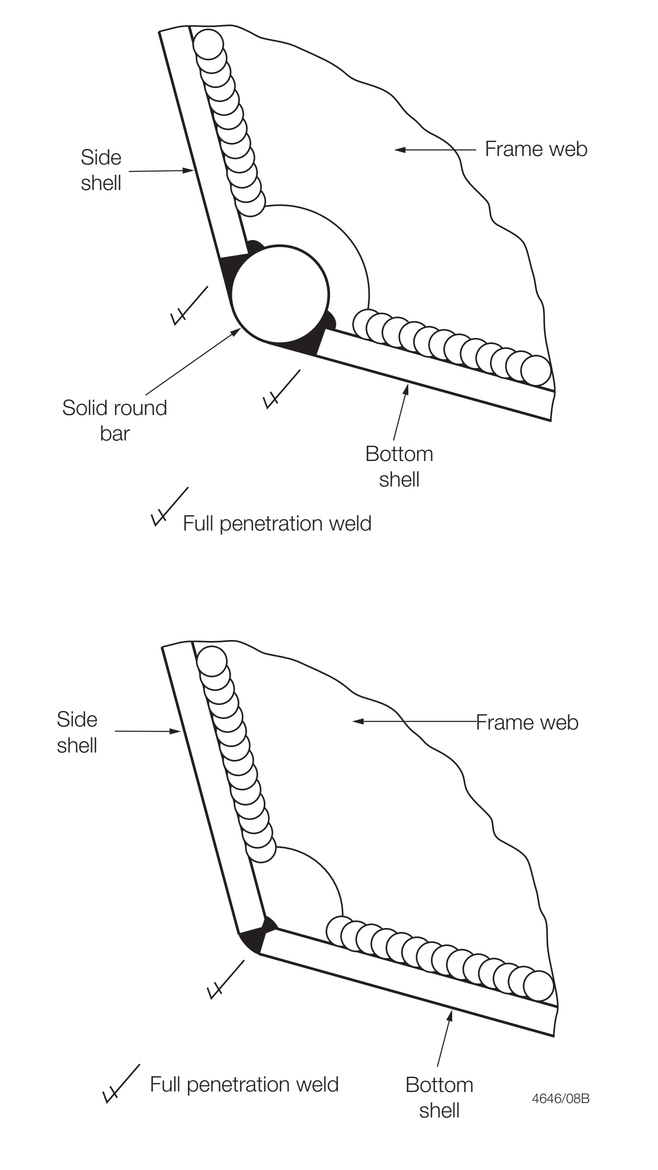
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	2

AREA:	Hull structure
ITEM:	Chine and chine bar details (2)

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT



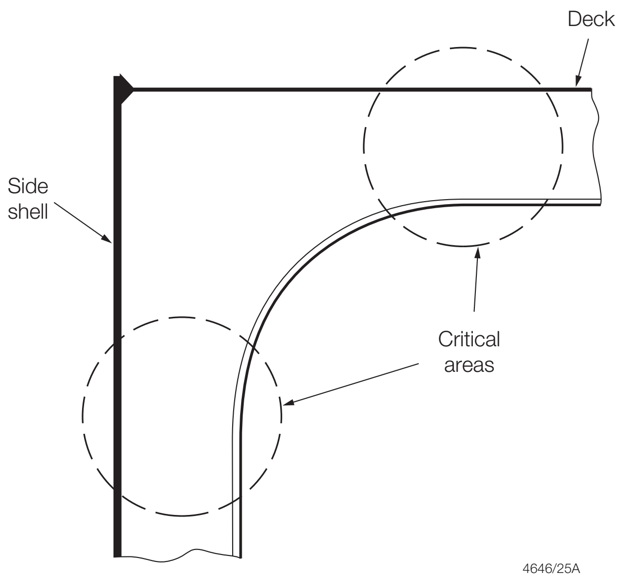
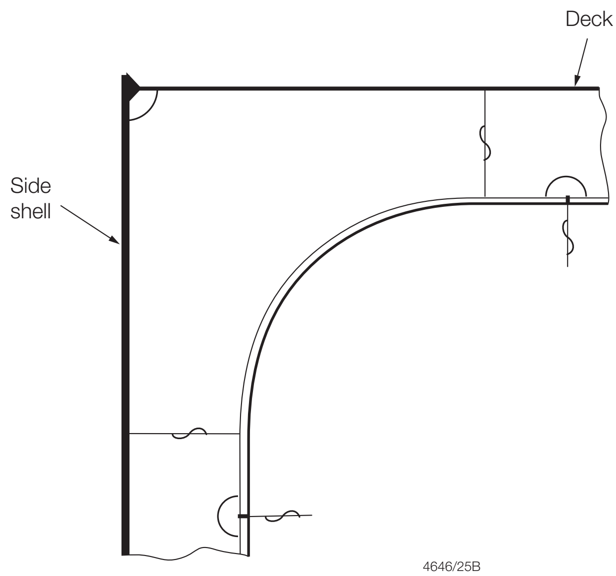


NOTES

Failure Mechanism	Fatigue fractures from areas of tri-axial stress.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of shell plating and between chine bar and shell plating is to be full penetration type. Welds to be returned around scallops.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	3

AREA:	Hull internal structure	
ITEM:	Frame to beam connection (radiused)	

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT
	

NOTES

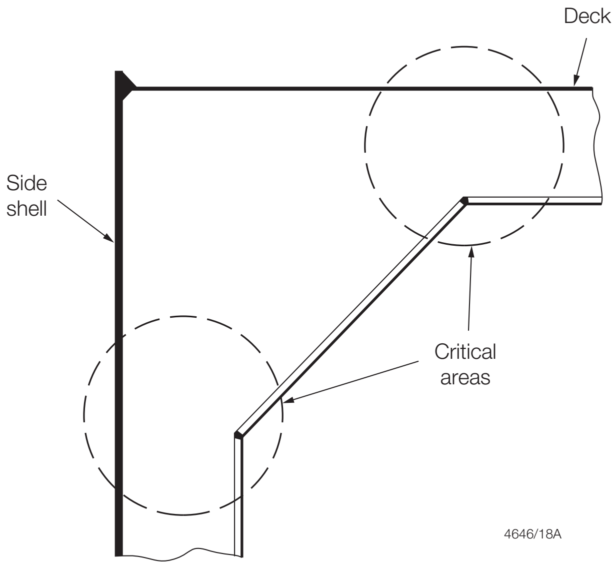
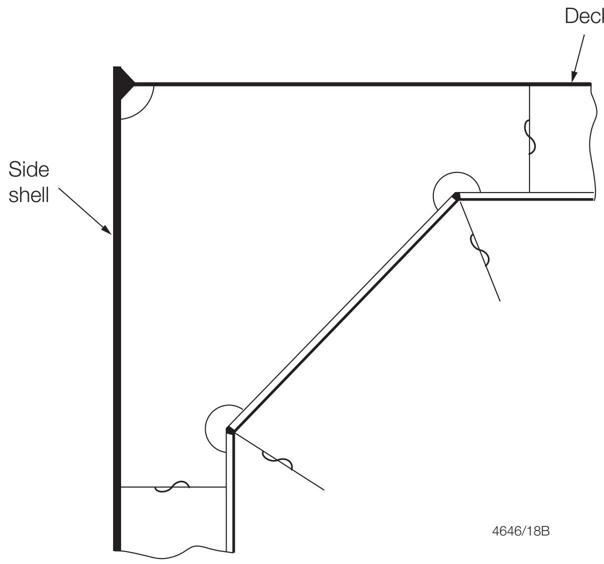
Failure Mechanism	Fatigue fractures in way of welds.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs to be accurately aligned. Butts in webs are to be staggered from the butts in face flats. All welds to be returned around scallops.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	4

Detail Design Improvement for Steel/Aluminium Construction

AREA: Hull internal structure

ITEM: Frame to beam connection (continuous bracket)

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT
	

NOTES

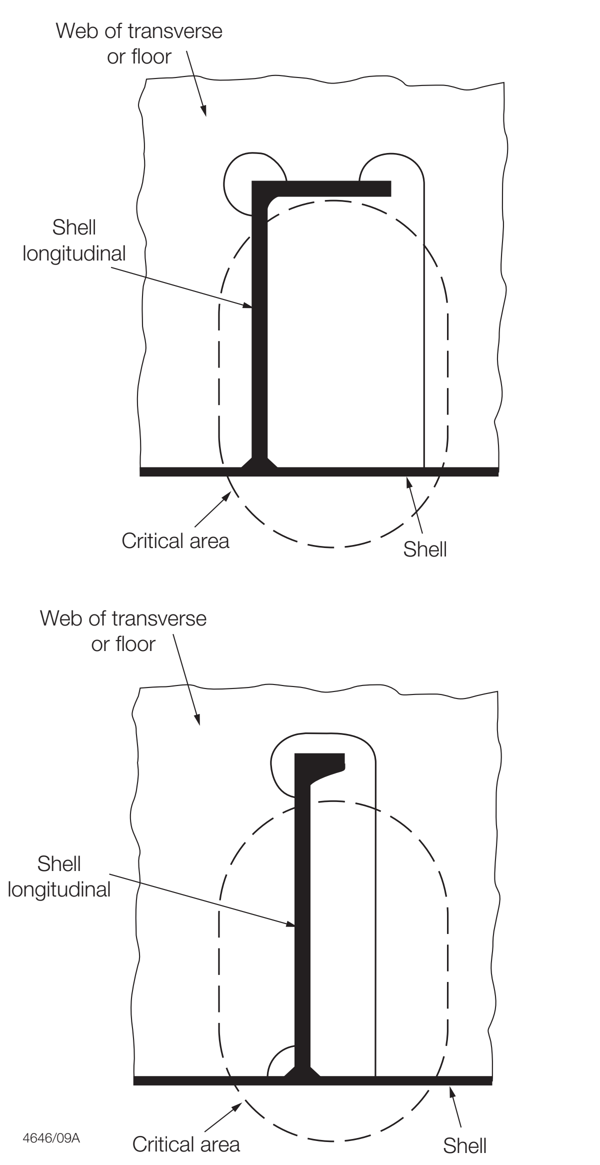
Failure Mechanism	Fatigue fractures in way of welds.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs to be carefully aligned. Butts in webs are to be staggered from the butts in face flats. All welds to be returned around scallops.

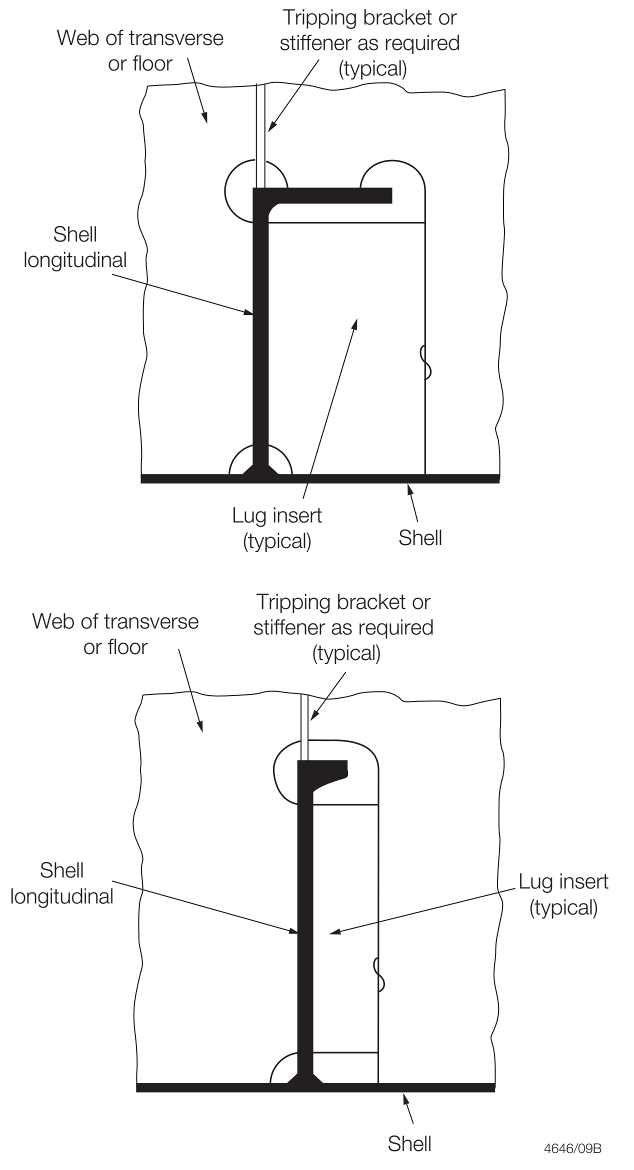
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	5

Detail Design Improvement for Steel/Aluminium Construction

AREA:	Hull internal structure
ITEM:	Lug connections between secondary stiffeners and primary stiffener webs (1)

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

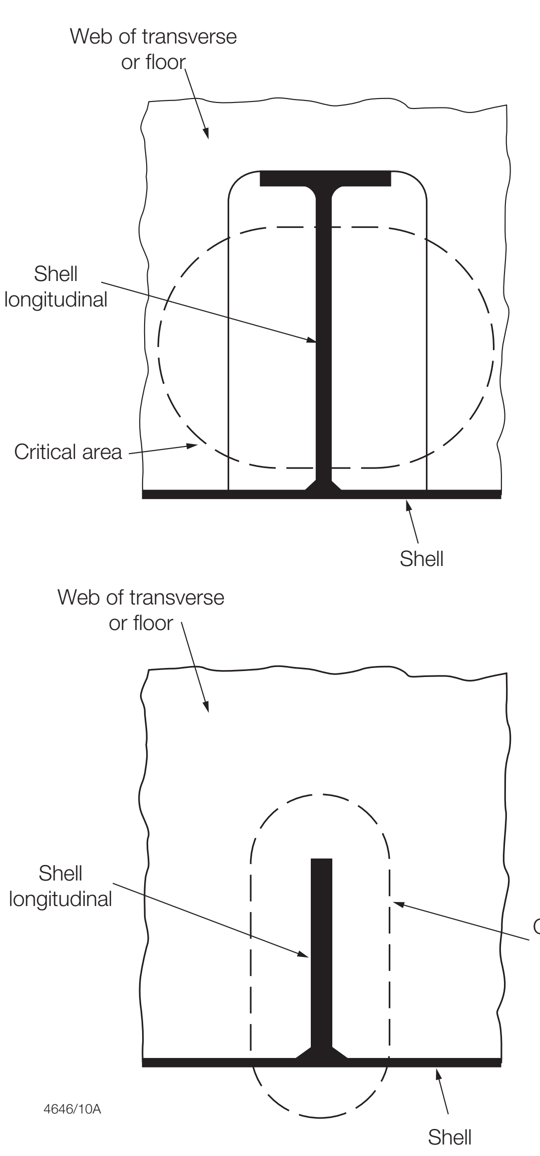
Failure Mechanism	Fatigue cracking of shell plate in way of hardspot, buckling and shear failure of the web of the primary member.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of lugs is to be double continuous. Welds to be returned around scallops. Lug inserts to align with primary stiffener web plating or floor.

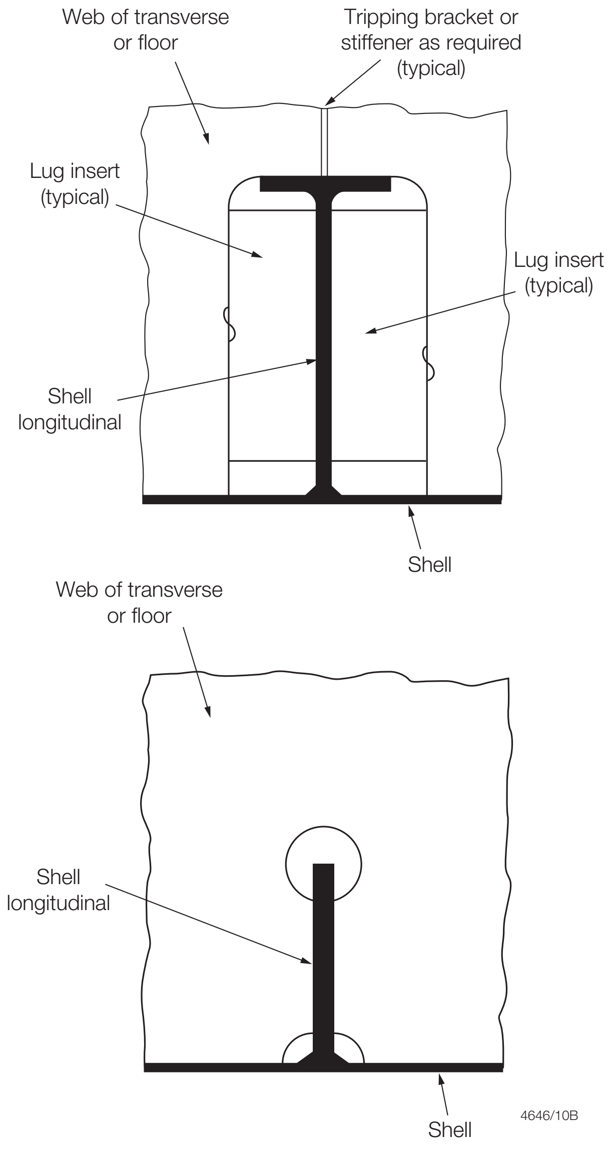
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	6

AREA:	Hull internal structure
ITEM:	Lug connections between secondary stiffeners and primary stiffener webs (2)

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





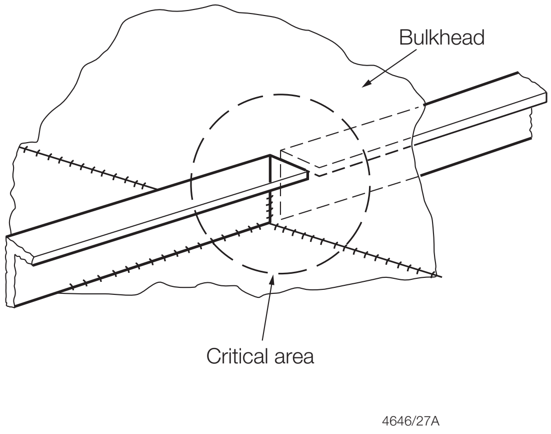
NOTES

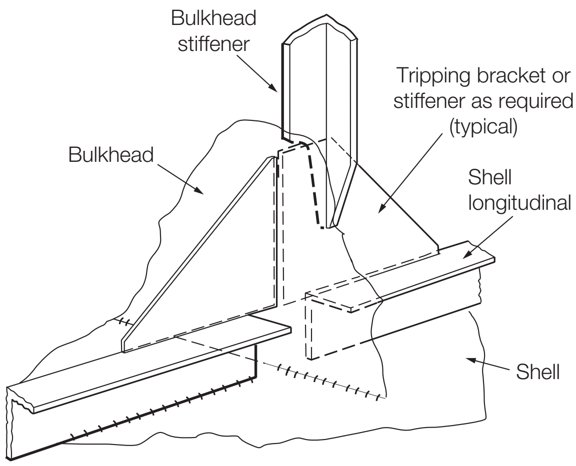
Failure Mechanism	Fatigue cracking of shell plate in way of hardspot, buckling and shear failure of the web of the primary member.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of lugs is to be double continuous. Welds to be returned around scallops. Lug inserts to align with primary stiffener web plating or floor.

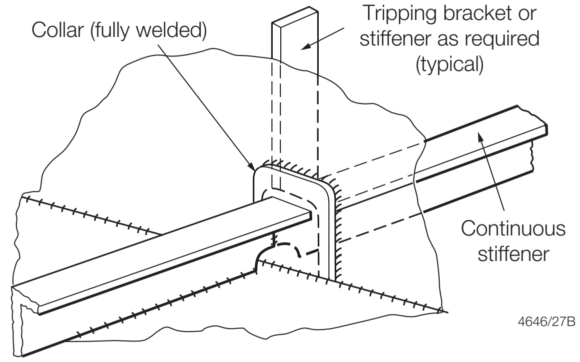
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	7

AREA:	Watertight/oiltight bulkheads
ITEM:	Shell longitudinals collared, brackets aligned

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT







NOTES

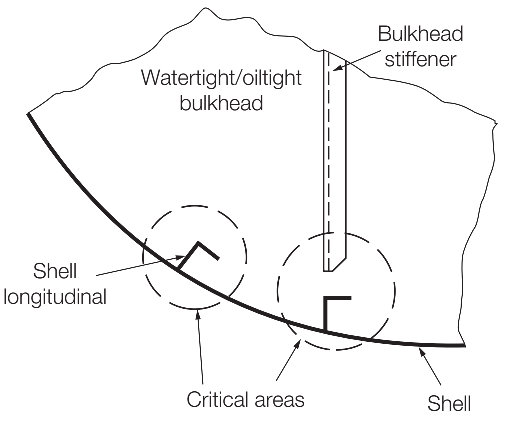
Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of collar and stiffener end connections is to be double continuous type. Welds to be returned around scallops.

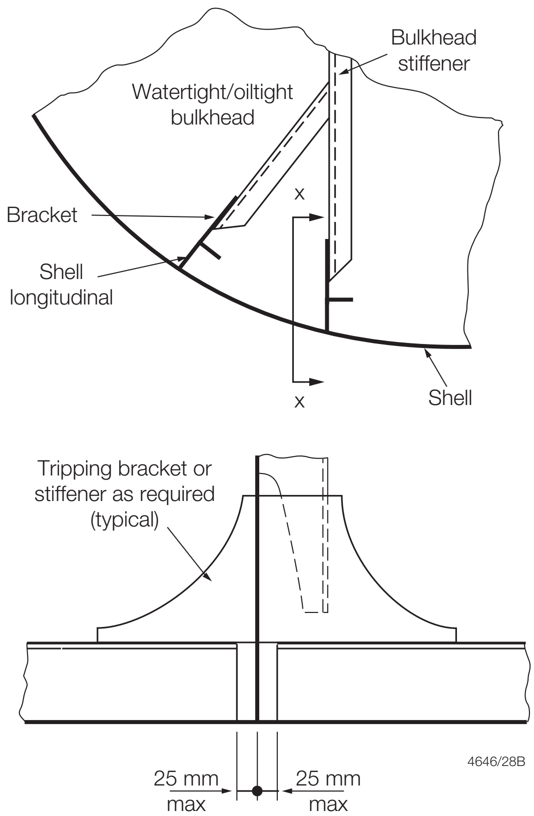
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	8

Detail Design Improvement for Steel/Aluminium Construction

AREA:	Watertight/oiltight bulkheads
ITEM:	Shell longitudinals (fitted brackets)

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





Section X – X
Stiffeners stopped

NOTES

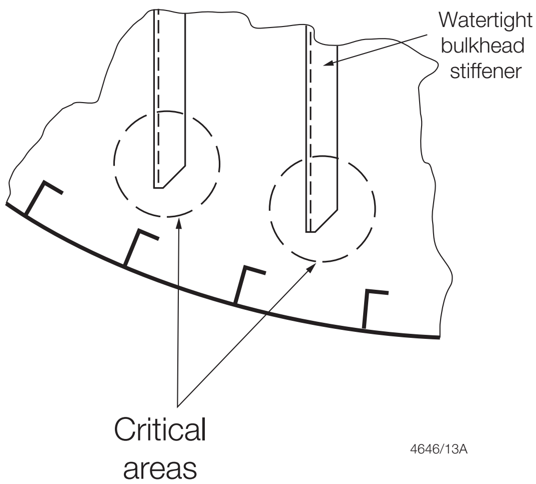
Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of brackets are to be accurately aligned through the bulkhead plating and with the webs of the longitudinal stiffeners. All welding in way of brackets and stiffener end connections is to be double continuous type.

