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REVIEW OF CURRENT PRACTICES OF FRACTURE REPAIR PROCEDURES FOR SHIP STRUCTURES

SHIP STRUCTURE COMMITTEE

2012

Ship Structure Committee

Ship Structure Sub-Committee

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REVIEW OF CURRENT PRACTICES OF FRACTURE REPAIR PROCEDURES FOR SHIP STRUCTURES

Over the past several decades, the shipbuilding industry has made significant advances in ship construction and repair in the areas of marine ship design, construction, personnel training, materials and equipment. In particular, inspection and fracture repair procedures have been developing rapidly in the marine industry with an aim to decrease costs and improve time effectiveness of inspections and repairs. These advances have helped make significant improvements in the safety of ships, people and the environment.

Industry experience with fractures and fracture repairs are reviewed and comprehensive, practical steel hull fracture repair guidance is provided. The results of this project consolidate existing repair references into one concise document, serve to update industry experts and contribute to a new repair guide that can assist directly with updates of industry standards such as the U.S. Coast Guard Navigation and Vessel Inspection Circular (NVIC) 7-68, entitled, "Notes on Inspection and Repair of Steel Hulls".

We thank the authors and Project Technical Committee for their dedication and research toward completing the objectives and tasks detailed throughout this paper and continuing the Ship Structure Committee's mission to enhance the safety of life at sea.

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16. Abstract

Fracture repair procedures have been developing rapidly in the marine industry with an aim to increase cost- and time-effectiveness. Current industry practice of evaluating and repairing fracture of seagoing vessels were investigated through in-house analysis and review of industry standards and recommendations by organizations such as IACS and TSCF.

During the remediation of a fracture, several factors need to be considered such as location, extent, and possible cause of fracture. A review of fracture reports and IACS documents was used to determine structural areas prone to fractures.

A generic scheme for classifying failures of structural components based on intended function and location has been proposed. This is to make recommendations on appropriate and timely corrective action for fracture repair.

Requirements and typical process of various fracture repair techniques were documented. A gap analysis between industry standards and USCG NVIC 7-68 was also carried out.

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CONVERSION FACTORS
(Approximate conversions to metric measures)

To convert from	to	Function	Value
LENGTH			
inches	meters	divide	39.3701
inches	millimeters	multiply by	25.4000
feet	meters	divide by	3.2808
VOLUME			
cubic feet	cubic meters	divide by	35.3149
cubic inches	cubic meters	divide by	61,024
SECTION MODULUS			
$inches^2$ $feet^2$	$centimeters^2$ $meters^2$	multiply by	1.9665
$inches^2$ $feet^2$	$centimeters^3$	multiply by	196.6448
$inches^4$	$centimeters^3$	multiply by	16.3871
MOMENT OF INERTIA			
$inches^2$ $feet^2$	$centimeters^2$ meters	divide by	1.6684
$inches^2$ $feet^2$	$centimeters^4$	multiply by	5993.73
$inches^4$	$centimeters^4$	multiply by	41.623
FORCE OR MASS			
long tons	tonne	multiply by	1.0160
long tons	kilograms	multiply by	1016.047
pounds	tonnes	divide by	2204.62
pounds	kilograms	divide by	2.2046
pounds	Newtons	multiply by	4.4482
PRESSURE OR STRESS			
$pounds/inch^2$	$Newtons/meter^2$ (Pascals)	multiply by	6894.757
kilo $pounds/inch^2$	mega $Newtons/meter^2$ (mega Pascals)	multiply by	6.8947
BENDING OR TORQUE			
foot tons	meter tons	divide by	3.2291
foot pounds	kilogram meters	divide by	7.23285
foot pounds	Newton meters	multiply by	1.35582
ENERGY			
foot pounds	Joules	multiply by	1.355826
STRESS INTENSITY			
kilo $pound/inch^2$ $inch^{1/2}$(ksi$\sqrt{in}$)	mega Newton $MNm^{3/2}$	multiply by	1.0998
J-INTEGRAL			
kilo pound/inch	$Joules/mm^2$	multiply by	0.1753
kilo pound/inch	kilo $Joules/m^2$	multiply by	175.3

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1 INTRODUCTION

The US Coast Guard (USCG) Navigation and Vessel Inspection Circular (NVIC) No. 7-68 "Notes on Inspection and Repair of Steel Hulls" has not been updated for more than 40 years. The technology of ship design and construction has significantly improved during the past four decades. As a result, a revision to the guidance and requirements stated in USCG NVIC 7-68 to reflect the repair methods practiced on the current commercial ship fleet is in order.

The USCG requested the Ship Structure Committee (SSC) to conduct a study to review industry experience of fractures and fracture repairs, and to develop a comprehensive and usable steel hull fracture repair guide that would eventually assist in the revision of NVIC 7-68.

SSC has contracted ABS to do this study. The Project Technical Committee (PTC) has agreed that this SSC project would include reviews of the ABS surveyor records for reported fractures and fracture repairs, current industry standards and practice of fracture repairs, guidance on classing criticality of structural failures, and fracture repair criteria.

1.1 USCG NVIC 7-68

The purpose of USCG NVIC 7-68 is to provide Coast Guard marine inspectors, vessel owners, and shipyards general information relating to good practice in the inspection and repair of steel-hulled vessels. This document was written in 1968 and provides general guidance on steel replacement-related repair work and welding.

The topics covered in NVIC 7-68 include the following:

I. Purpose

II. General (background of structure deterioration, defects and damage, and factors bearing on required repairs)

III. Notes on