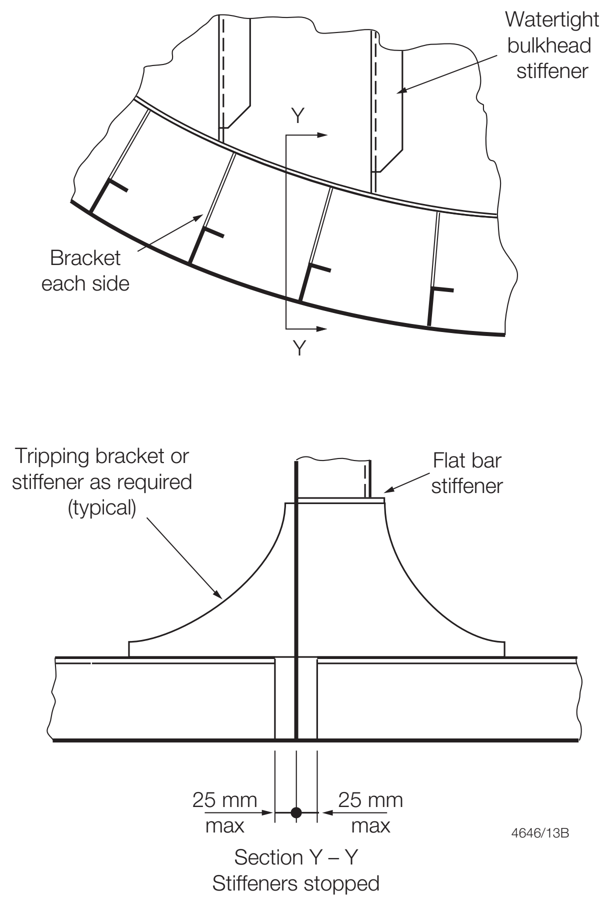
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	9

Detail Design Improvement for Steel/Aluminium Construction

AREA:	Watertight/oiltight bulkheads with boundary bar
ITEM:	Shell longitudinals (fitted brackets)

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of brackets are to be accurately aligned through the bulkhead plating and with the webs of the longitudinal stiffeners. All welding in way of brackets and stiffener end connections is to be double continuous type.

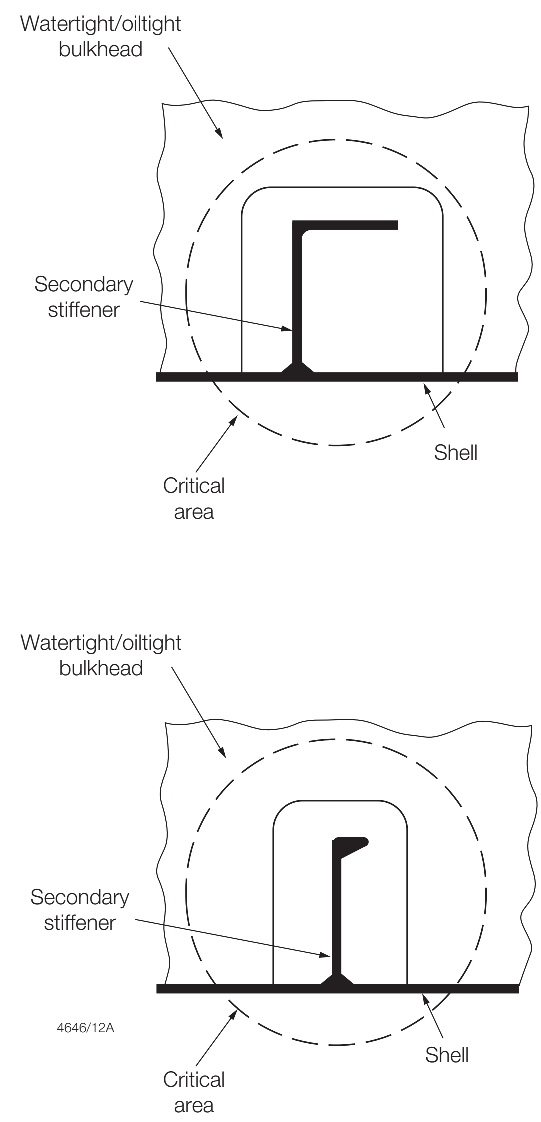
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	10

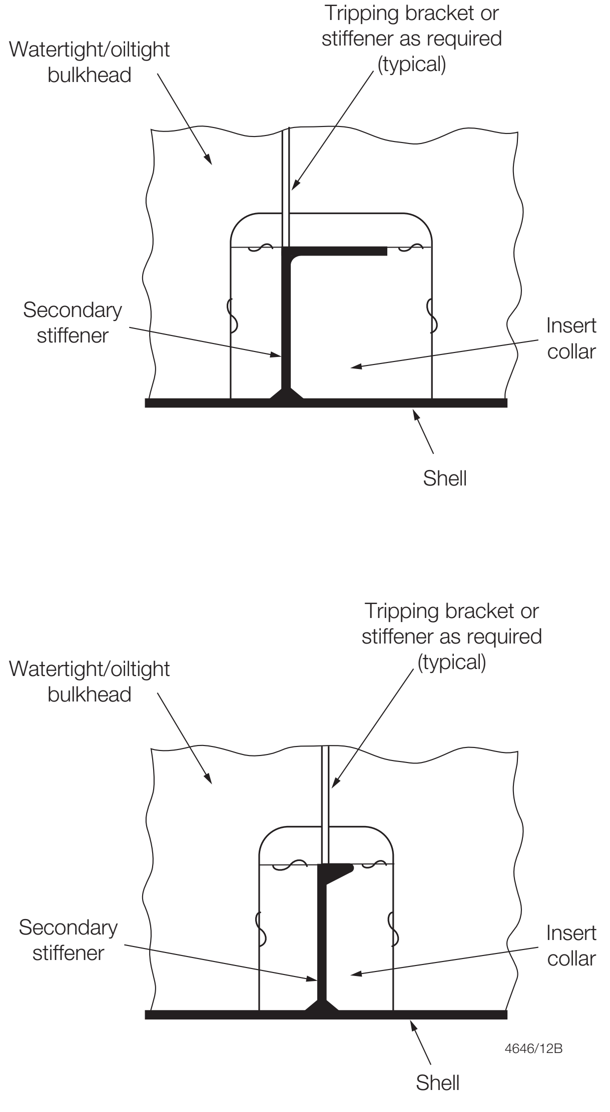
AREA: Watertight/oiltight bulkheads

ITEM: Collar inserts in way of secondary stiffening members

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





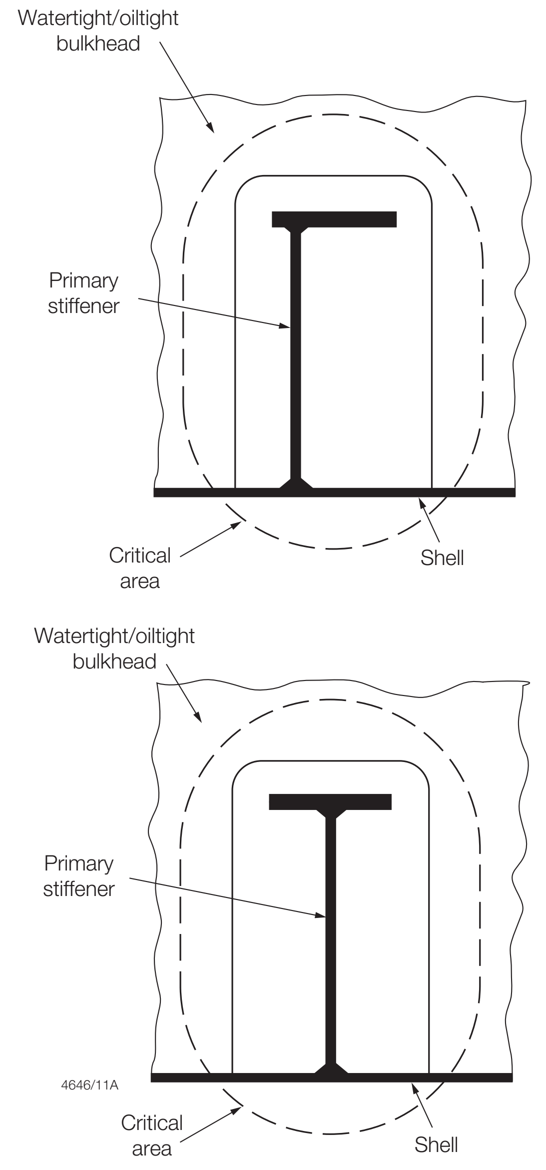
NOTES

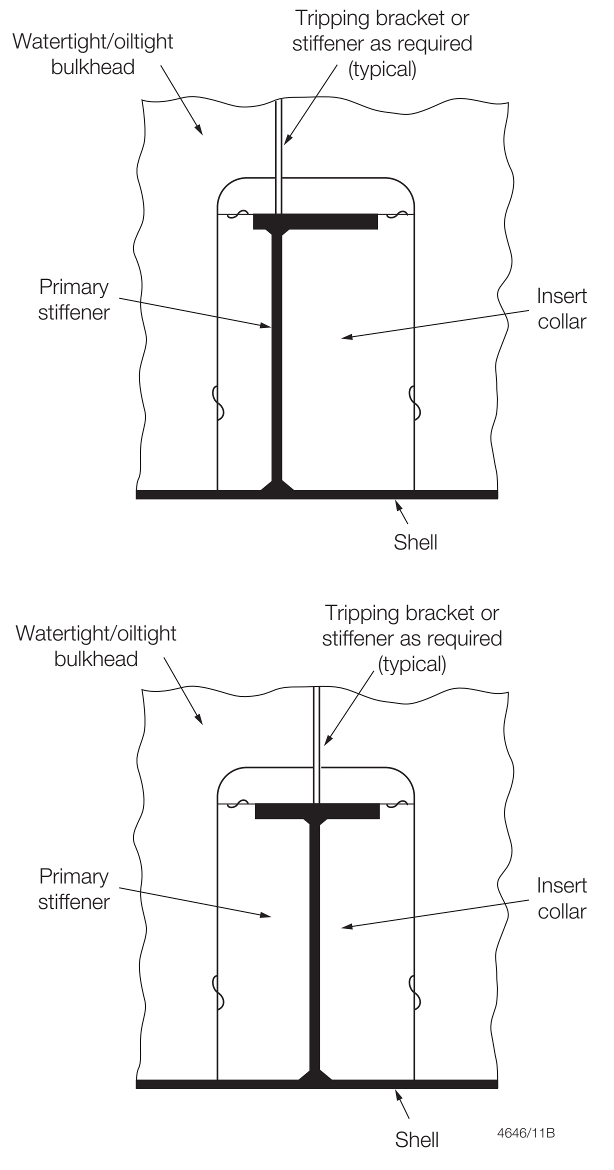
Failure Mechanism	Fatigue fractures and leakage.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Inserts to align with watertight/oiltight bulkhead plating. All welding in way of collar inserts and stiffener end connections is to be double continuous type.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	11

AREA:	Watertight/oiltight bulkheads
ITEM:	Collar inserts in way of primary stiffening members

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Fatigue fractures and leakage.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Inserts to align with watertight/oiltight bulkhead plating. All welding in way of collar inserts and stiffener end connections is to be double continuous type.

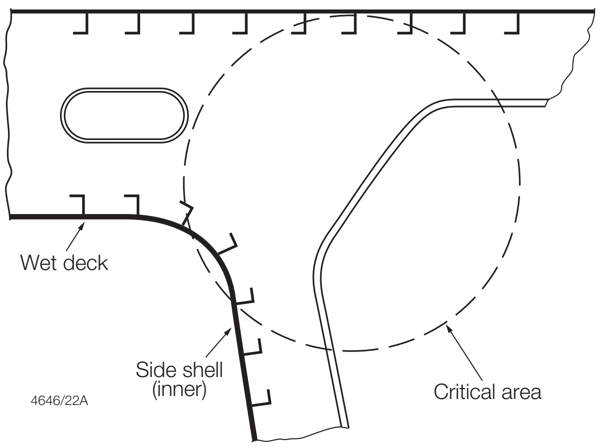
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	12

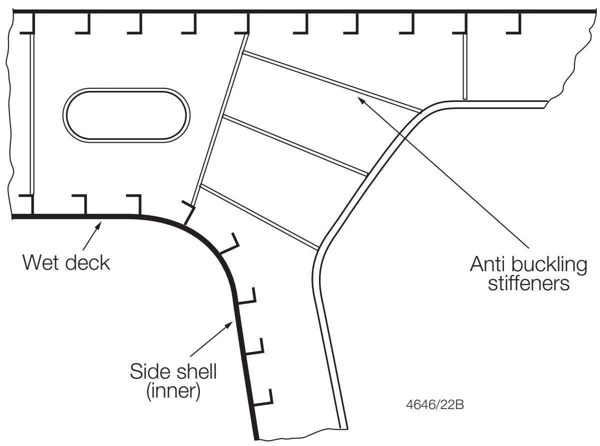
Detail Design Improvement for Steel/Aluminium Construction

AREA:	Cross-deck structure, multi-hulls
ITEM:	Inner side web frame to deck transverse connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Buckling of deep webs.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively.

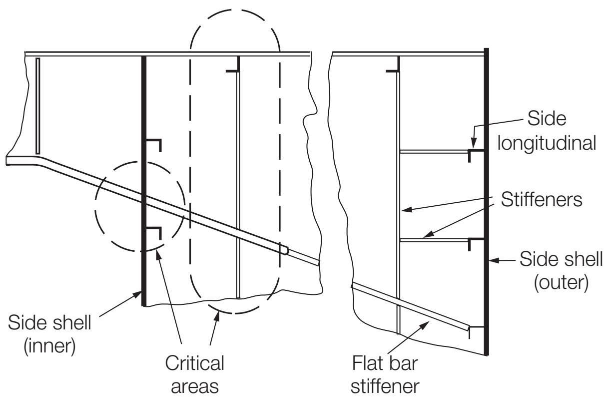
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	13

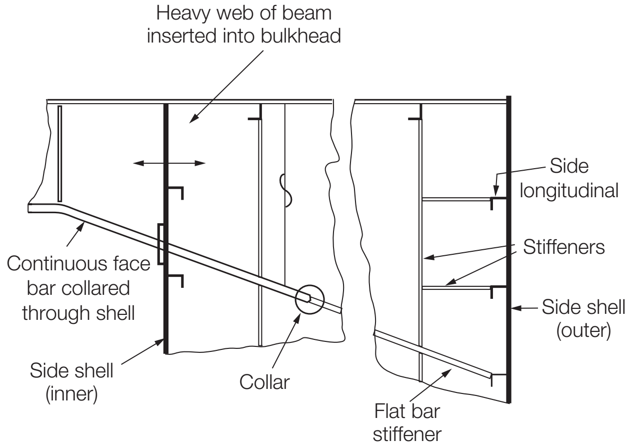
AREA: Cross-deck structure

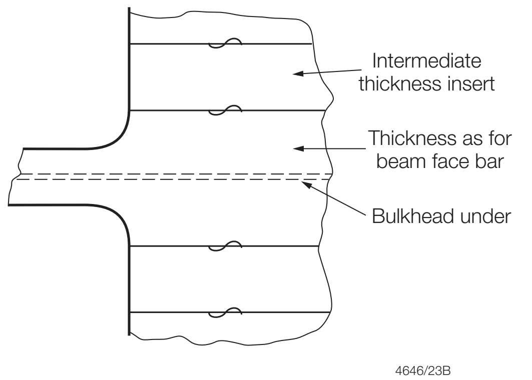
ITEM: Deck transverse to watertight bulkhead connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT







Plan view

NOTES

Failure Mechanism	Failure fractures in areas of high stress, cracking due to both stress concentrations and tri-axial stress.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welds in way of shell penetration are to be full penetration type.

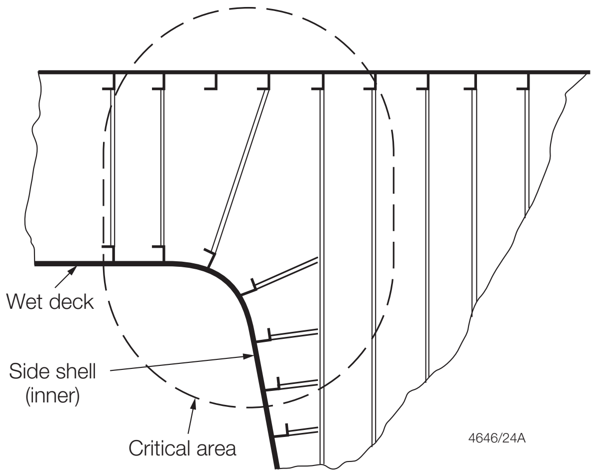
GROUP 1	GUIDANCE NOTES FOR DESIGN DETAILS STEEL/ALUMINIUM CONSTRUCTION	FIGURE 14

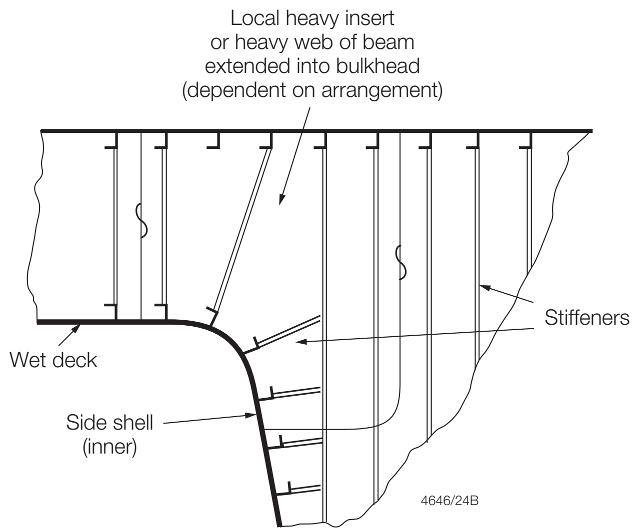
Detail Design Improvement for Steel/Aluminium Construction

AREA:	Multi-hull structure
ITEM:	Cross-deck beam to bulkhead connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Buckling of deep webs and bulkhead in way of connection.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of deep transverses are to be accurately aligned with the bulkhead plating. All welding in way of end connection is to be double continuous type.

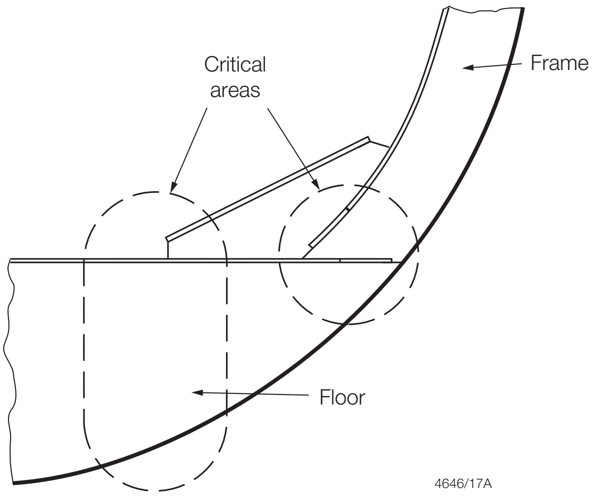
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	STEEL/ALUMINIUM CONSTRUCTION	15

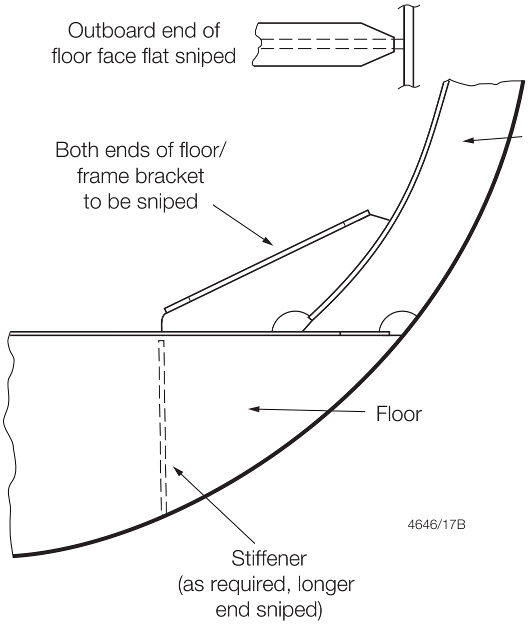
AREA: Hull internal structure

ITEM: Floor to frame connection (bracketed)

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Buckling of floor under bracket toe. Fracturing of frame and floor structure in way of end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of brackets and end connections is to be double continuous type. All welds to be returned around scallops. Webs of frames to be accurately aligned with floor plating.

GROUP 2	GUIDANCE NOTES FOR DESIGN DETAILS STEEL/ALUMINIUM CONSTRUCTION	FIGURE 16

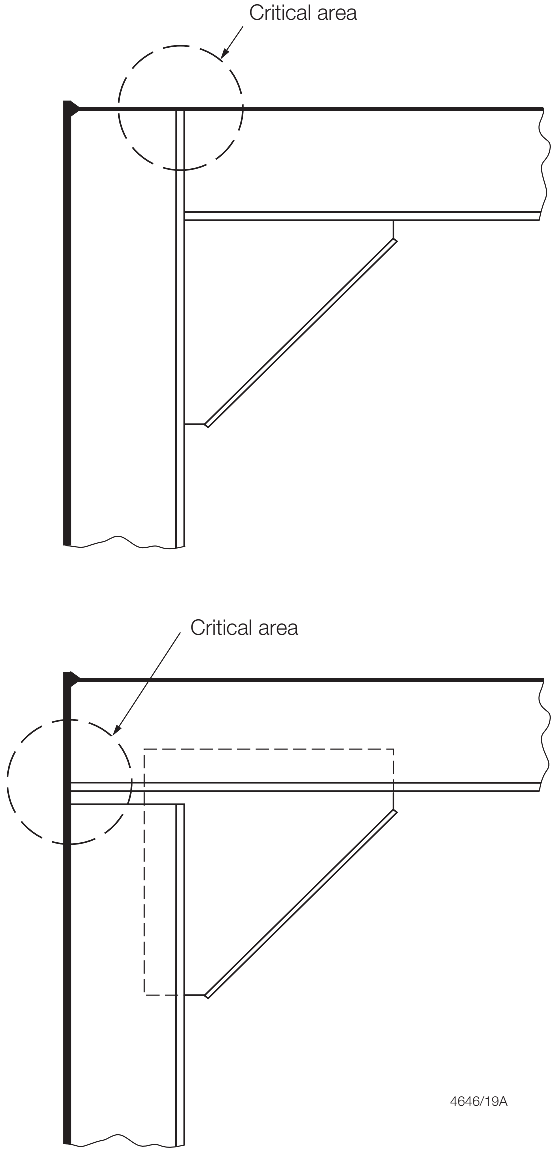
Detail Design Improvement for Steel/Aluminium Construction

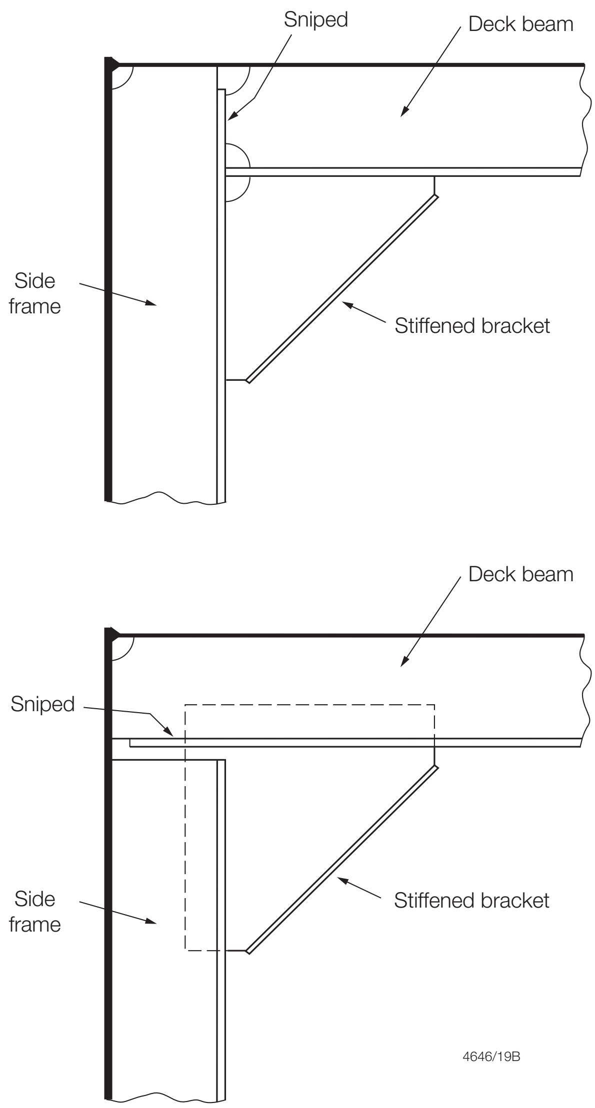
AREA:	Hull internal structure
ITEM:	Frame to beam connection

Lloyd's Register

CRITICAL AREAS

DETAIL DESIGN IMPROVEMENT





NOTES

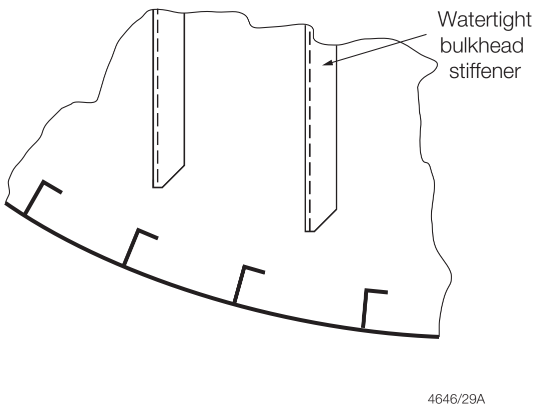
Failure Mechanism	Fractures in the shell and deck plating due to stress concentration arising from hard spots.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of deck beam to be accurately aligned with webs of frames. All welding in way of end connections and brackets is to be double continuous type. All welds to be returned around scallops.

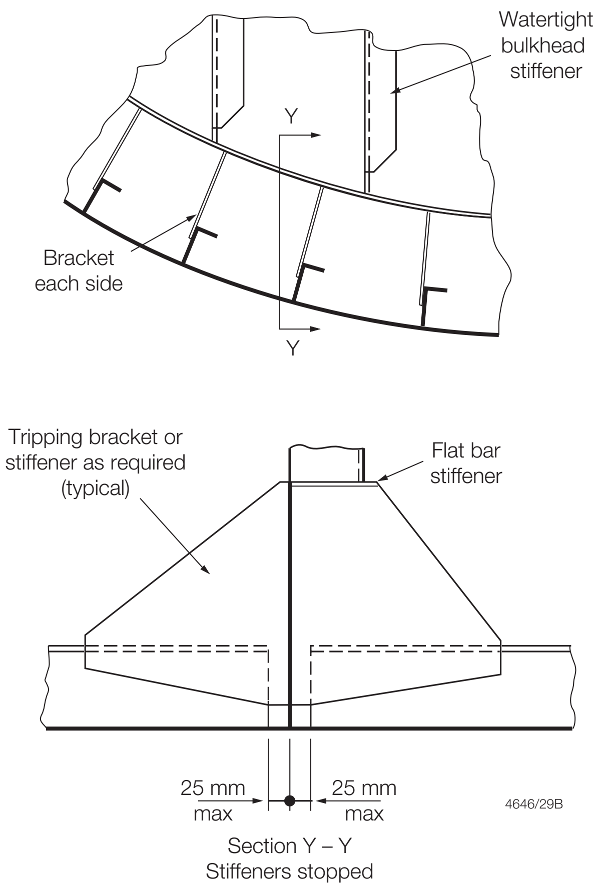
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	STEEL/ALUMINIUM CONSTRUCTION	17

AREA:	Watertight/oiltight bulkheads with boundary bar
ITEM:	Shell longitudinals (lapped brackets)

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of brackets are to be accurately aligned through the bulkhead platings. All welding in way of brackets and stiffener end connections is to be double continuous type.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	STEEL/ALUMINIUM CONSTRUCTION	18

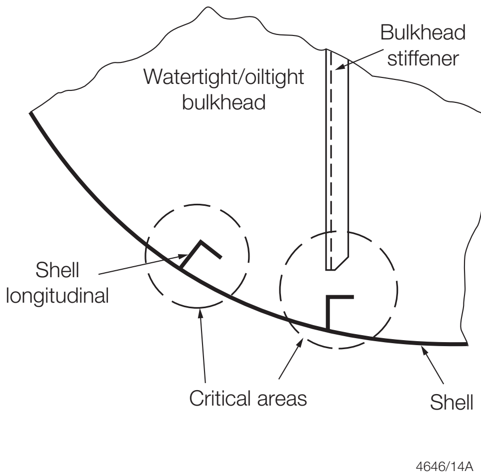
Detail Design Improvement for Steel/Aluminium Construction

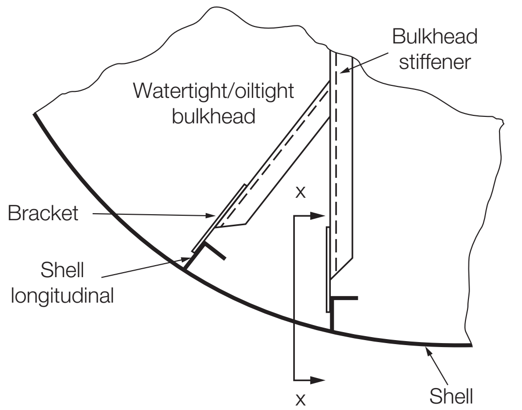
AREA: Watertight/oiltight bulkheads

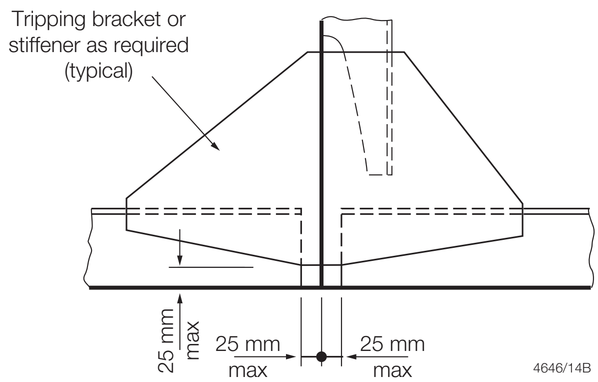
ITEM: Shell longitudinals (lapped brackets)

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT







Section X – X

NOTES

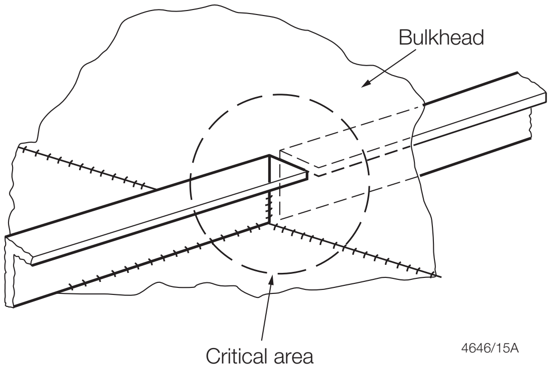
Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of brackets are to be accurately aligned through the bulkhead platings. All welding in way of brackets and end connections of stiffeners is to be double continuous type.

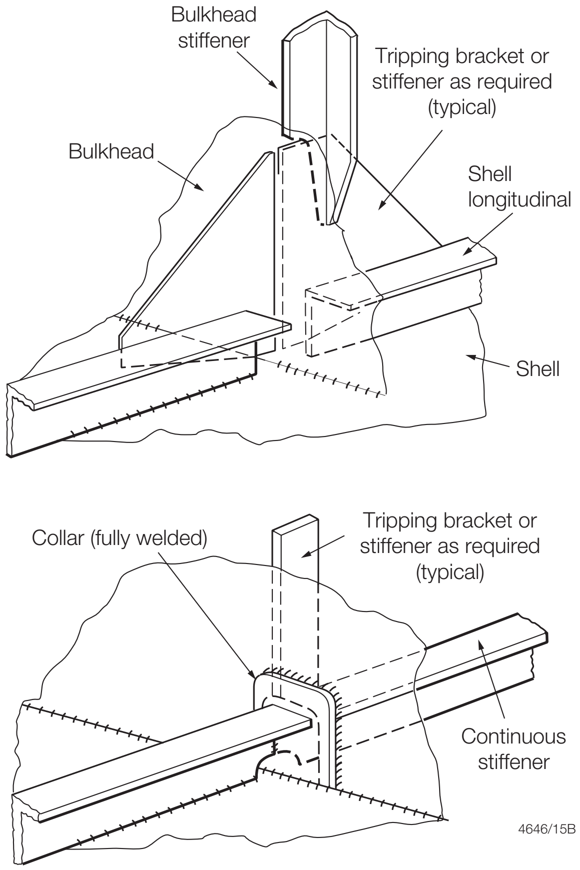
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	STEEL/ALUMINIUM CONSTRUCTION	19

AREA:	Watertight/oiltight bulkheads
ITEM:	Shell longitudinals collared, brackets lapped

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Fractures in bulkhead plating arising from stress concentrations in way of longitudinal stiffener end connections.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding in way of collar and stiffener end connections is to be double continuous type. Welds are to be returned around scallops.

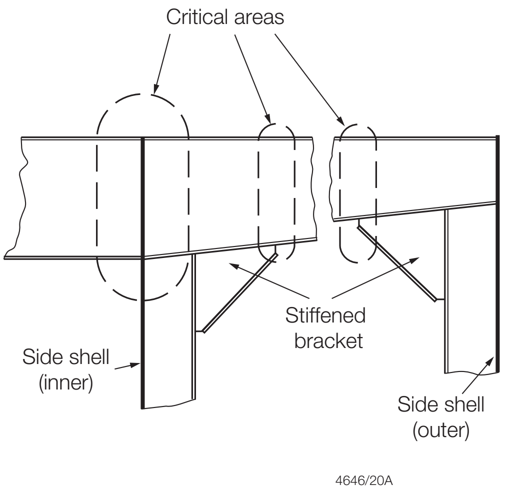
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	STEEL/ALUMINIUM CONSTRUCTION	20

Detail Design Improvement for Steel/Aluminium Construction

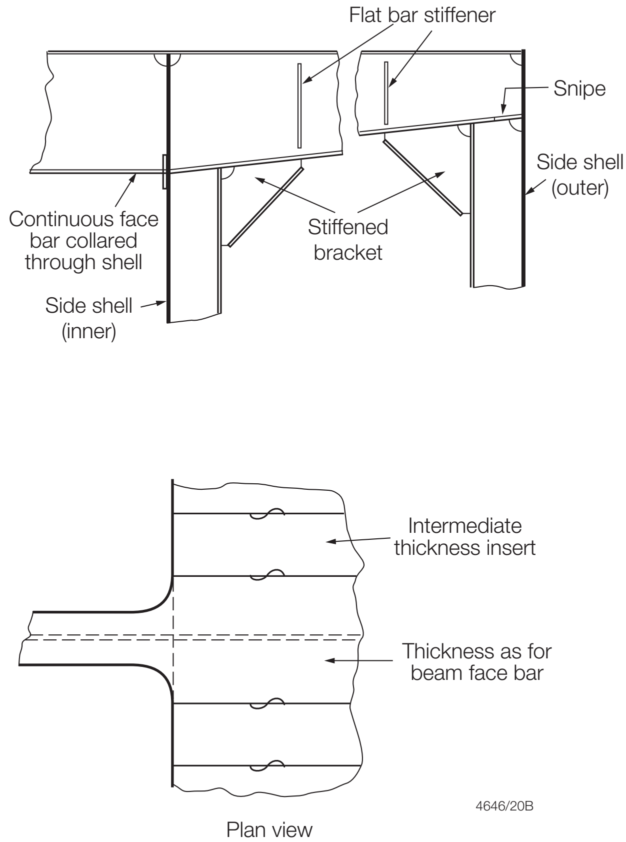
AREA:	Cross-deck structure, multi-hulls
ITEM:	Connection between cross-deck beams and side hulls

Lloyd's Register

CRITICAL AREAS



DETAIL DESIGN IMPROVEMENT



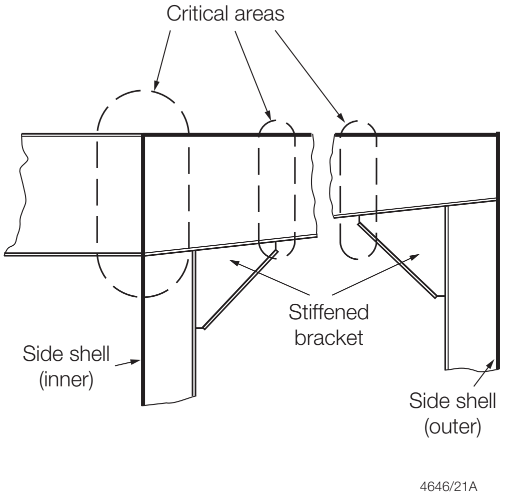
NOTES

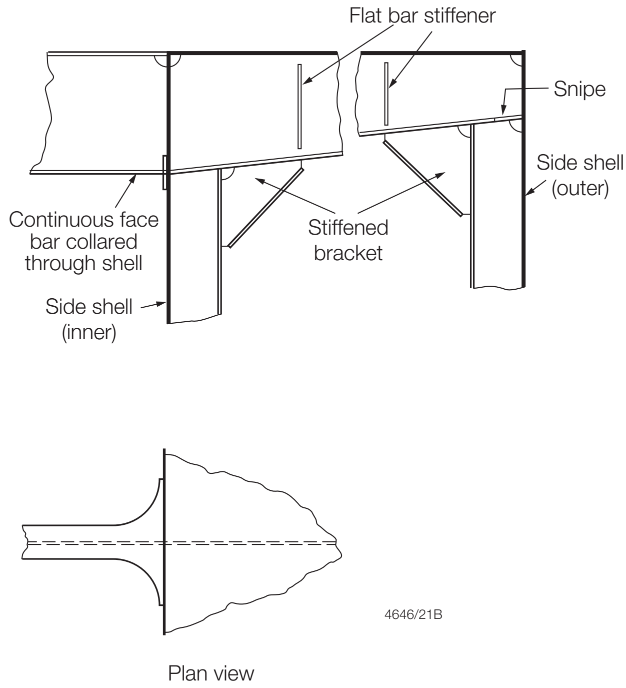
Failure Mechanism	Buckling of webs of cross-deck beams, and fracturing of deck plating in way of end connection due to hard spot.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of frames to be accurately aligned with webs of cross-deck beams. All welds in way of end connection of frames are to be double continuous type. Webs of transverse beams are to be accurately aligned.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	STEEL/ALUMINIUM CONSTRUCTION	21

AREA:	Cross-deck structure, multi-hulls
ITEM:	Connection between cross-deck beams and side hulls

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

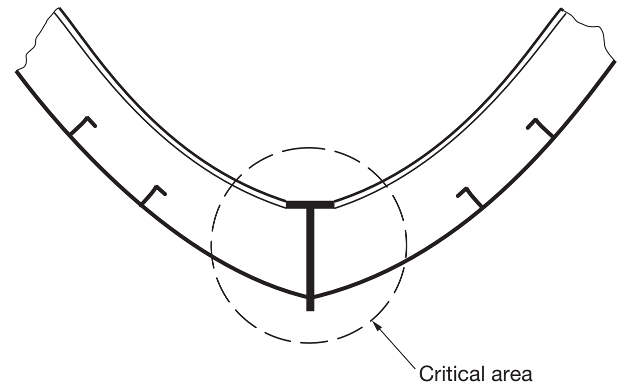
Failure Mechanism	Buckling of webs of cross-deck beams, and fracturing of deck plating in way of end connection due to hard spot.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of frames to be accurately aligned with webs of cross-deck beams. All welds in way of end connections to be double continuous type. Webs of transverse beams are to be accurately aligned.

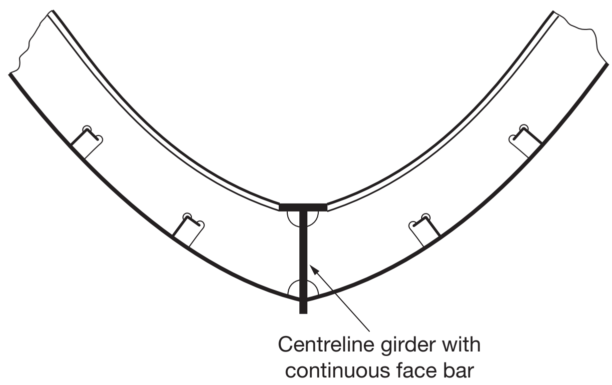
GROUP 3	GUIDANCE NOTES FOR DESIGN DETAILS STEEL/ALUMINIUM CONSTRUCTION	FIGURE 22

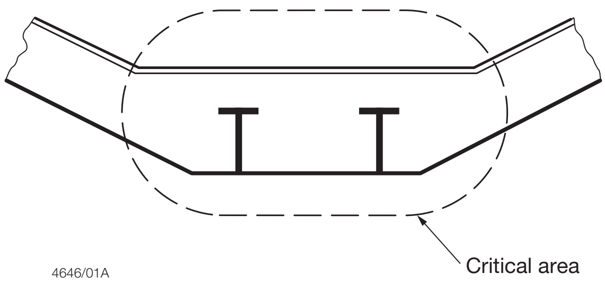
AREA:	Hull centreline structure
ITEM:	Bar and plate keels

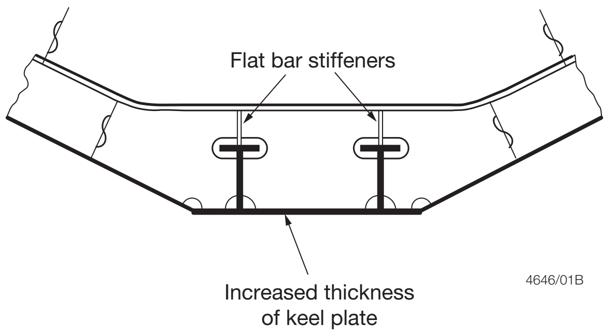
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









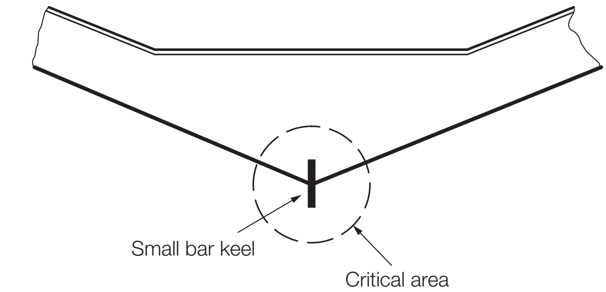
NOTES

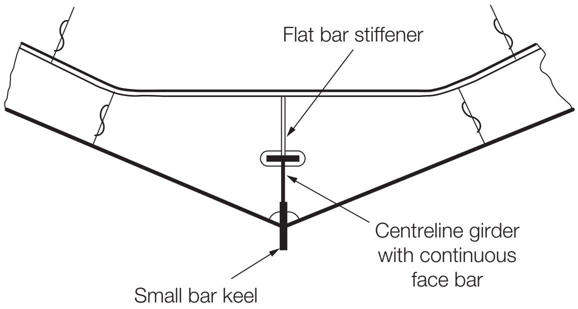
Failure Mechanism	Fracturing of centre girder(s), buckling of keel plate and floors.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Butts in webs are to be staggered from butts in face flats.

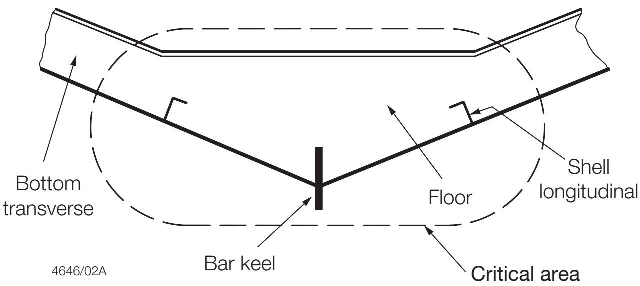
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	STEEL/ALUMINIUM CONSTRUCTION	23

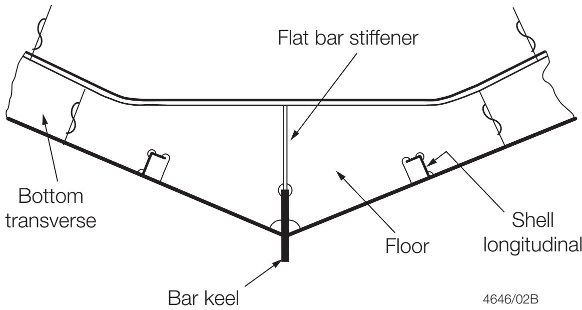
AREA:	Hull centreline structure
ITEM:	Bar keels

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









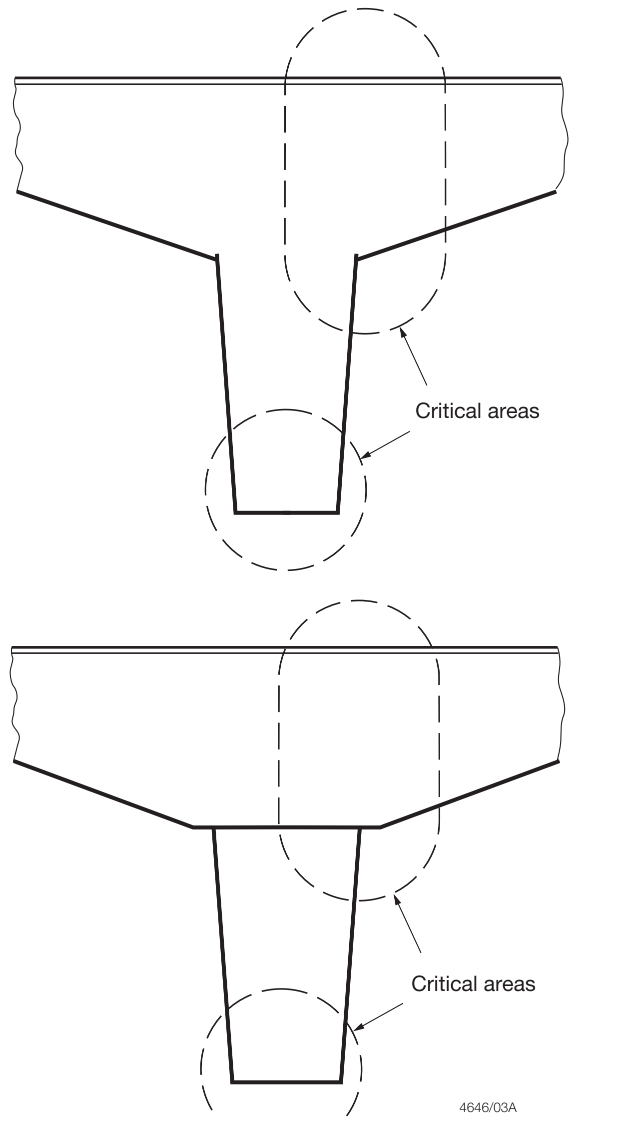
NOTES

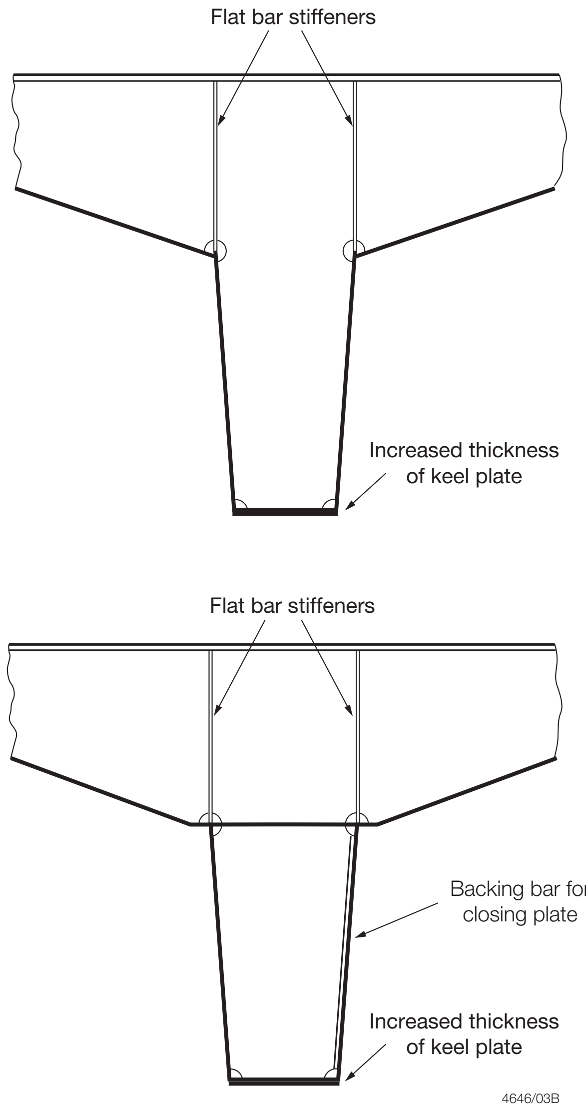
Failure Mechanism	Buckling of bar keel, shell plate and floors.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Butts in webs are to be staggered from butts in face flats.

GROUP 3	GUIDANCE NOTES FOR DESIGN DETAILS STEEL/ALUMINIUM CONSTRUCTION	FIGURE 24

AREA:	Hull centreline structure
ITEM:	Fabricated plate keel/skeg

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

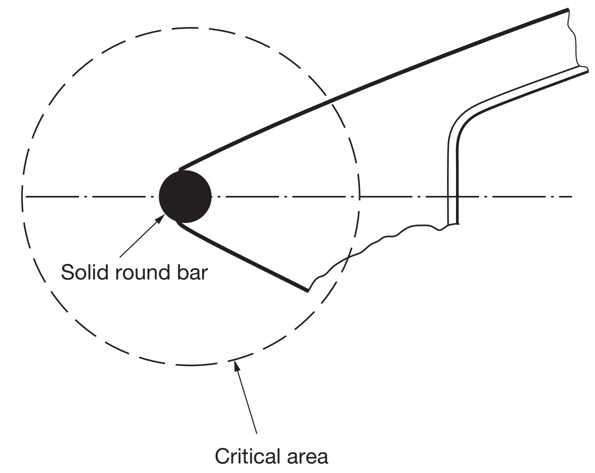
Failure Mechanism	Buckling of keel plate, shell and floor. Fractures from stress concentrations.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively.

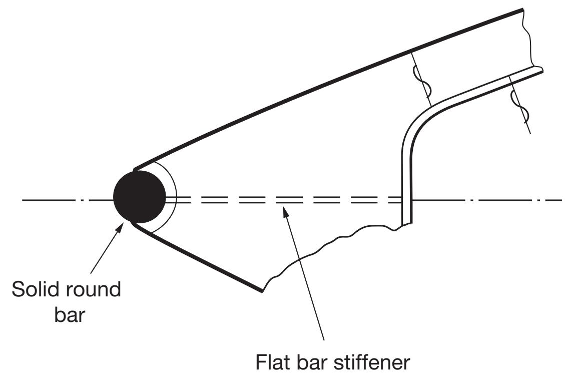
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	STEEL/ALUMINIUM CONSTRUCTION	25

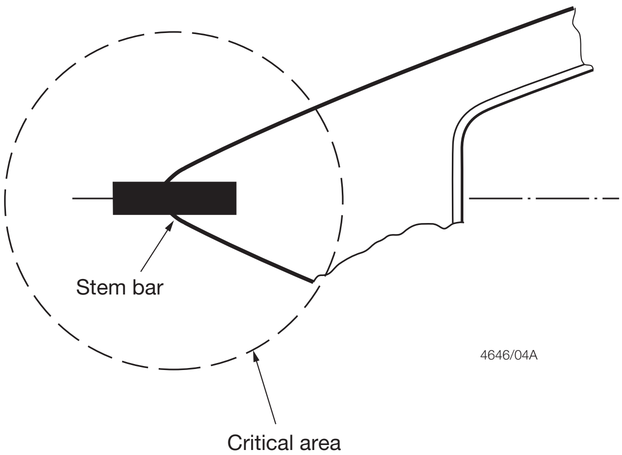
AREA:	Hull centreline structure
ITEM:	Round bar and flat bar stems

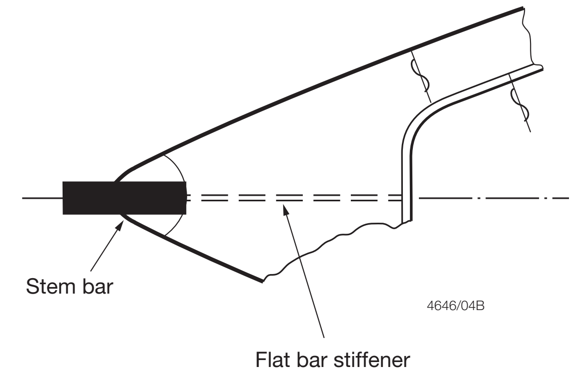
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









NOTES

Failure Mechanism	Buckling of stem plating due to collision and impact with floating debris.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding between stem bar and shell plating to be full penetration type. Butts in webs are to be staggered from butts in face flats.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	STEEL/ALUMINIUM CONSTRUCTION	26

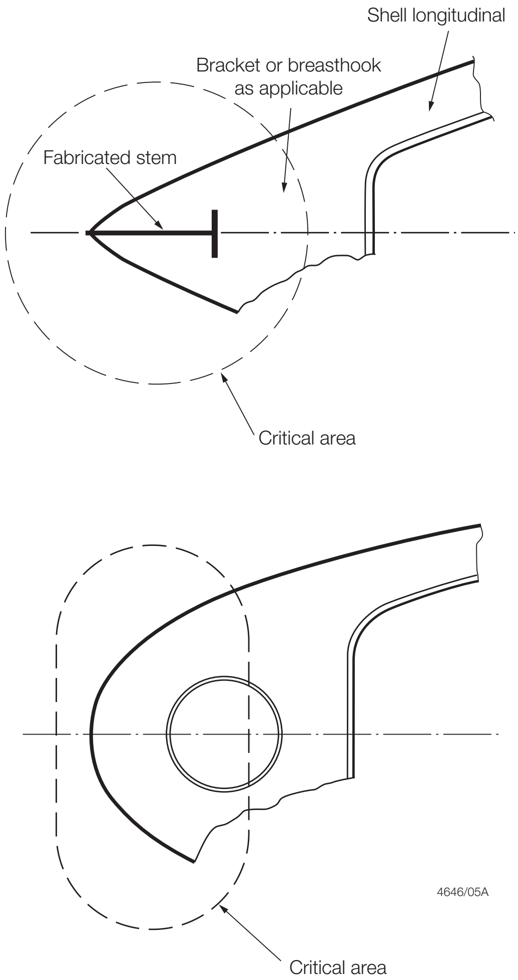
Detail Design Improvement for Steel/Aluminium Construction

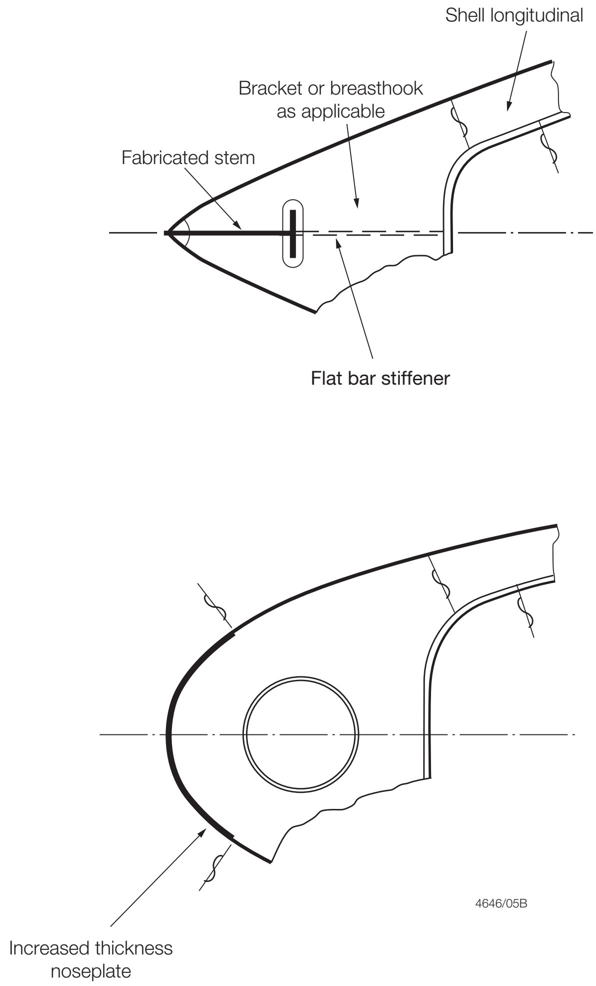
AREA: Hull centreline structure

ITEM: Fabricated and plate stems

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

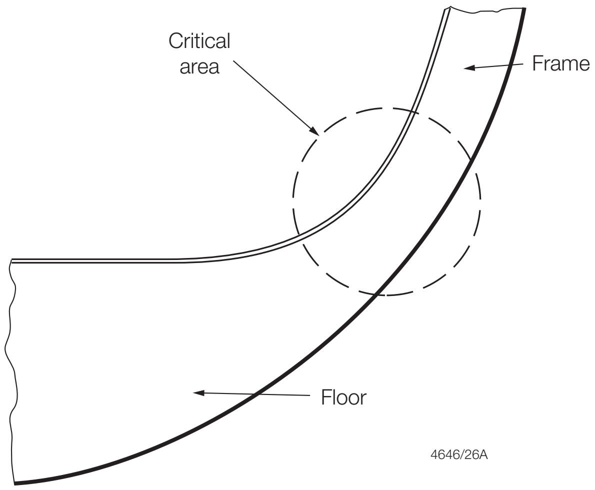
Failure Mechanism	Buckling of stem plating due to collision and impact with floating debris.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. All welding between stem and shell plating to be full penetration type. Butts in webs are to be staggered from the butts in face flats.

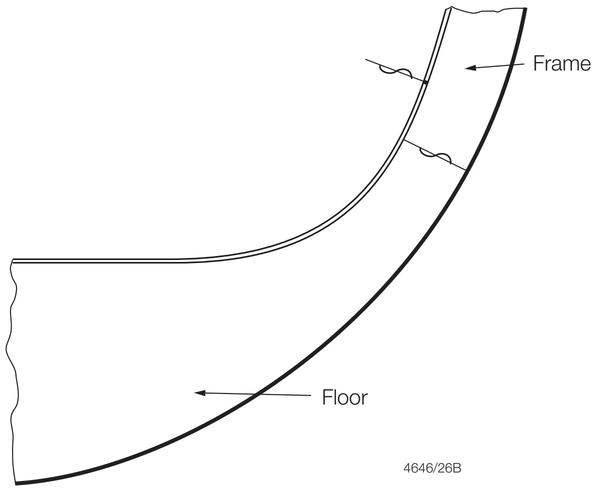
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	STEEL/ALUMINIUM CONSTRUCTION	27

Detail Design Improvement for Steel/Aluminium Construction

AREA:	Internal hull structure
ITEM:	Floor to frame connection (radiused)

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

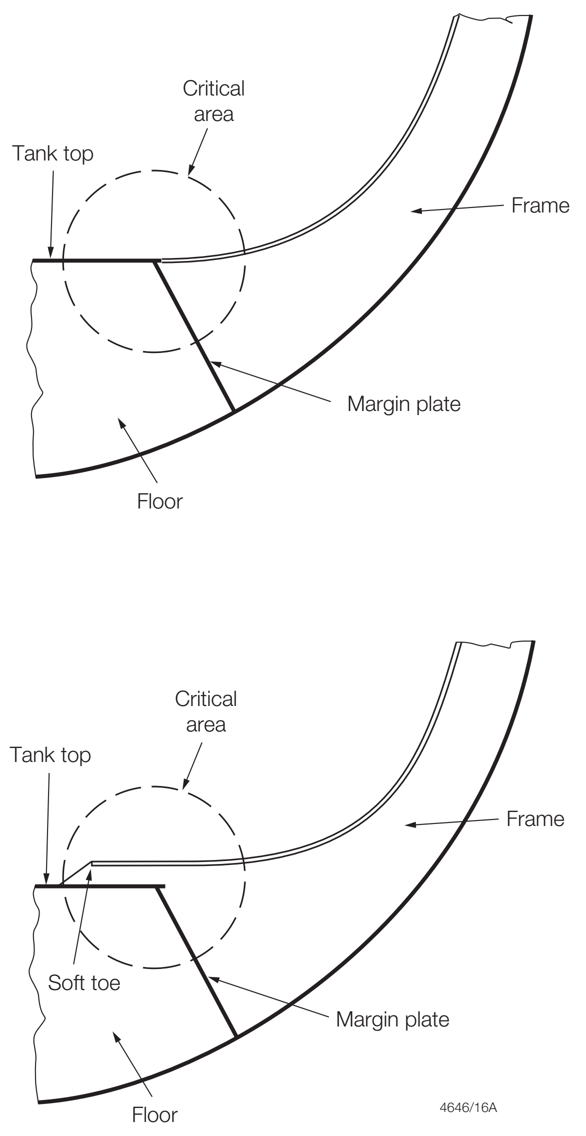
Failure Mechanism	Fatigue fractures in way of welds.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs and face flats are to be accurately aligned with butts between face flats staggered from the butts in the frame webs.

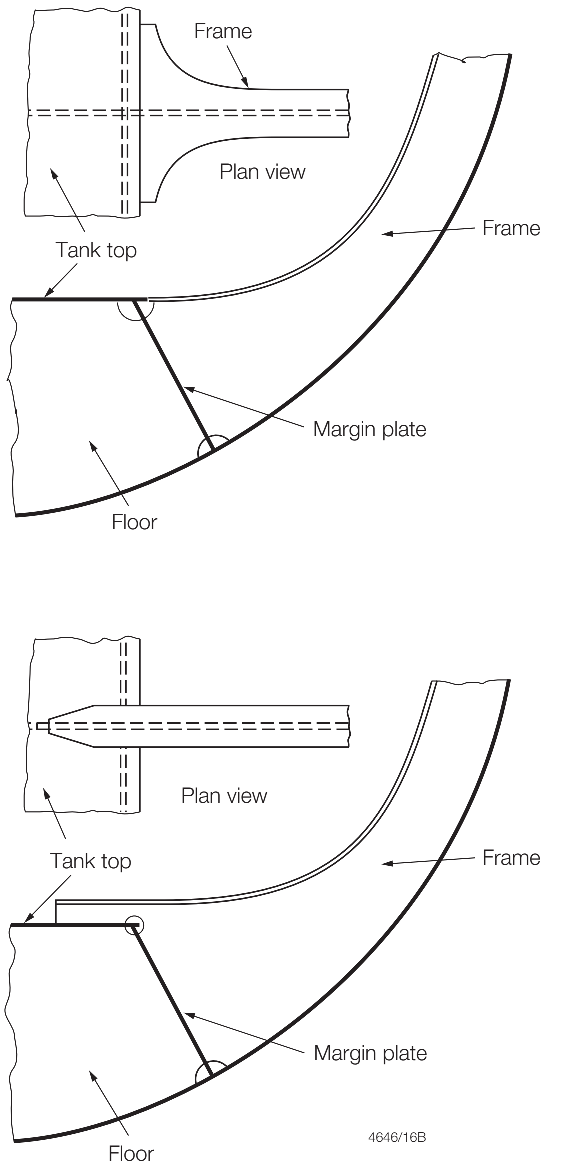
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	STEEL/ALUMINIUM CONSTRUCTION	28

Detail Design Improvement for Steel/Aluminium Construction

AREA:	Hull internal structure
ITEM:	Web frame to tank boundary connection

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Fractures arising from stress concentrations.
Building Tolerance	To be in accordance with Pt 3, Ch 1 of the Rules for Special Service Craft.
Welding Requirements	To be in accordance with Pt 6, Ch 2 and Pt 7, Ch 2 of the Rules for Special Service Craft, for steel and aluminium alloy craft respectively. Webs of frames to be accurately aligned with floor plating. All welds in way of end connection of frames are to be double continuous type.

GROUP 3	GUIDANCE NOTES FOR DESIGN DETAILS STEEL/ALUMINIUM CONSTRUCTION	FIGURE 29

Section

1 **Identification of critical areas**

2 **Structural details**

Section 1 Identification of critical areas

1.1 General

1.1.1 LR has applied direct calculation procedures in the structural appraisal and approval of new buildings and in various investigations on special service craft of composite construction. Through these procedures and the wealth of information collected on the LR 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 craft. These are referred to to as critical locations and are highlighted in this Chapter.

1.1.2 This Chapter identifies the critical areas within various structural elements of the hull structure and transverse bulkheads.

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.

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 craft 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 'in-service' experience of the performance of existing craft 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 both the primary and secondary structures of all craft 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 craft to stresses higher than in surrounding areas.

1.2.2 At the design appraisal stage, a plan of the structure should, where appropriate, be prepared by the Builder or designer 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.

1.3 Misalignment during construction

1.3.1 The very nature of composite construction involves the manufacture of the material at the same time as the product and therefore, the alignment of the moulds and formers is one of the major considerations. The bonded interface between structural components in sub-assembly areas, prefabrication stages must also be carefully controlled to ensure accurate alignment and to achieve a satisfactory bond.

1.3.2 The most critical type of joint is the bonded 'tee joint' where it is subjected to high magnitudes of tensile and shear stresses. Particular attention must also be given to the transition between different types of stiffener members i.e., top-hat to plate laminates.

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 craft.

1.4 Fatigue considerations

1.4.1 The bottom shell area of high speed craft is subjected to the highest cyclic loading throughout the life of such craft.

1.4.2 The fatigue cracks in bottom shell laminates in way of internal hard spots, and in way of longitudinal end-connections, has been well documented. Constructional details in way of these areas, designed to increase fatigue life, are now incorporated by many Builders as standard. It is, therefore, important that due consideration be given to these details at the design stage to reduce the risk of fatigue cracking during service.

1.4.3 Detailed recommendations are detailed herein for the critical areas, *see* Section 2.

■ *Section 2* Structural details

2.1 Detail design improvement

2.1.1 For the purposes of these Guidance Notes, structural locations have been divided into five separate groups, with a series of examples of critical structural areas together with alternative associated detail design improvements.

2.1.2 A summary of the data presented is given in Table 5.2.1 whilst the full details are given in Figs. 1 to 30 as contained in this Section.

2.1.3 Generally, where alternative structural detail design improvements are provided, the details shown will provide improved fatigue strength.

2.1.4 Where 'top-hat' sections are shown, the same requirements apply to plate and other stiffening members sections.

Detail Design Improvement for Composite Construction

Table 5.2.1

Group	Application	Area	Item	Fig. No
	High speed craft			
1	Sandwich	Chine in way of side shell and bottom shell connection	Chine reinforcement	1
		Stem	Stem reinforcement	2
		Hull bottom structure	Bulkhead to hull connection	3
		Hull bottom structure	Bulkhead to hull connection	4
2	Single skin	Hull structure	Spray rails	5
		Hull structure	Spray rails	6
		Chine in way of side shell and bottom shell connection	Chine reinforcement	7
		Hull internal structure	Bulkhead to hull connection	8
		Hull internal structure	Bulkhead to hull connection	9
	Low speed craft			
3	Sandwich	Hull internal structure	Bulkhead to hull connection	10
		Hull internal structure	Bulkhead to hull connection	11
4	Single skin	Hull bottom structure	Bulkhead to hull connection	12
		Hull bottom structure	Bulkhead to hull connection	13
5	General detail	Hull centreline structure	Keel/stem reinforcement and keel stiffening	14
		Hull centreline structure	Keel/stem reinforcement and keel stiffening	15
		Hull structure	Deck to hull connection	16
		Hull structure	Transom boundary	17
		Hull structure	Deck to hull connection	18
		Hull bottom structure	Limber holes	19
		Hull bottom structure	Machinery seating, tapping plates	20
		Hull internal structure	Deep girders and floors	21
		Hull internal structure	'Top-hat' stiffeners penetrating tank boundaries	22
		Hull internal structure	Lower deck/tank top to bottom shell connection	23
		Hull internal structure	Integral tanks access manholes	24
		Skeg (open type)	Skeg stiffening and reinforcement	25
		Skeg (closed type)	Skeg diaphragm plates and sealing laminate	26
		Deck structure	Well deck, lower/sole deck to hull connection	27
		Deck structure	Well deck, lower/sole deck to hull connection	28
		Deck	Bulkhead to deck connection	29
		Deck	Deckhouse to deck connection	30

Detail Design Improvement for Composite Construction

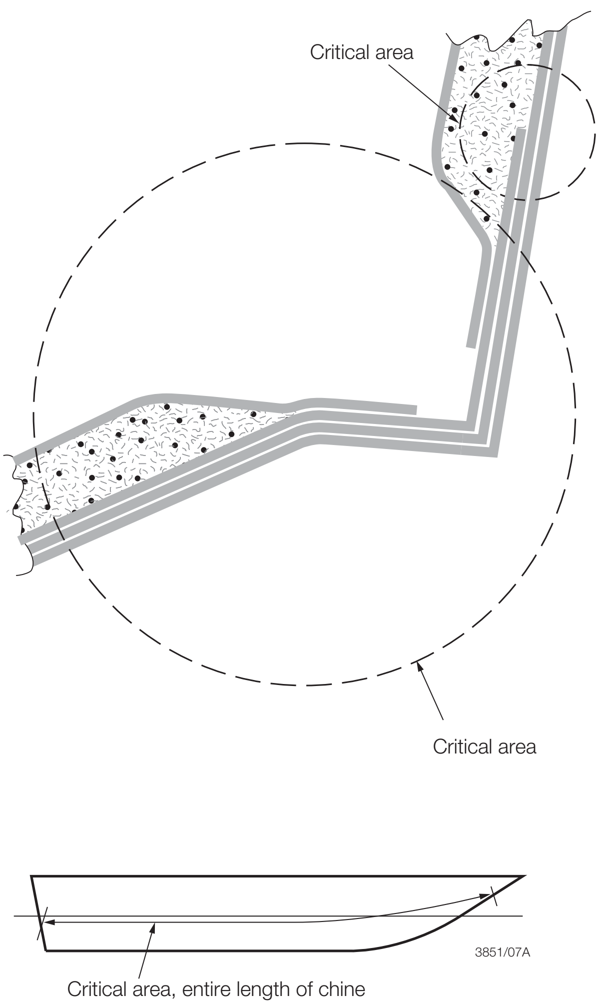
AREA: Chine in way of side shell and bottom shell connection

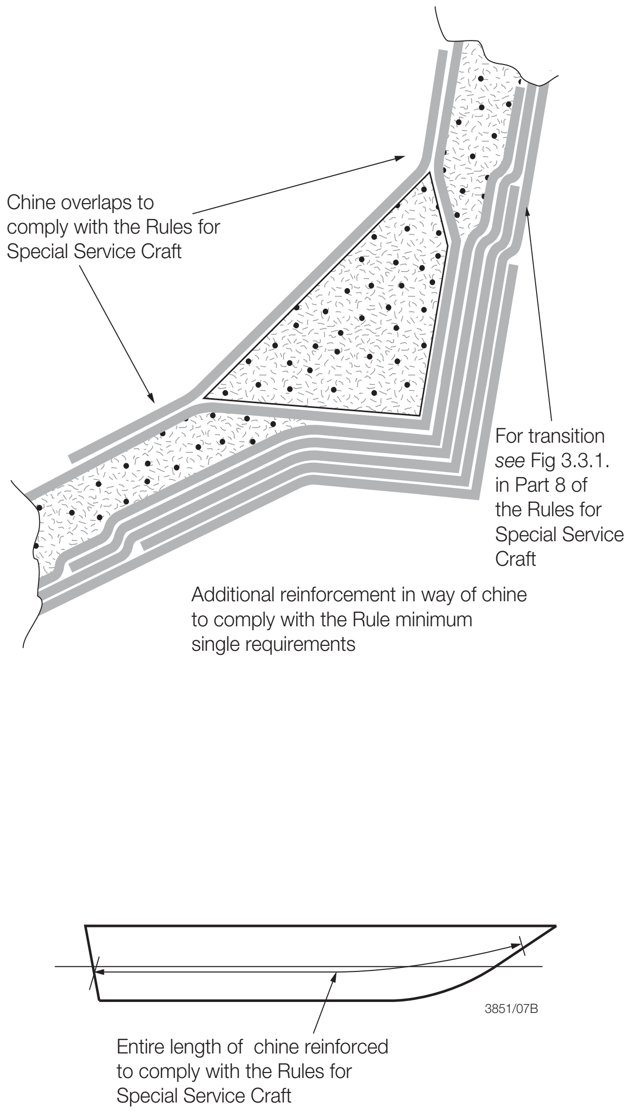
ITEM: Chine reinforcement

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Sandwich construction





NOTES

Failure Mechanism	Excess loads due to grounding, docking, slinging, hydrodynamic and other types of impact.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	COMPOSITE CONSTRUCTION	1

Detail Design Improvement for Composite Construction

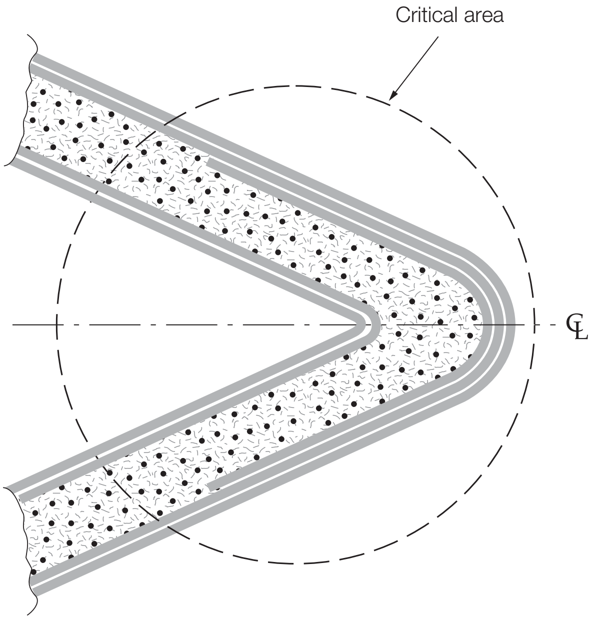
AREA: Stem

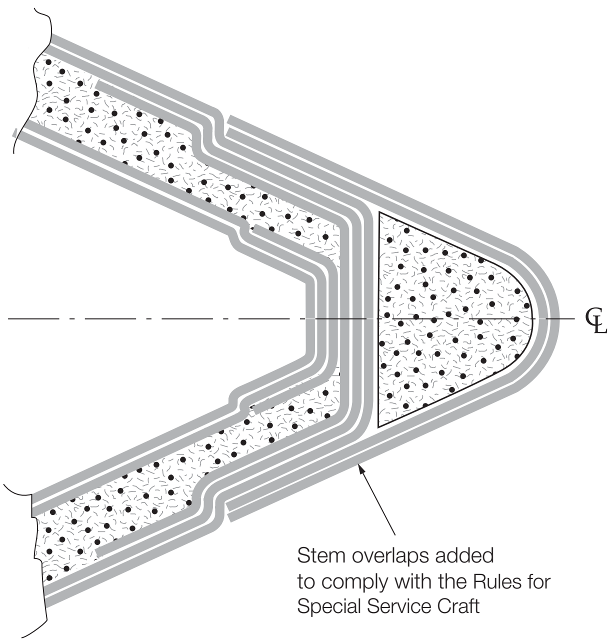
ITEM: Stem reinforcement

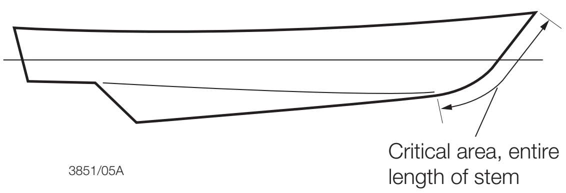
Lloyd's Register

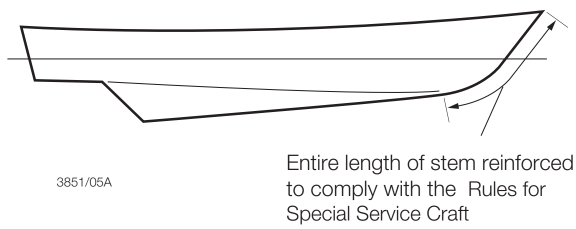
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Sandwich construction









NOTES

Failure Mechanism	Excess loads due to collision and impact with floating debris.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP		FIGURE
1	GUIDANCE NOTES FOR DESIGN DETAILS COMPOSITE CONSTRUCTION	2

Detail Design Improvement for Composite Construction

AREA: Hull bottom structure

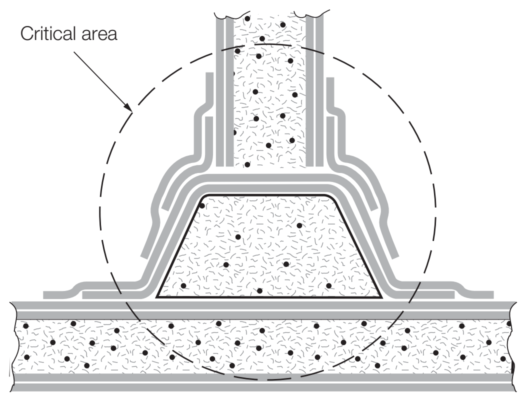
ITEM: Bulkhead to hull connection

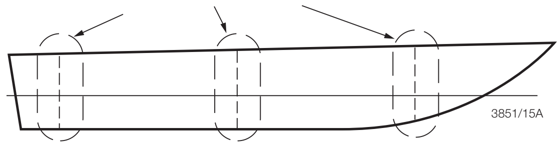
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

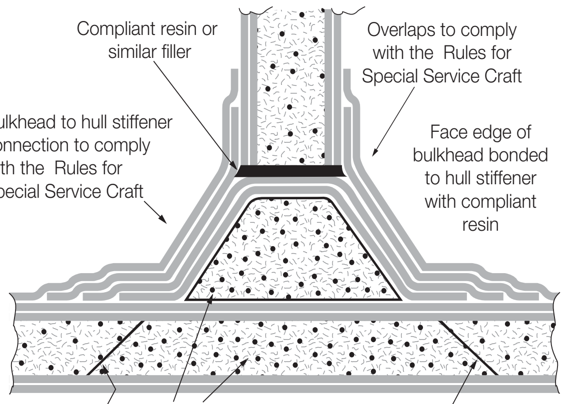
CRITICAL AREAS

Sandwich construction, high speed

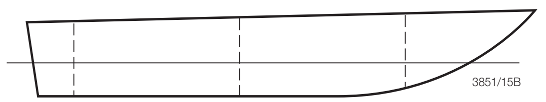




DETAIL DESIGN IMPROVEMENT



All bulkhead hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Crushing of the sandwich core under the bulkhead, and delamination of the sandwich bulkhead due to excess loads arising from berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	COMPOSITE CONSTRUCTION	3

Detail Design Improvement for Composite Construction

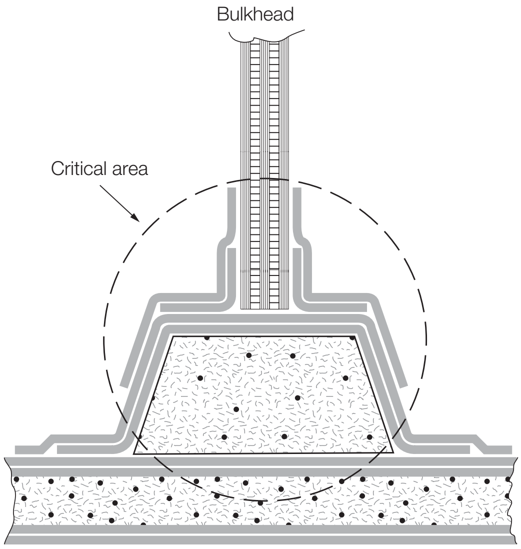
AREA: Hull bottom structure

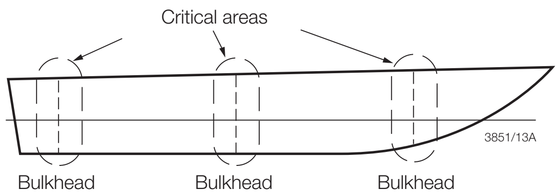
ITEM: Bulkhead to hull connection

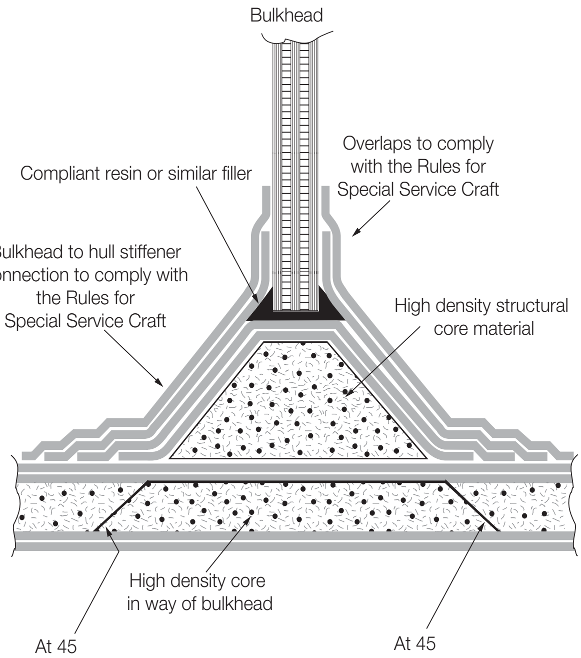
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

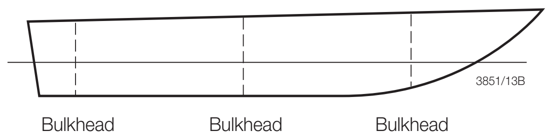
Sandwich construction, high speed







All bulkhead hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Crushing of the sandwich core under the bulkhead due to excess loads arising from berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

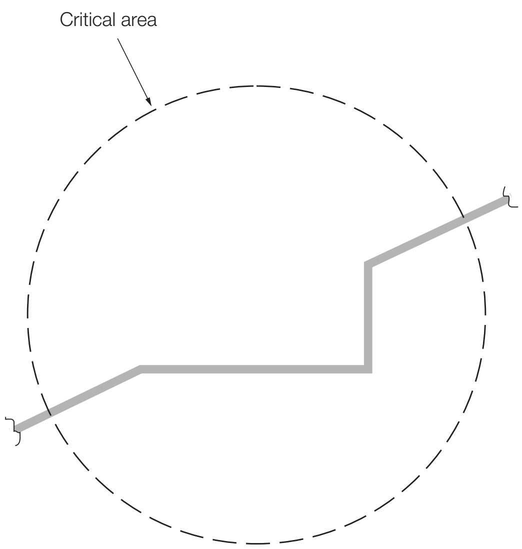
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
1	COMPOSITE CONSTRUCTION	4

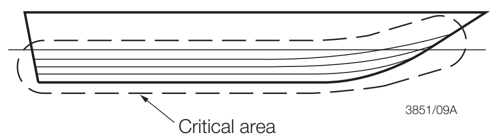
Detail Design Improvement for Composite Construction

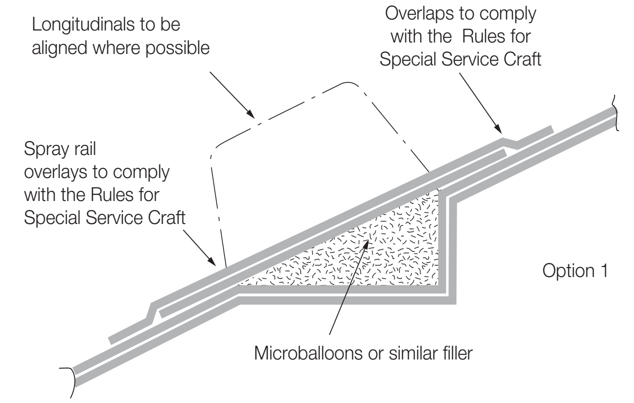
AREA: Hull structure

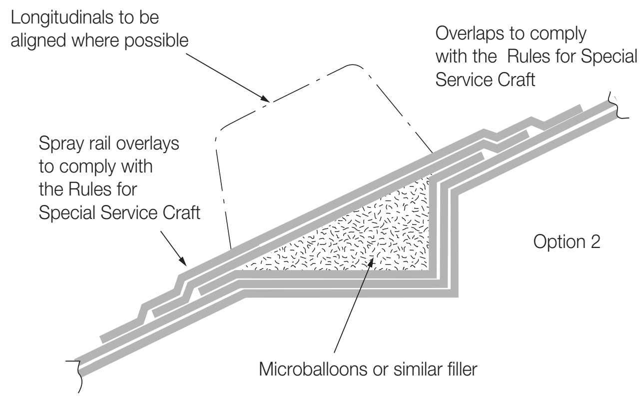
ITEM: Spray rails

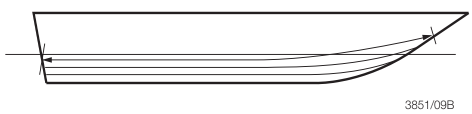
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT
Single skin construction	











Entire length of spray rails overlaid to comply with the Rules for Special Service Craft

NOTES

Failure Mechanism	Excess loads due to grounding and impact.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	COMPOSITE CONSTRUCTION	5

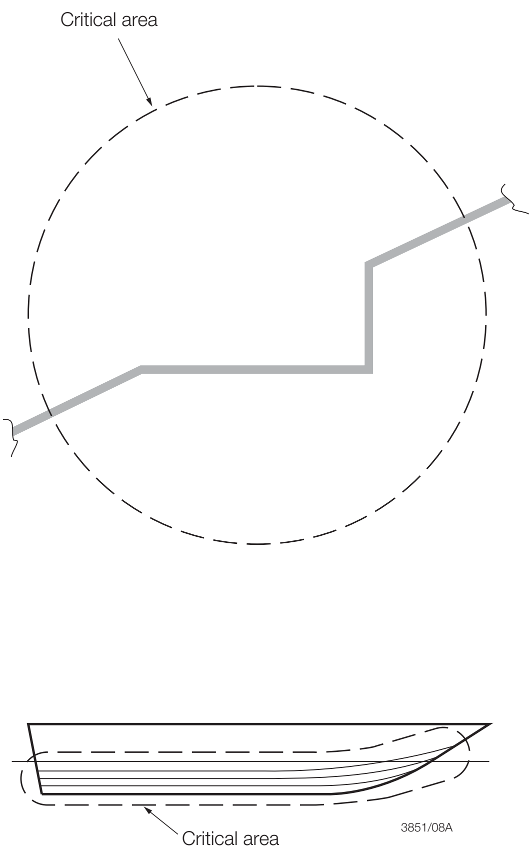
Detail Design Improvement for Composite Construction

AREA:	Hull structure
ITEM:	Spray rails

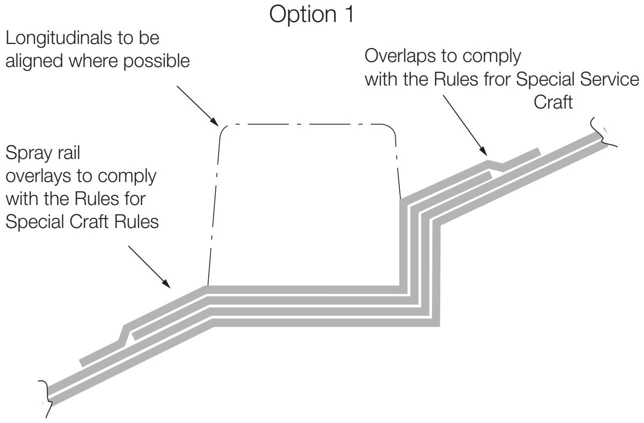
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Single skin construction



Option 1



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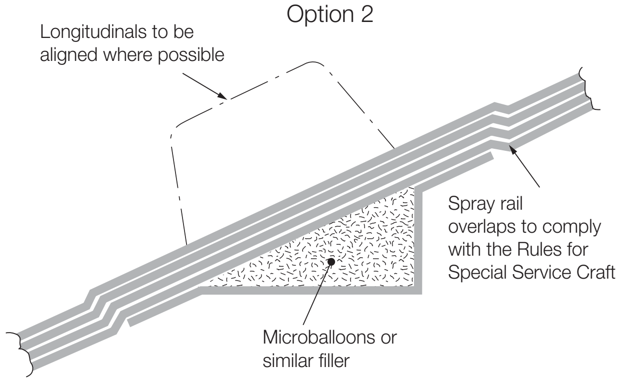
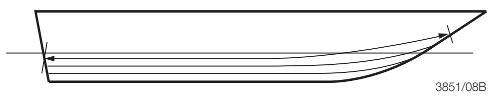




Entire length of spray rails overlaid to comply with the Rules for Special Service Craft

NOTES

Failure Mechanism	Excess loads due to grounding and impact.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with the Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	COMPOSITE CONSTRUCTION	6

Detail Design Improvement for Composite Construction

Chapter 5

Section 2

AREA: Chine in way of side shell and bottom shell connection

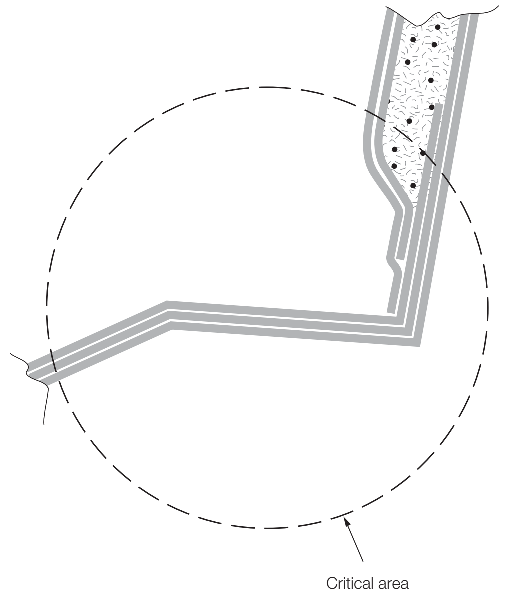
ITEM: Chine reinforcement

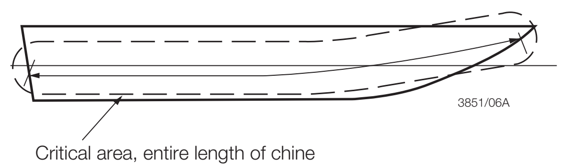
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

CRITICAL AREAS

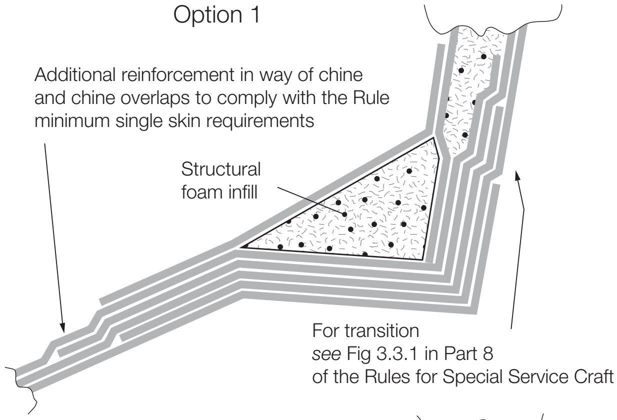
Sandwich side and single skin bottom





DETAIL DESIGN IMPROVEMENT

Option 1



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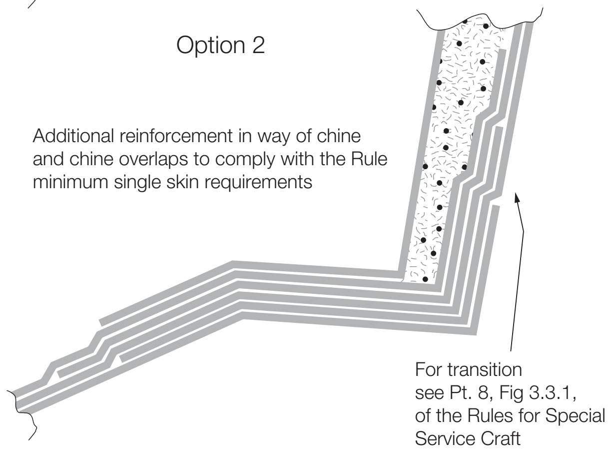
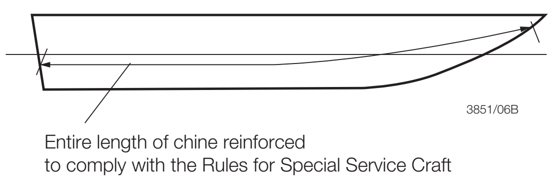




NOTES

Failure Mechanism	Excess loads due to grounding, docking, slinging and hydrodynamic impact.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft
Laminating Requirements	To be in accordance with the Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	COMPOSITE CONSTRUCTION	7

Detail Design Improvement for Composite Construction

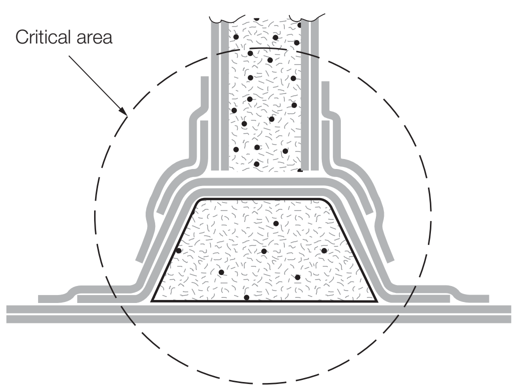
AREA: Hull internal structure

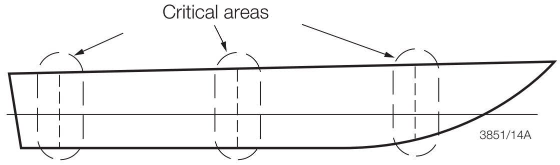
ITEM: Bulkhead to hull connection

Lloyd's Register

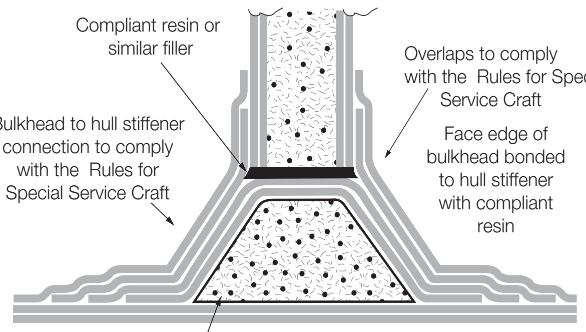
CRITICAL AREAS

Single skin construction, high speed

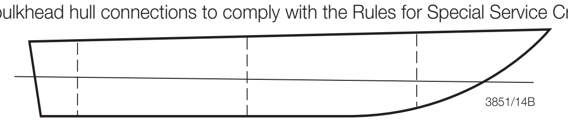




DETAIL DESIGN IMPROVEMENT



All bulkhead hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with the Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	COMPOSITE CONSTRUCTION	8

Detail Design Improvement for Composite Construction

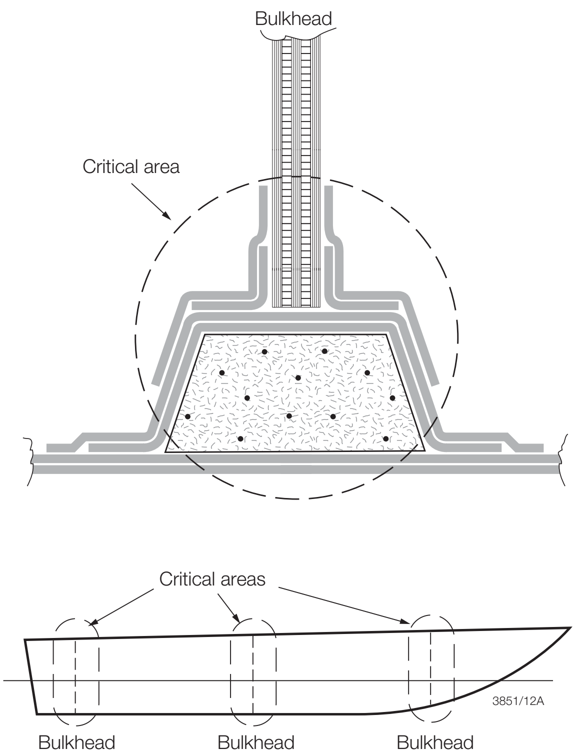
AREA: Hull internal structure

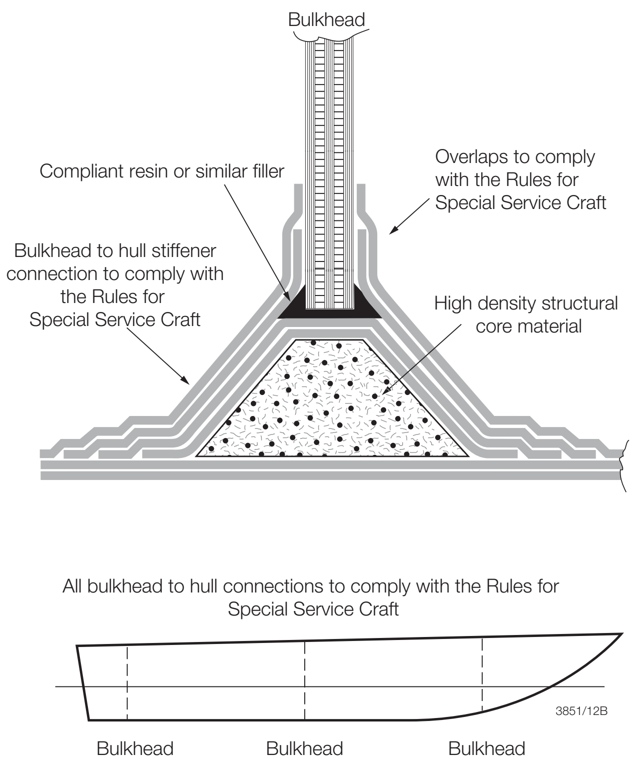
ITEM: Bulkhead to hull connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Single skin construction, high speed





NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
2	COMPOSITE CONSTRUCTION	9

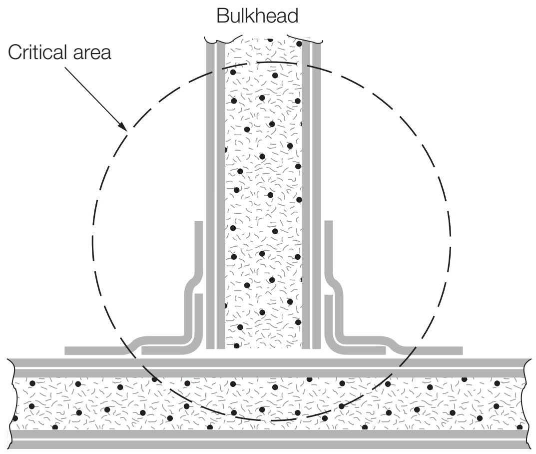
Detail Design Improvement for Composite Construction

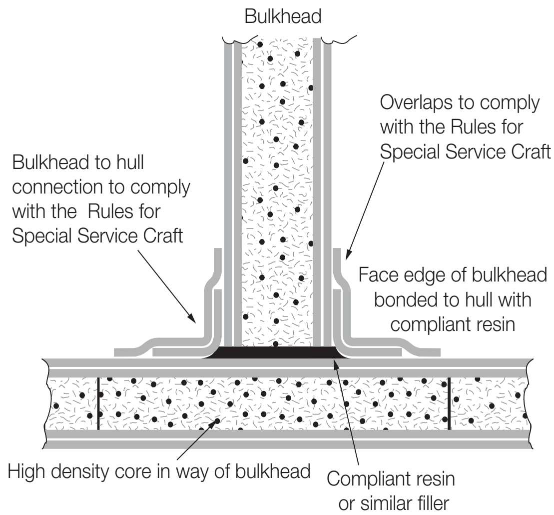
AREA: Hull internal structure

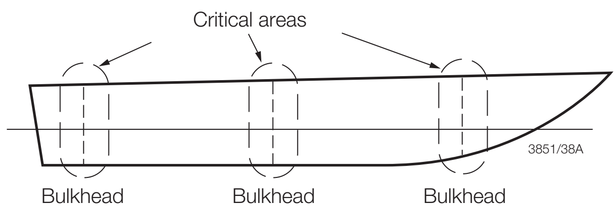
ITEM: Bulkhead to hull connection

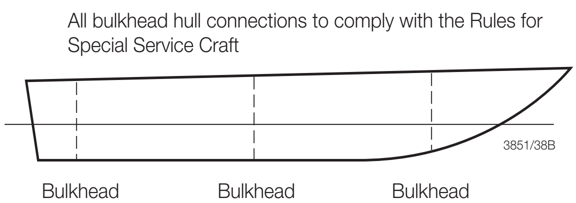
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Sandwich construction, low speed









NOTES

Failure Mechanism	Crushing of the sandwich core under the bulkhead, and delamination of the sandwich bulkhead due to excess loads arising from berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	COMPOSITE CONSTRUCTION	10

Detail Design Improvement for Composite Construction

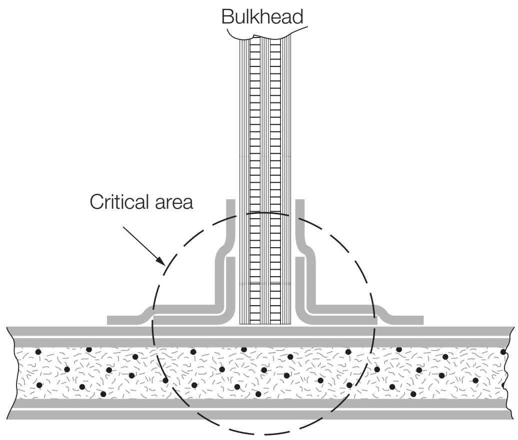
Chapter 5

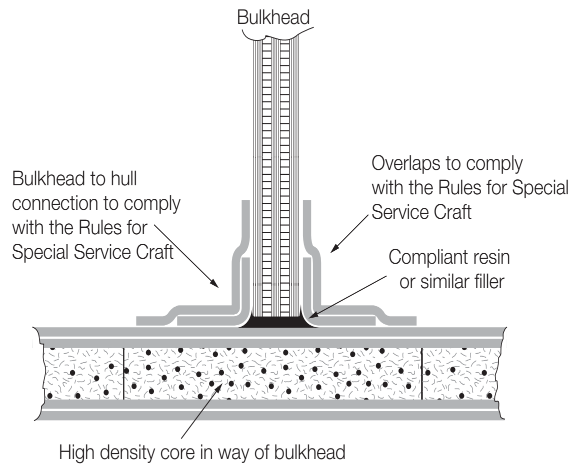
Section 2

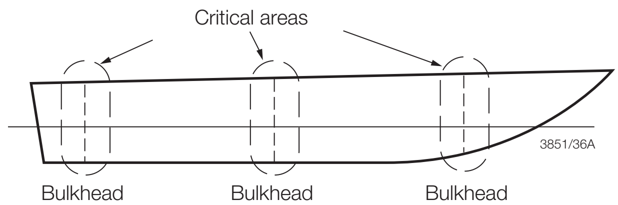
AREA:	Hull internal structure	Lloyd's Register
ITEM:	Bulkhead to hull connection	

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

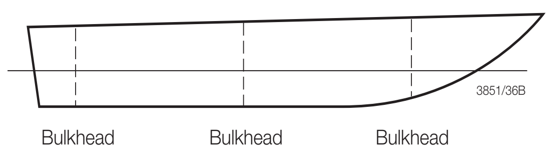
Sandwich construction, low speed







All bulkhead hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Crushing of the sandwich core under the bulkhead due to excess loads arising from berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
3	COMPOSITE CONSTRUCTION	11

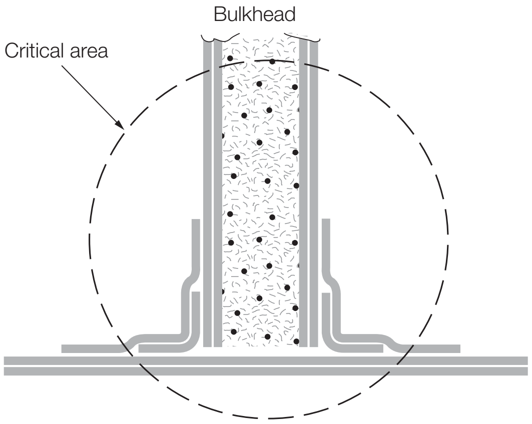
Detail Design Improvement for Composite Construction

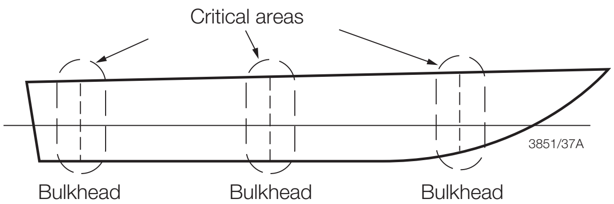
AREA:	Hull bottom structure
ITEM:	Bulkhead to hull connection

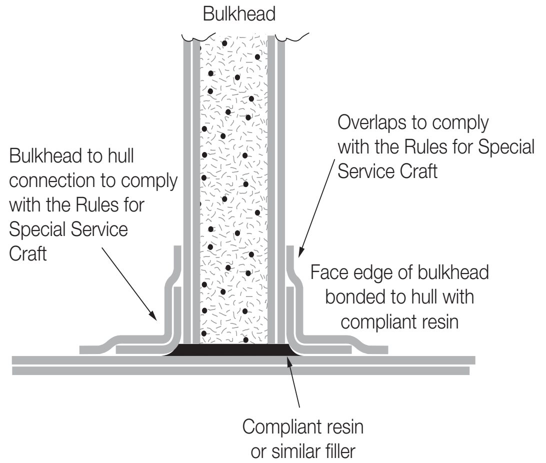
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

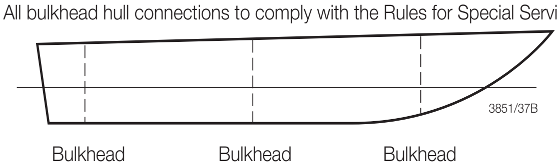
Single skin construction, low speed







All bulkhead hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
4	COMPOSITE CONSTRUCTION	12

Detail Design Improvement for Composite Construction

AREA: Hull bottom structure

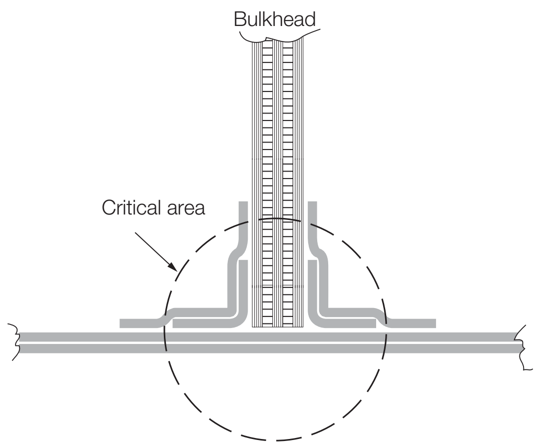
ITEM: Bulkhead to hull connection

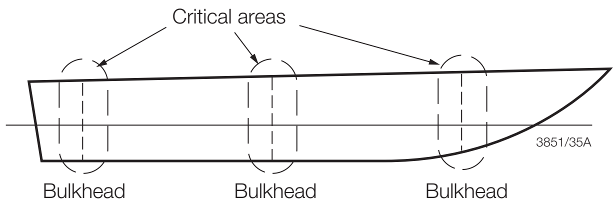
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

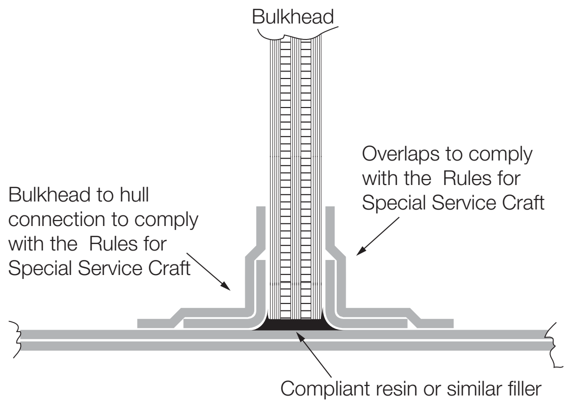
CRITICAL AREAS

Single skin construction, low speed

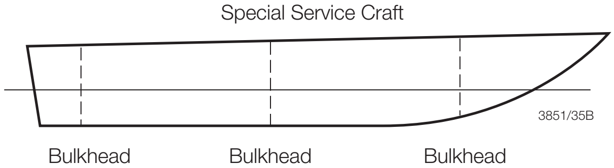




DETAIL DESIGN IMPROVEMENT



All bulkhead to hull connections to comply with the Rules for Special Service Craft



NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact and racking.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

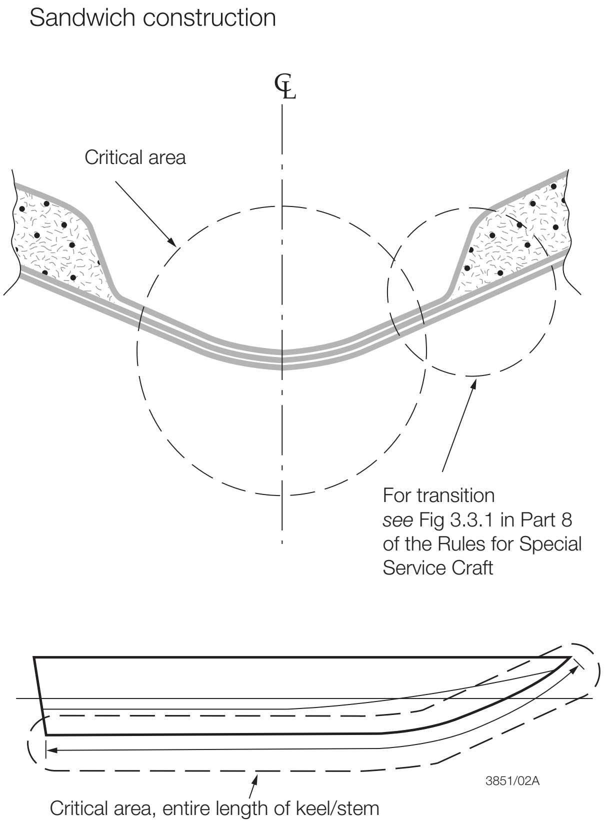
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
4	COMPOSITE CONSTRUCTION	13

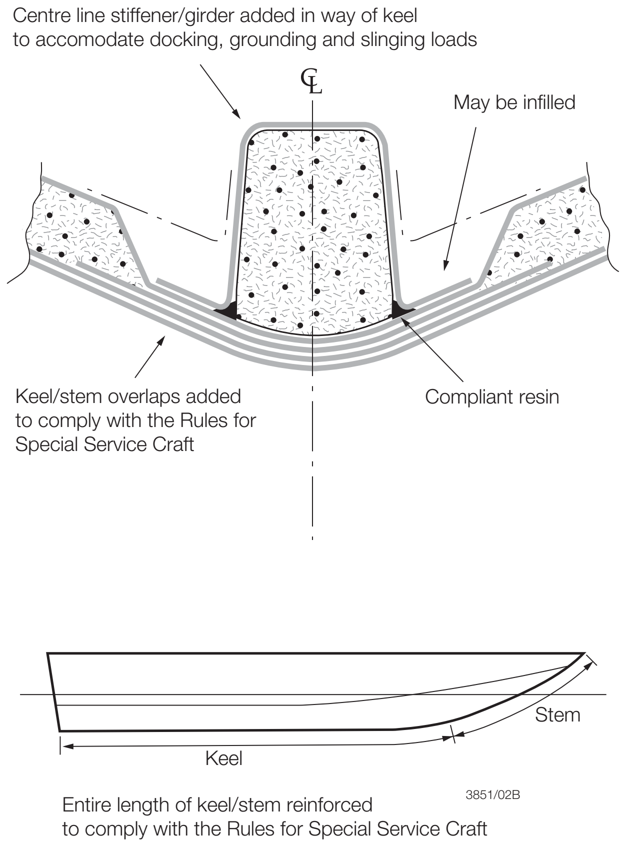
Detail Design Improvement for Composite Construction

AREA:	Hull centreline structure
ITEM:	Keel/stem reinforcement and keel stiffening

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Excess loads due to grounding, docking and slinging.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with the Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	14

Detail Design Improvement for Composite Construction

AREA: Hull centreline structure

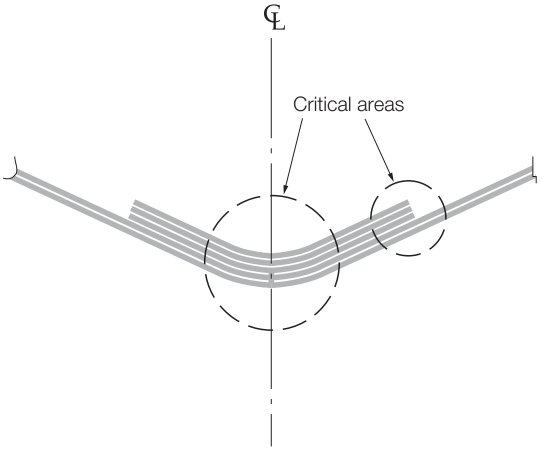
ITEM: Keel/stem reinforcement and keel stiffening

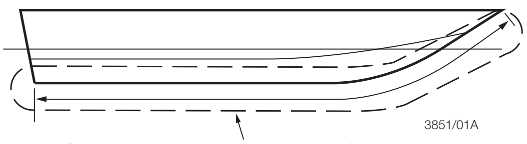
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

CRITICAL AREAS

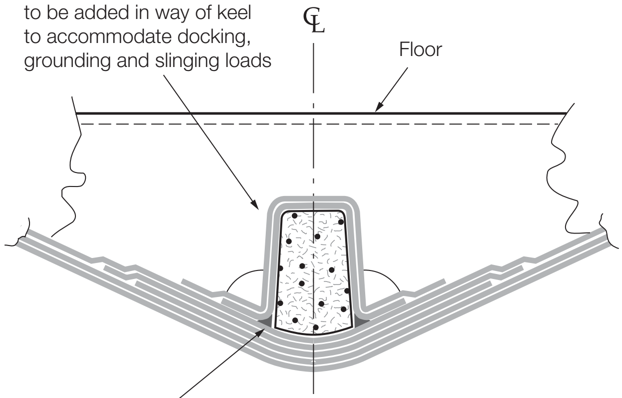
Single skin construction

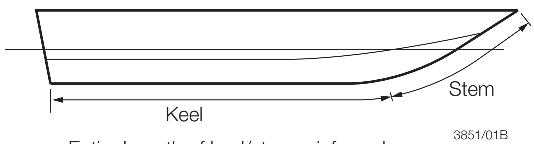




Critical area, entire length of keel/stem

DETAIL DESIGN IMPROVEMENT





Entire Length of keel/stem reinforced to comply with the Rules for Special Service Craft

NOTES

Failure Mechanism	Excess loads due to grounding, docking and slinging.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	15

Detail Design Improvement for Composite Construction

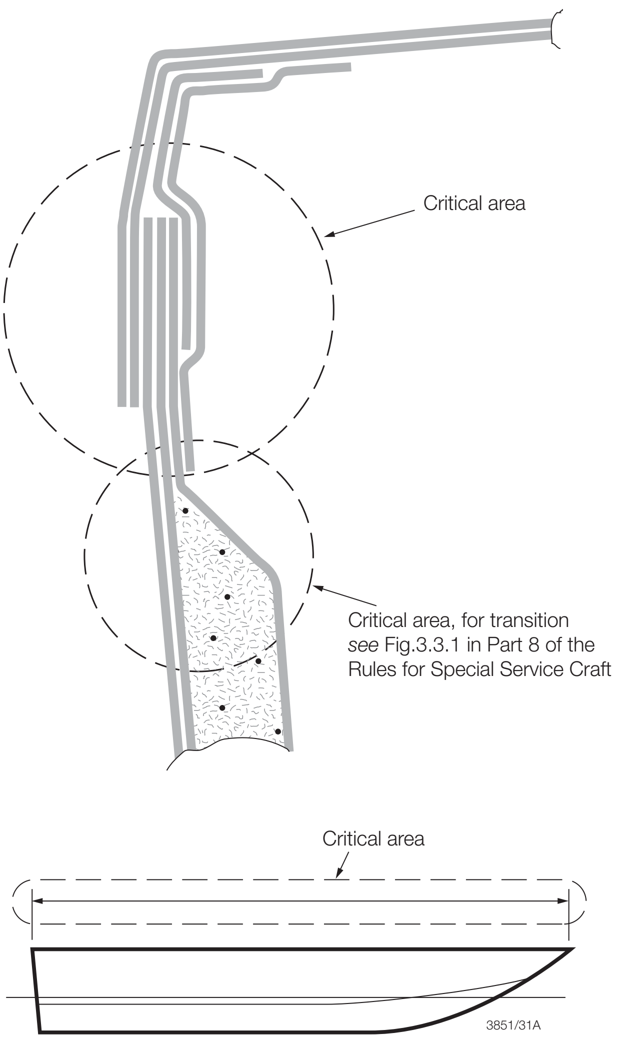
AREA: Hull structure

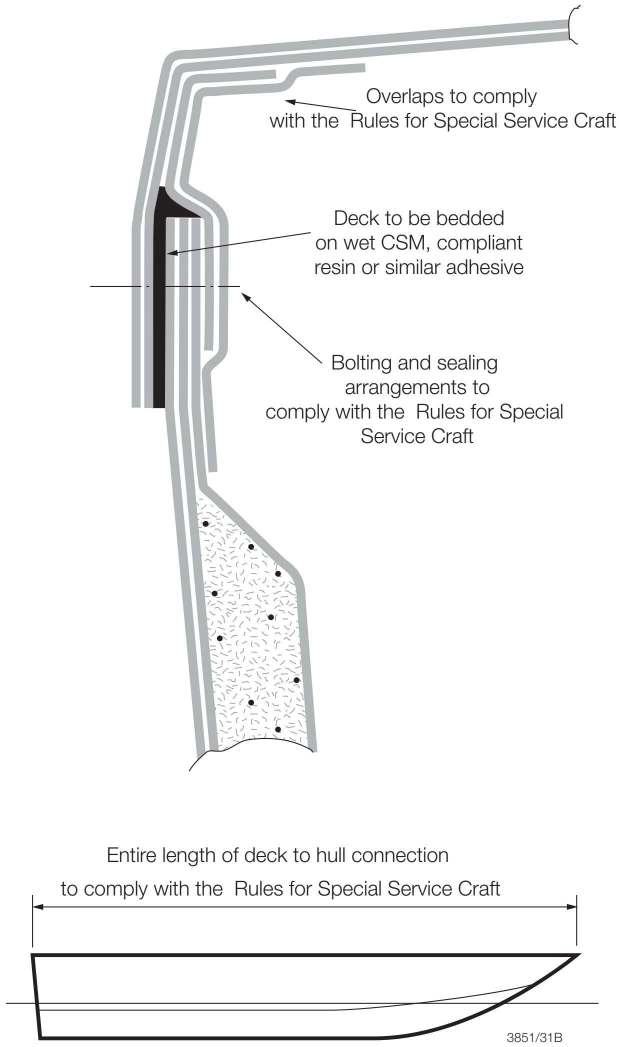
ITEM: Deck to hull connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Sandwich construction





NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact from green seas and other loadings arising from heavy weather.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	16

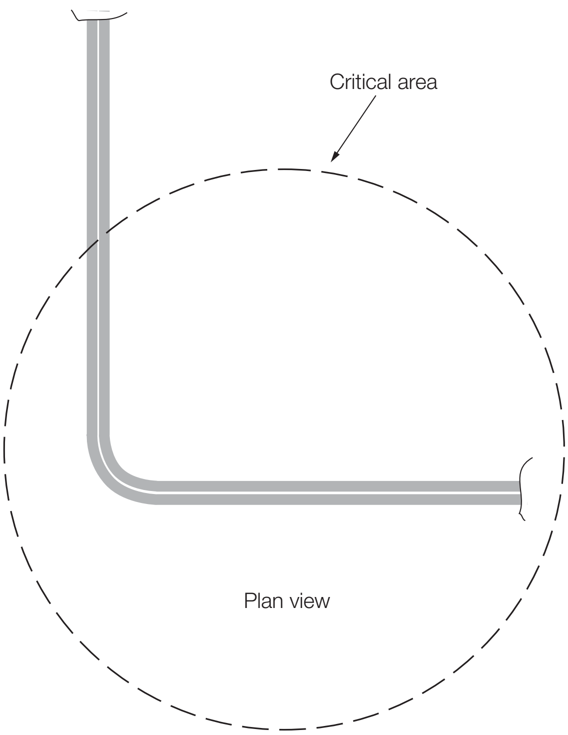
Detail Design Improvement for Composite Construction

AREA:	Hull structure
ITEM:	Transom boundary

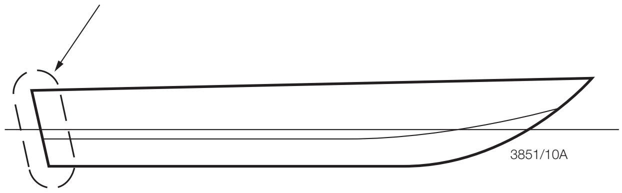
Lloyd's Register

CRITICAL AREAS

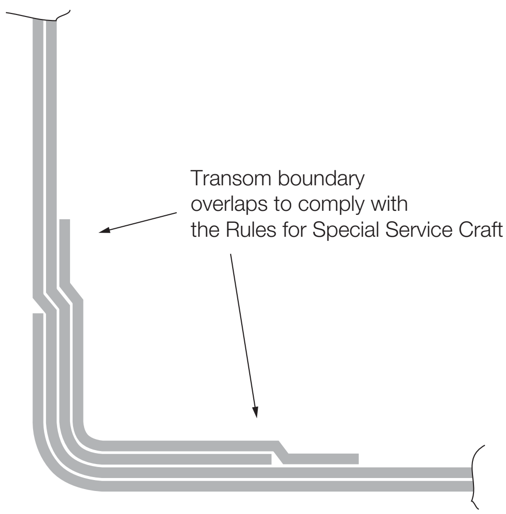
Single skin construction



Critical area, entire length of transom boundary

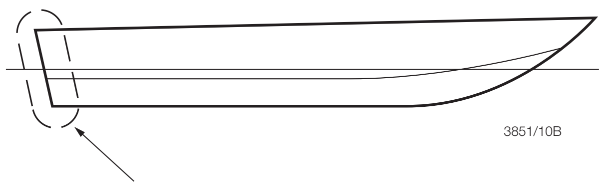


DETAIL DESIGN IMPROVEMENT



Plan view

Additional reinforcement in way of transom boundary to comply with the Rules for Special Service Craft



Entire length of transom boundary reinforced to comply with the Rules for Special Service Craft

NOTES

Failure Mechanism	Excess loads due to docking and impact due to berthing.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	17

Detail Design Improvement for Composite Construction

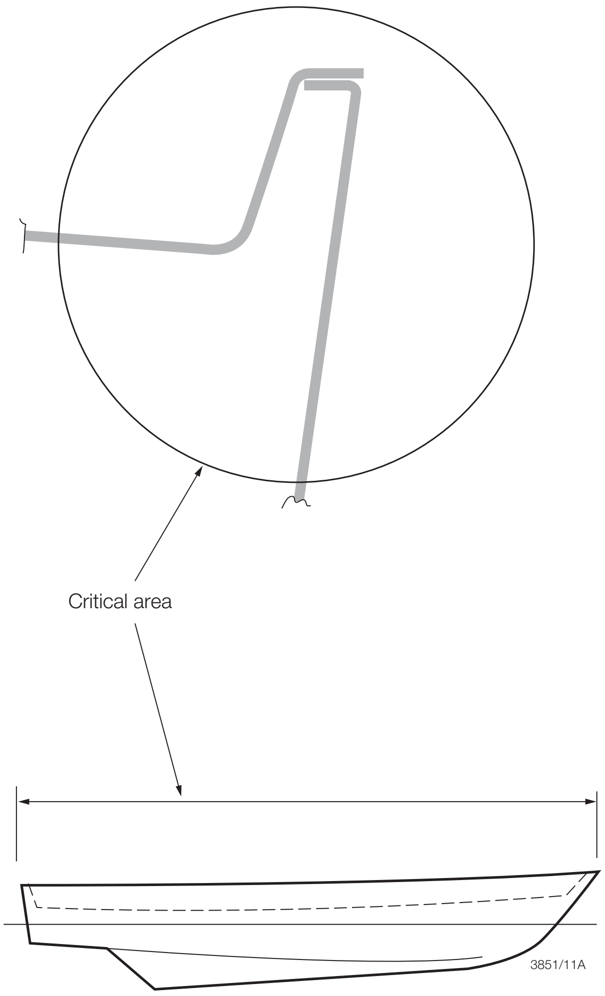
AREA: Hull structure

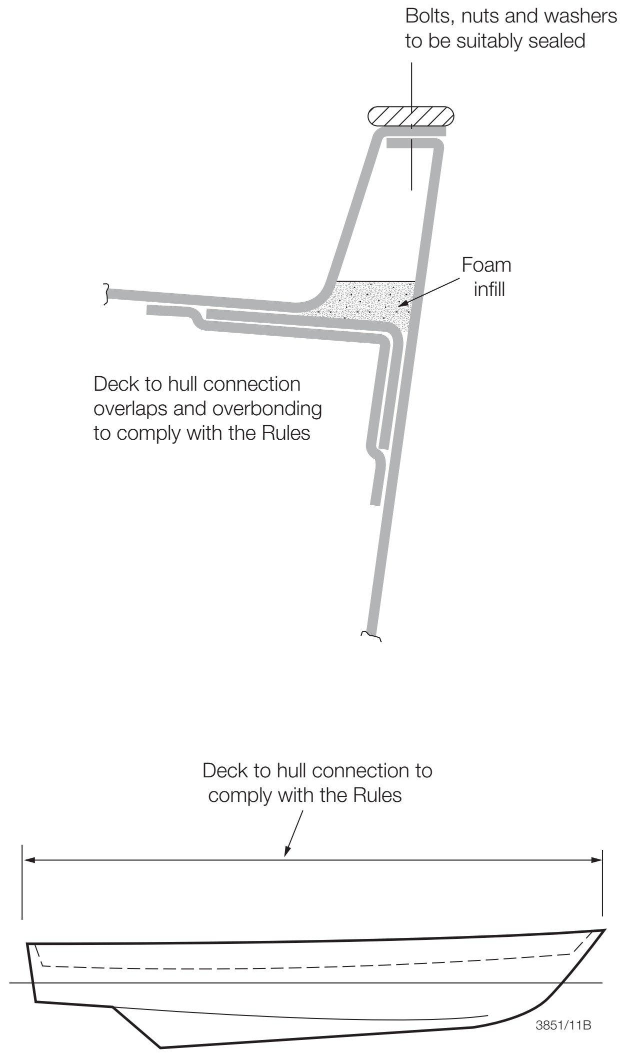
ITEM: Deck to hull connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Single skin construction





NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact from green seas and other loadings arising from heavy weather.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP 5	GUIDANCE NOTES FOR DESIGN DETAILS COMPOSITE CONSTRUCTION	FIGURE 18

Detail Design Improvement for Composite Construction

Chapter 5

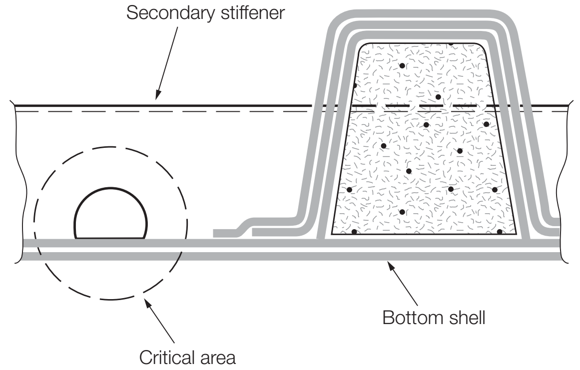
Section 2

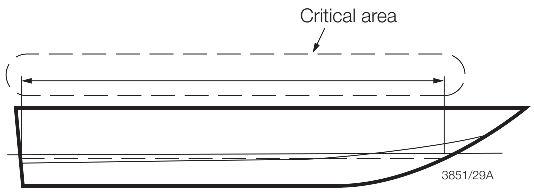
AREA: Hull bottom structure

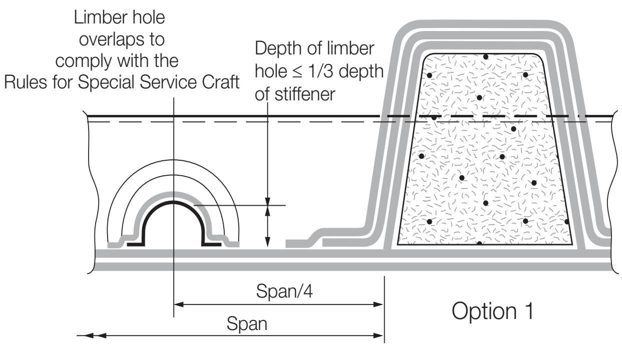
ITEM: Limber holes

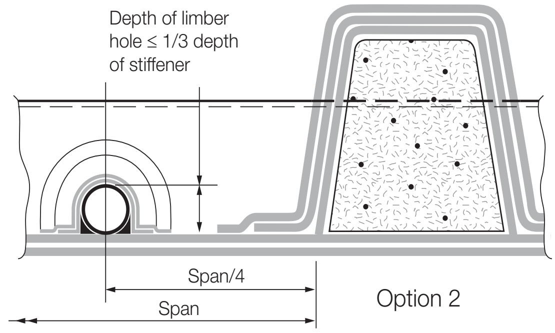
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Single skin construction

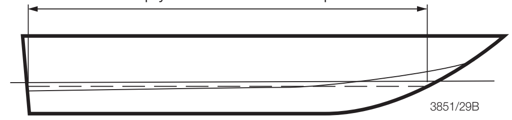








All limber holes to comply with the Rules for Special Service Craft



NOTES

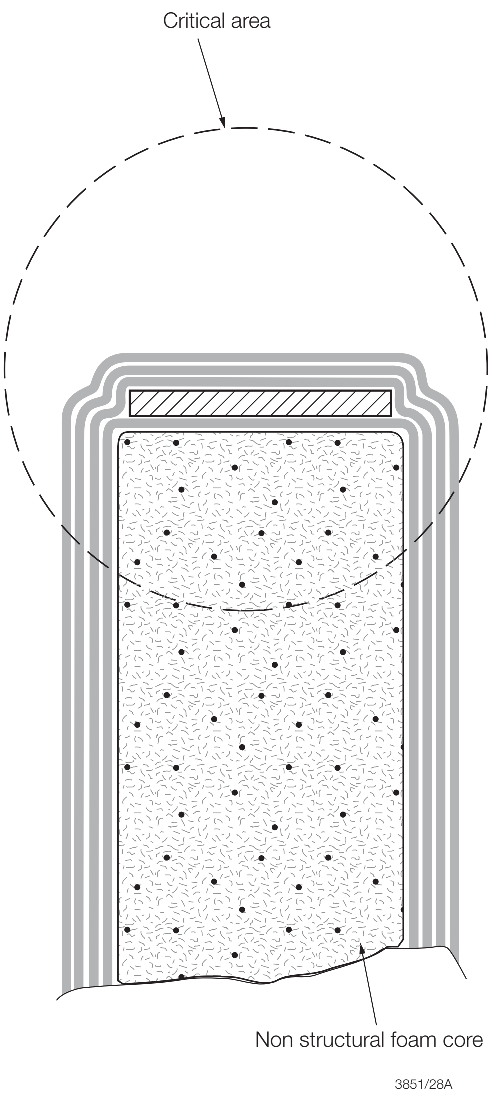
Failure Mechanism	Excess loads due to hydrodynamic impact, grounding, docking and slinging leading to stiffener web failure.
Building Tolerance	All FRP materials to be in accordance with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

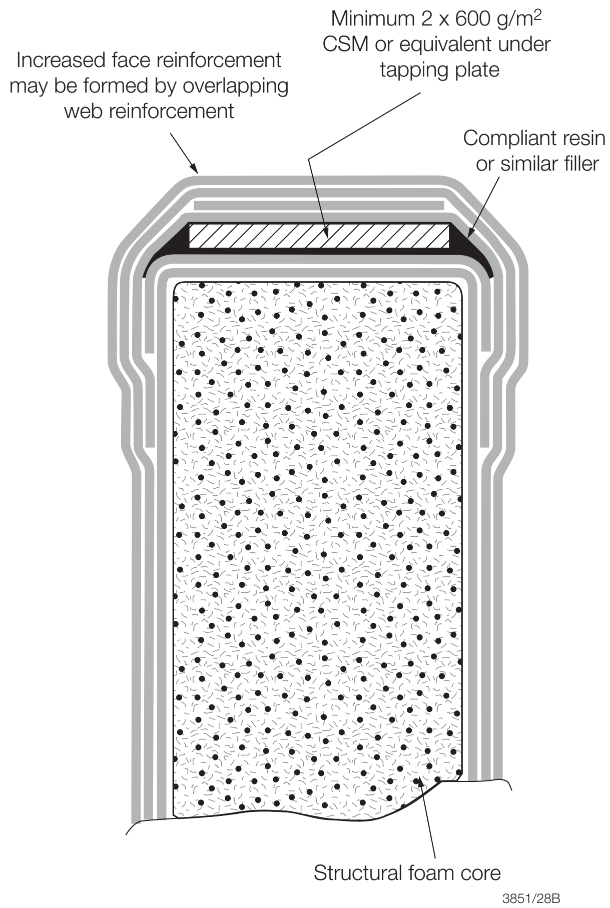
GROUP 5	GUIDANCE NOTES FOR DESIGN DETAILS COMPOSITE CONSTRUCTION	FIGURE 19

AREA:	Hull bottom structure
ITEM:	Machinery seating, tapping plates

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





Tapping plate is to be suitably abraded, all sharp edges removed and all corners radiused prior to encapsulating

NOTES

Failure Mechanism	Engine loadings arising from thrust, torque and mass.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	20

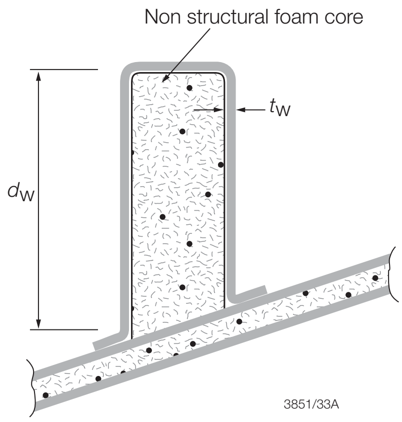
AREA: Hull internal structure

ITEM: Deep girders and floors

Lloyd's Register

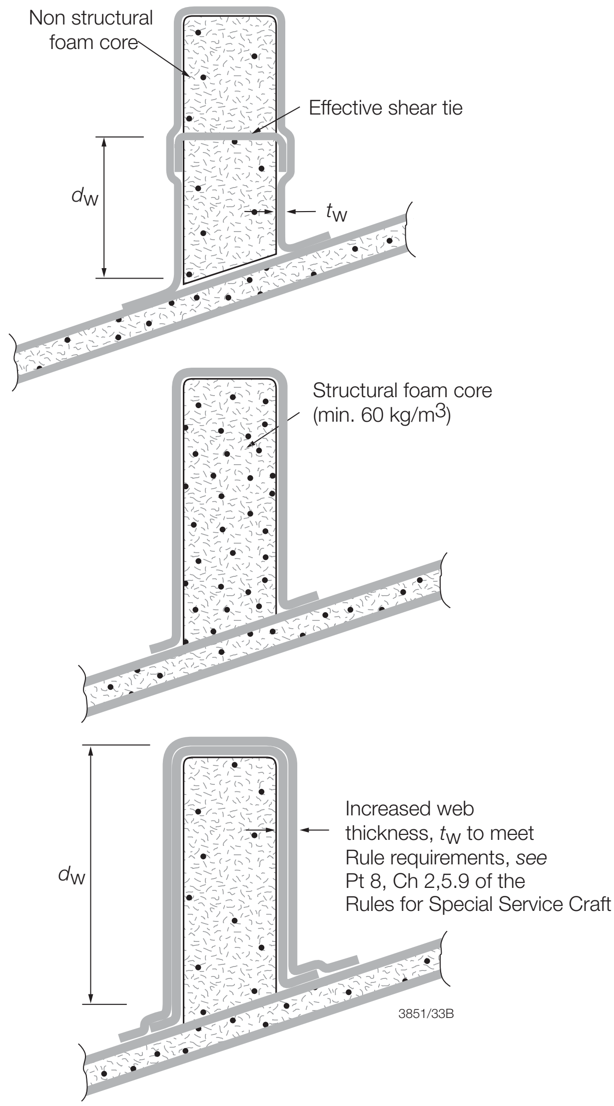
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT

Sandwich construction/single skin construction



t_W is to satisfy the Rule requirement for d_W, *see* Pt 8, Ch 2,5.9 of the Rules for Special Service Craft

d_W = unsupported web depth
t_W = web thickness



NOTES

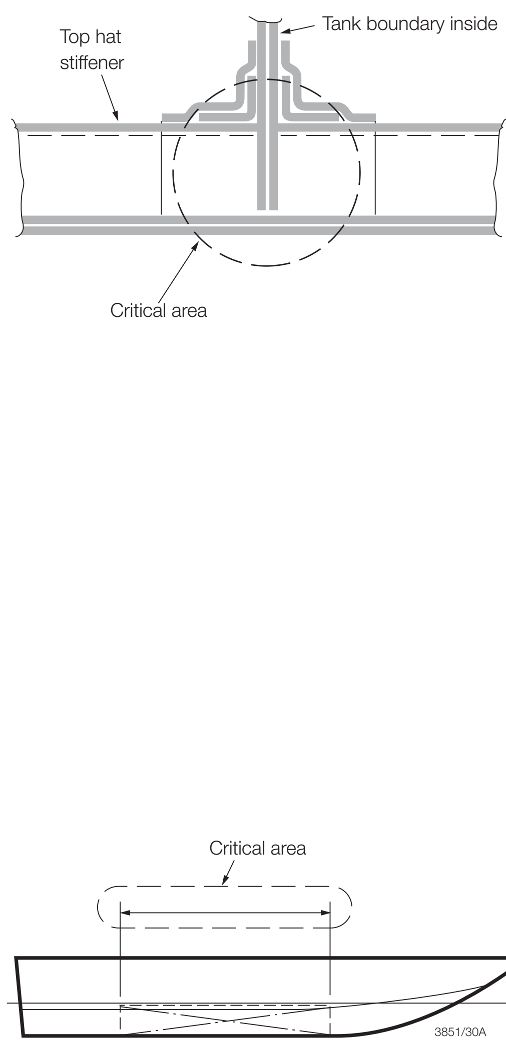
Failure Mechanism	Web buckling under design load, docking and berthing loads.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

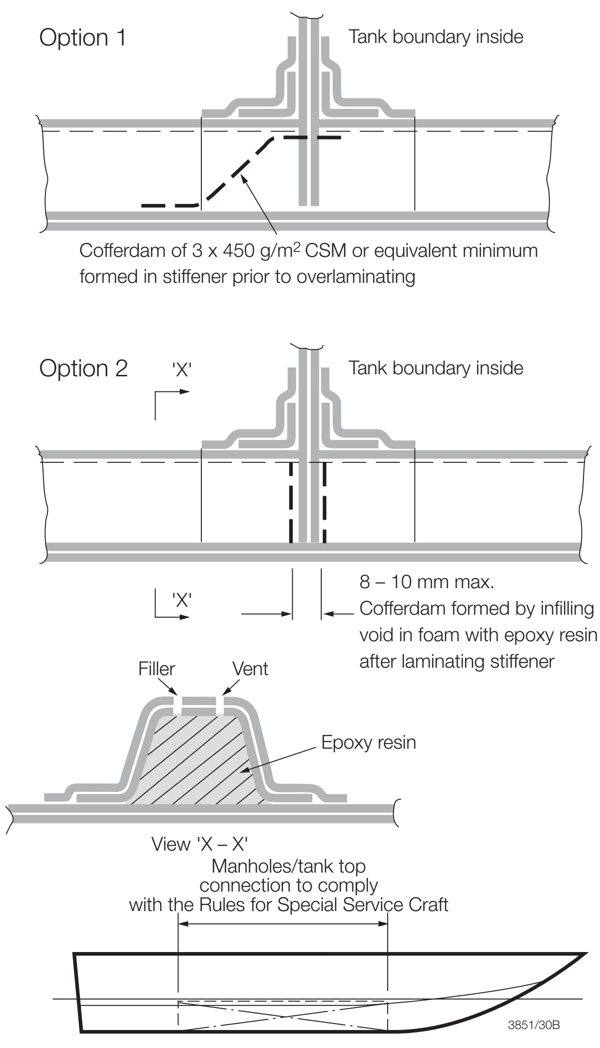
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	21

Detail Design Improvement for Composite Construction

AREA:	Hull internal structure
ITEM:	'Top-hat' stiffeners penetrating tank boundaries

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Ingress and permeation of fluid along stiffener.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft. Fit-up is to be very good.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	22

Detail Design Improvement for Composite Construction

Chapter 5
Section 2

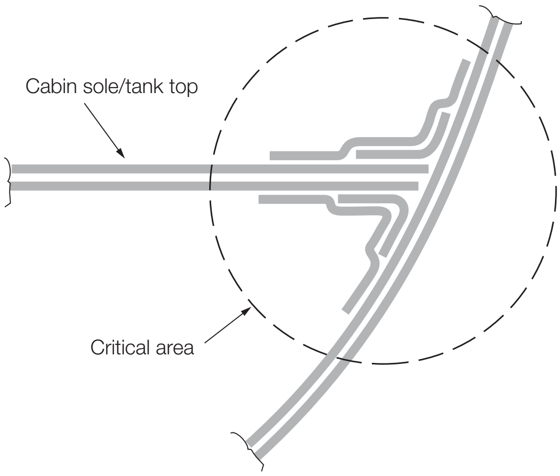
AREA: Hull internal structure

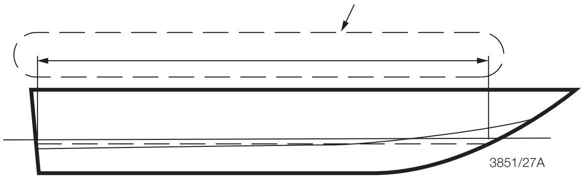
ITEM: Lower deck/tank top to bottom shell connection

Lloyd's Register

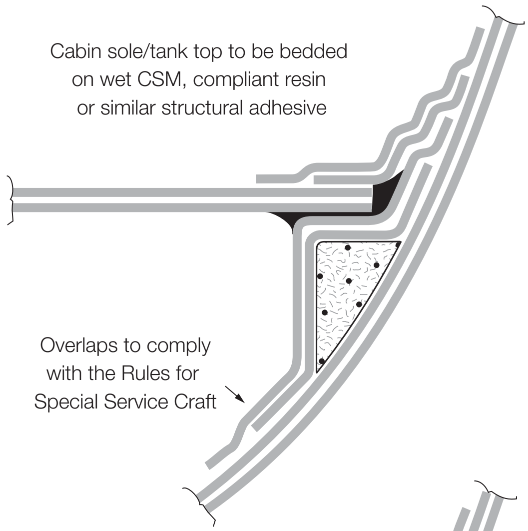
CRITICAL AREAS

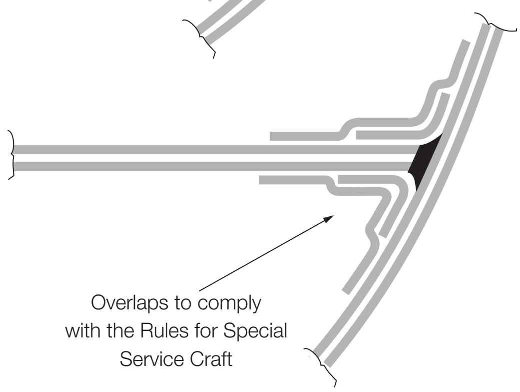
Single skin construction

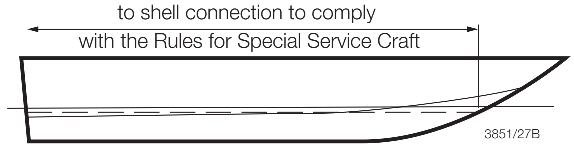




DETAIL DESIGN IMPROVEMENT







NOTES

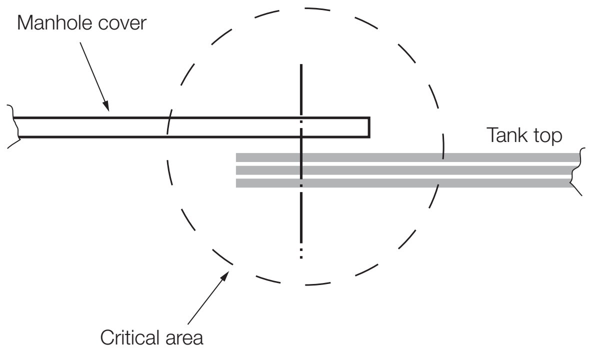
Failure Mechanism	Excess loads due to impact also hydrostatic pressure where the internal structure forms the boundary of an integral tank.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

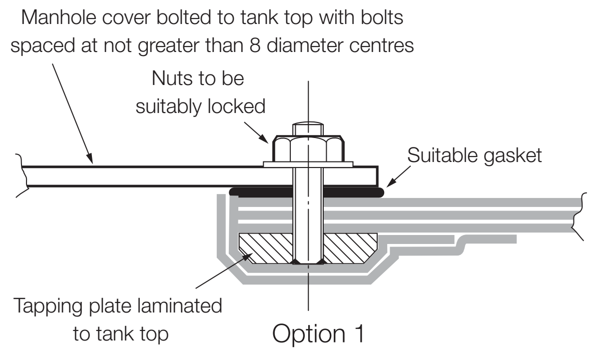
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	23

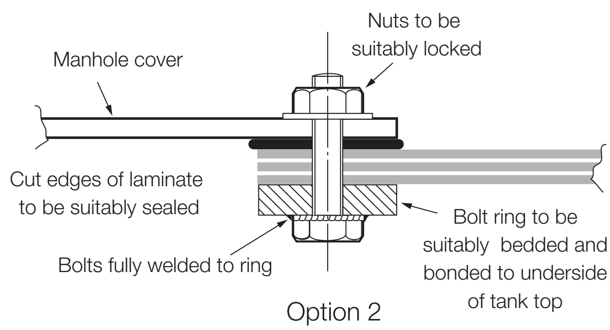
AREA:	Hull internal structure
ITEM:	Integral tanks access manholes

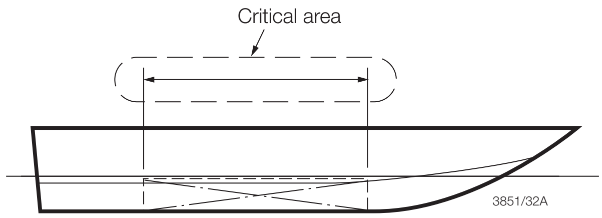
Lloyd's Register

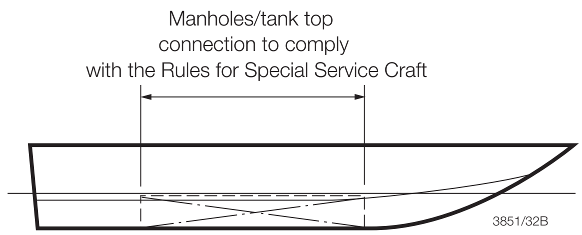
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT











NOTES

Failure Mechanism	Leakage under hydrostatic pressure.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	24

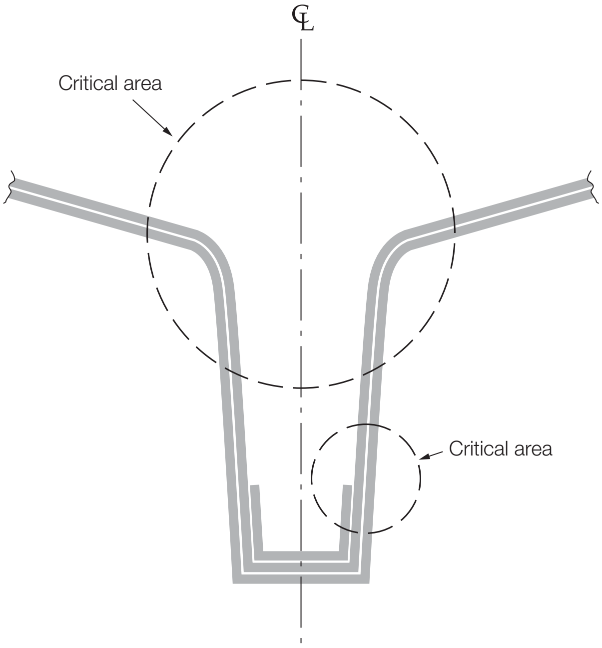
Detail Design Improvement for Composite Construction

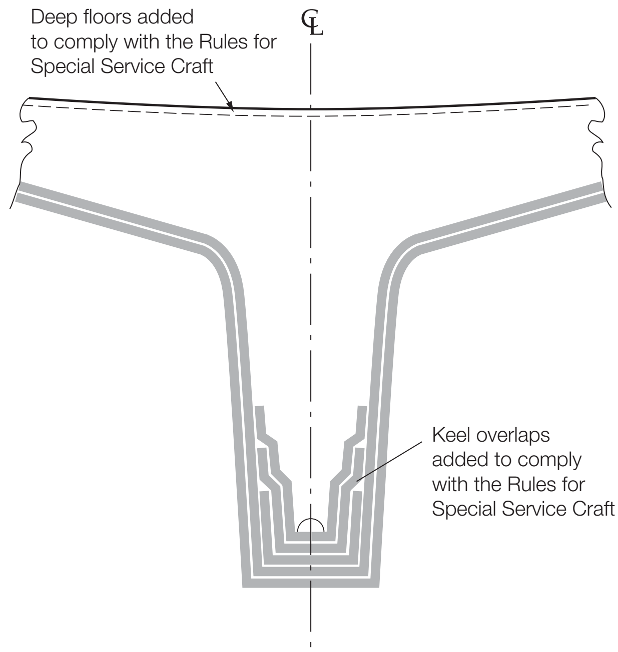
AREA: Skeg (open type)

ITEM: Skeg stiffening and reinforcement

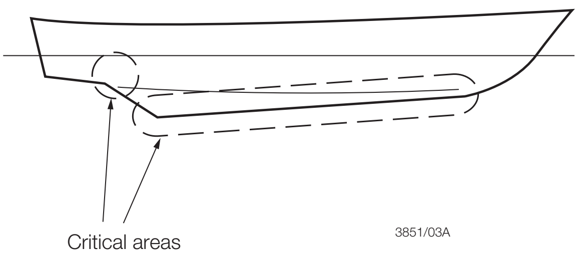
Lloyd's Register

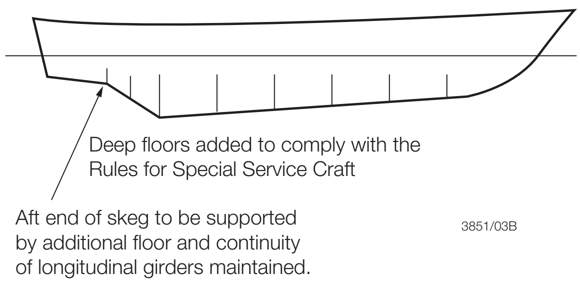
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





Note : Where the hull is moulded in two halves, the bottom shell laminate is to be reinstated across CL prior to additional reinforcements to comply with the Rule keel requirements.





NOTES

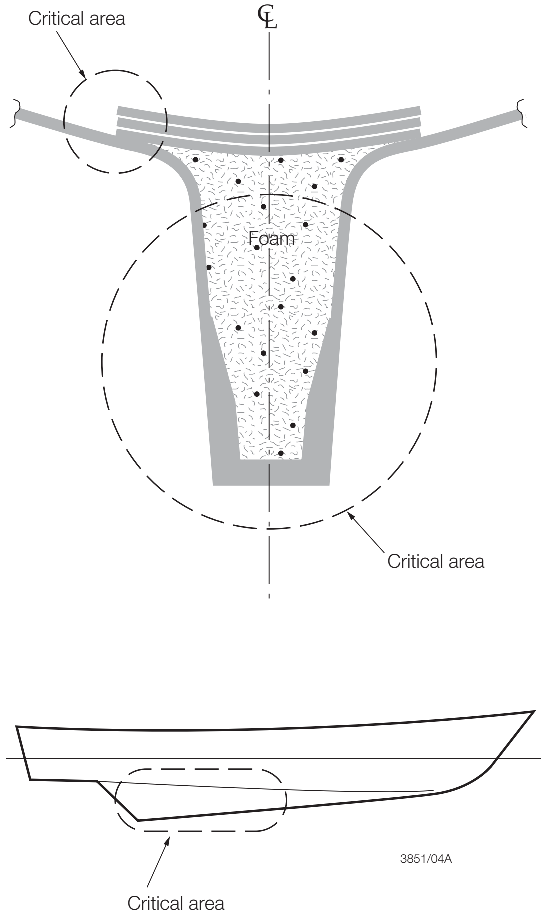
Failure Mechanism	Excess loads due to grounding, docking, slinging and hydrostatic pressure.
Building Tolerance	All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

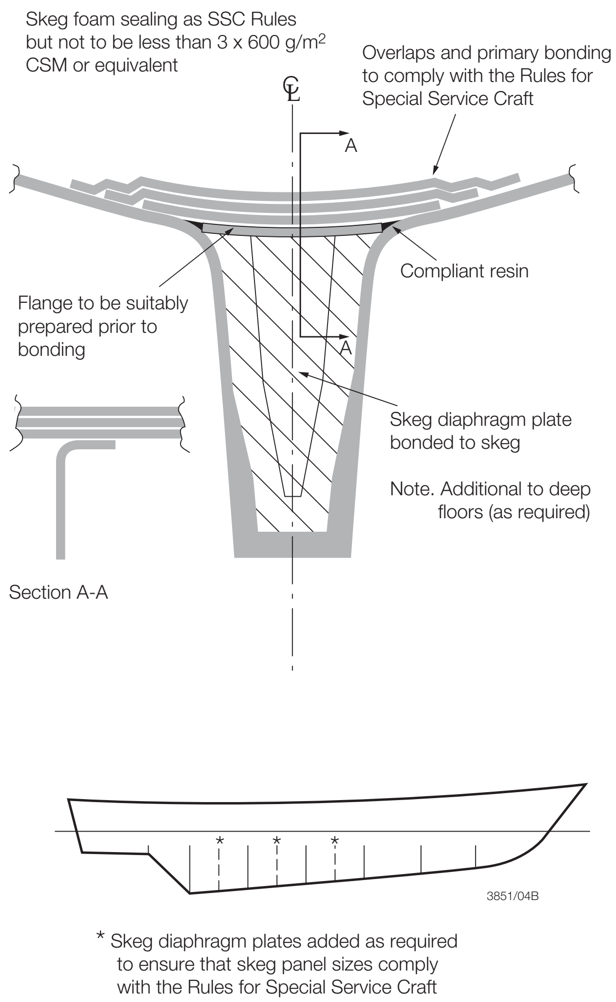
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	25

AREA:	Skeg (closed type)
ITEM:	Skeg diaphragm plates and sealing laminate

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Excess loads due to grounding, docking, slinging and hydrostatic pressure both externally and internally in the case of integral tanks.
Building Tolerance	To align with bottom framing. All FRP materials to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	26

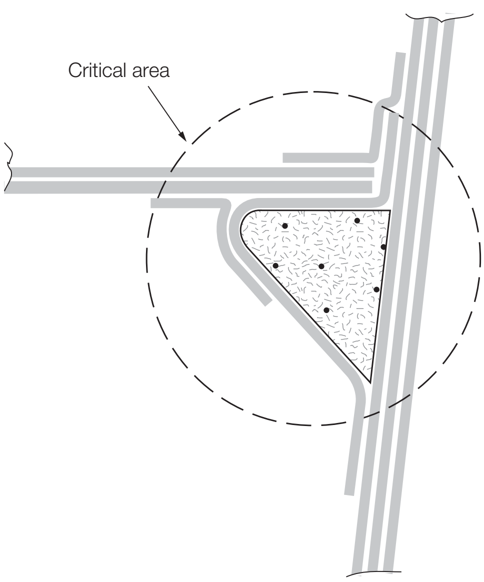
Detail Design Improvement for Composite Construction

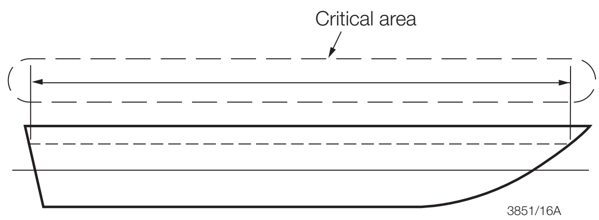
AREA: Deck structure

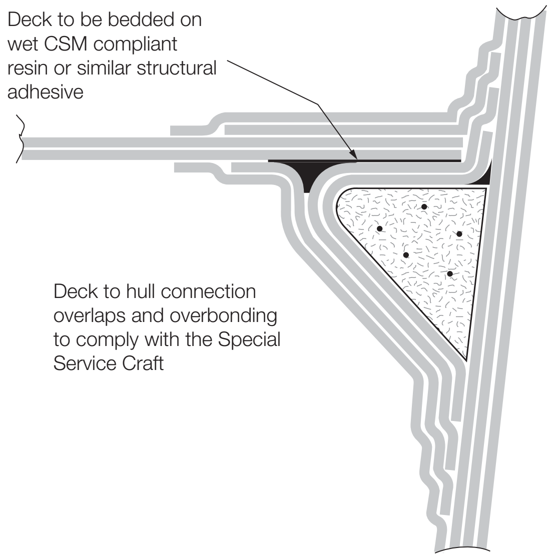
ITEM: Well deck, lower/sole deck to hull connection

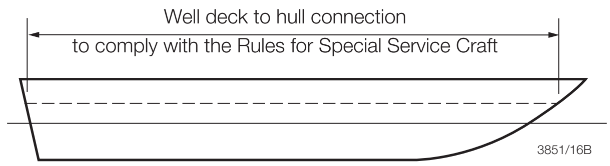
Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









NOTES

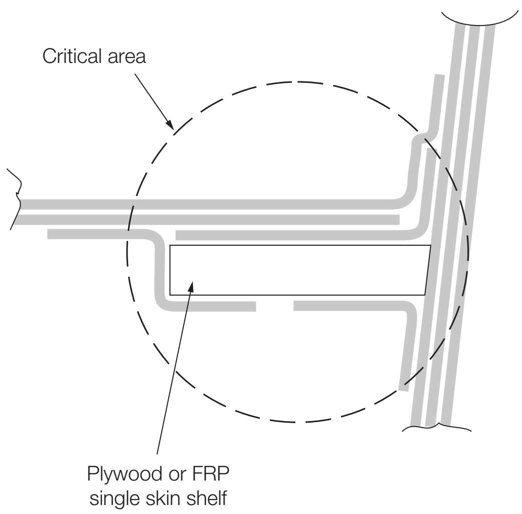
Failure Mechanism	Excess loads due to berthing and slinging.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

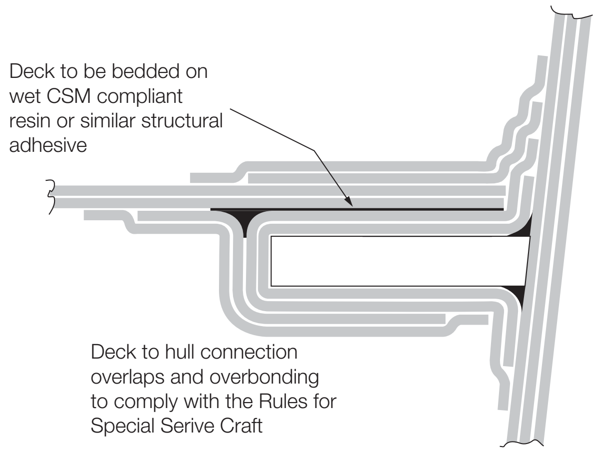
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	27

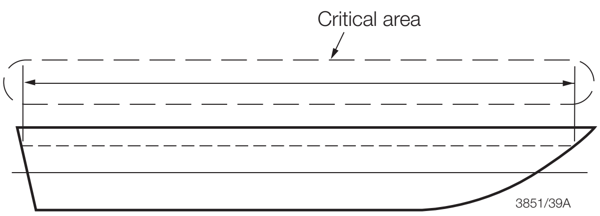
AREA: Deck structure

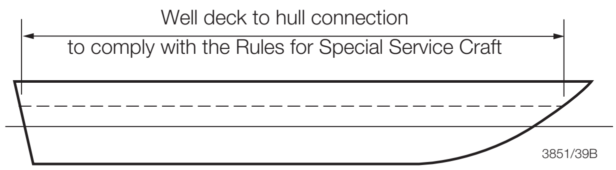
ITEM: Well deck, lower/sole deck to hull connection

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT









NOTES

Failure Mechanism	Excess loads due to berthing and slinging.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

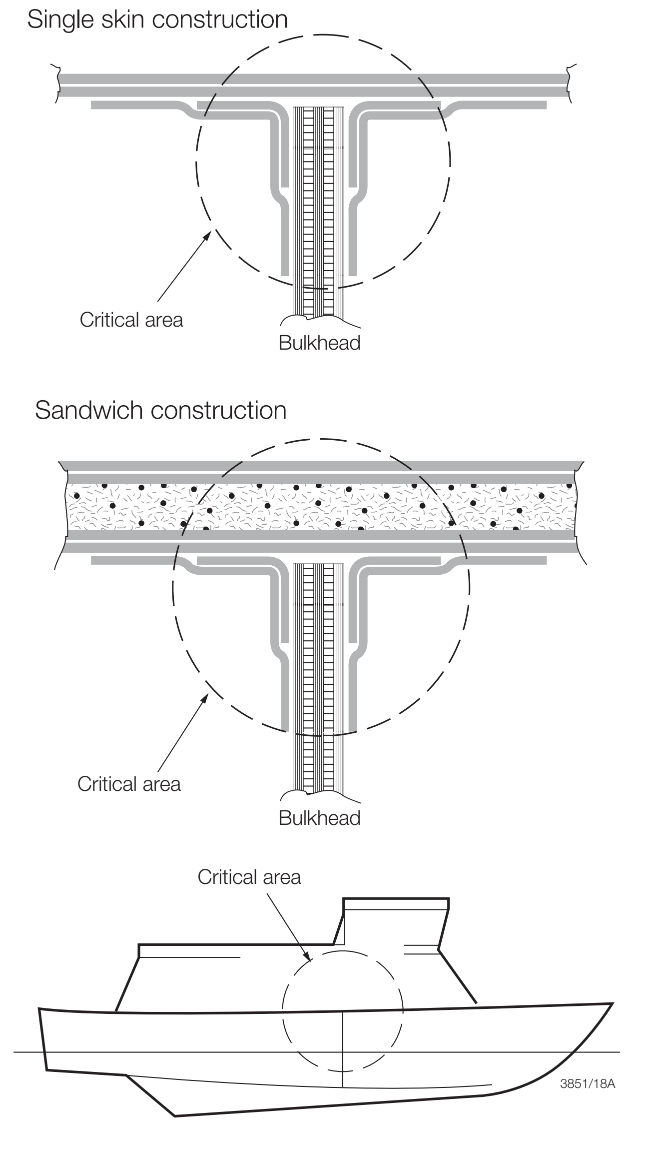
GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	28

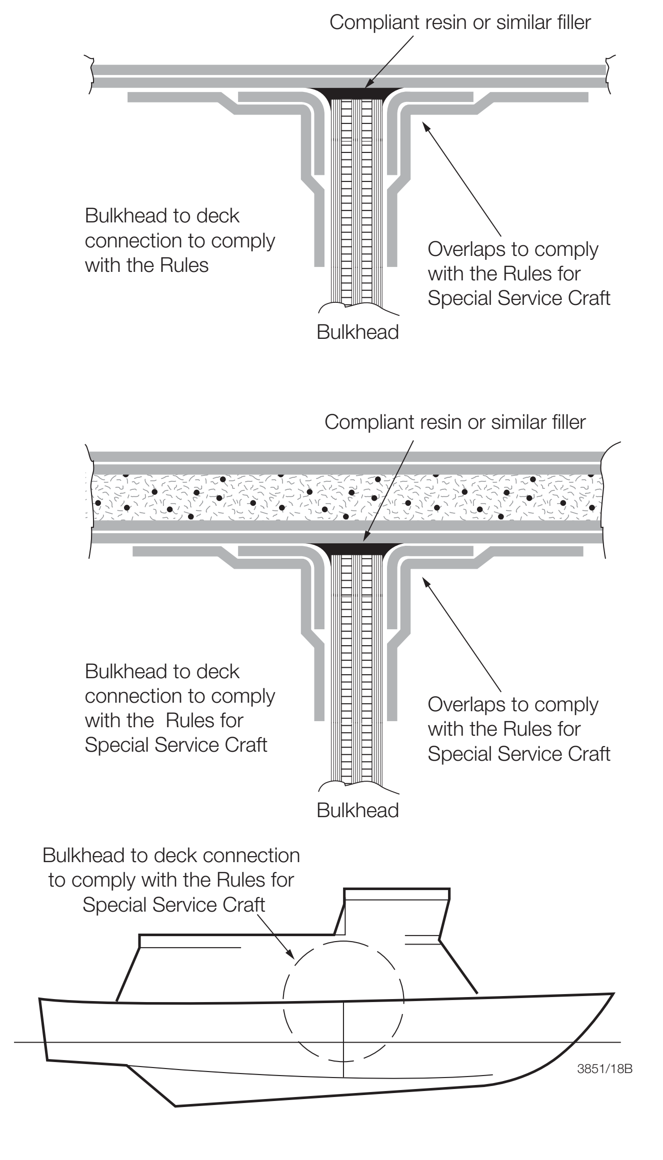
Detail Design Improvement for Composite Construction

AREA:	Deck
ITEM:	Bulkhead to deck connection

Lloyd's Register

CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Excess loads due to berthing, slinging and impact.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft. Alignment and fit to be good, all gaps to be filled.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP 5	GUIDANCE NOTES FOR DESIGN DETAILS COMPOSITE CONSTRUCTION	FIGURE 29

Detail Design Improvement for Composite Construction

Chapter 5

Section 2

AREA: Deck

ITEM: Deckhouse to deck connection

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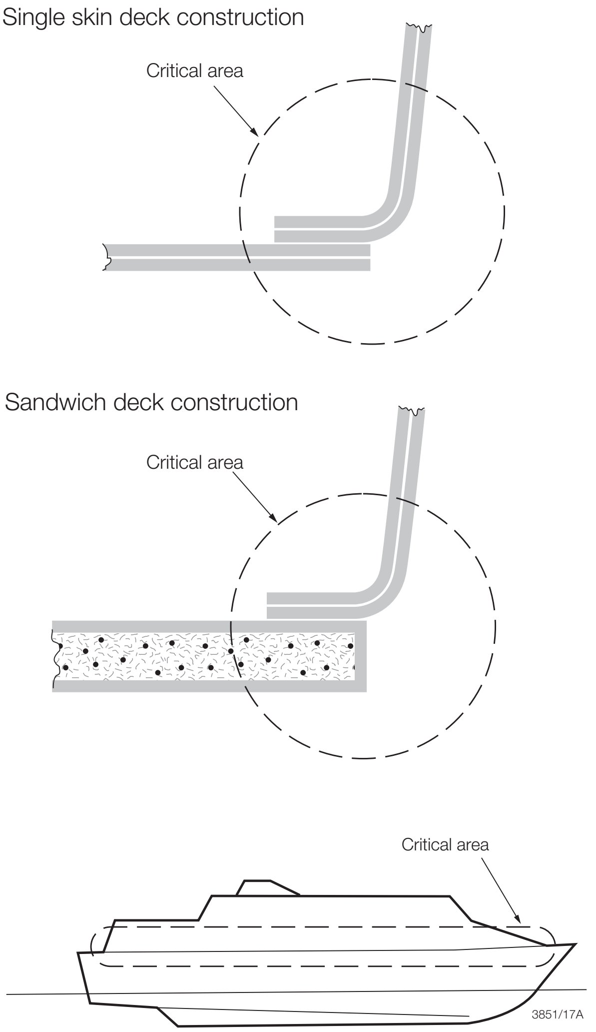
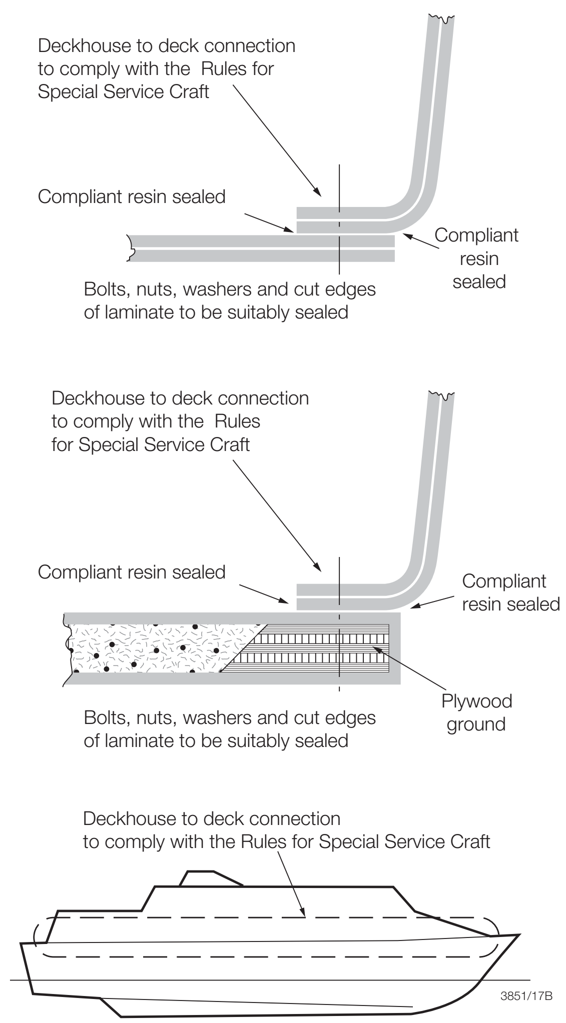
CRITICAL AREAS	DETAIL DESIGN IMPROVEMENT





NOTES

Failure Mechanism	Excess loads due to berthing, slinging, impact from green seas and other loads arising from heavy weather.
Building Tolerance	All FRP material to comply with the Rules for Special Service Craft.
Laminating Requirements	To be in accordance with Part 8 of the Rules for Special Service Craft.

GROUP	GUIDANCE NOTES FOR DESIGN DETAILS	FIGURE
5	COMPOSITE CONSTRUCTION	30

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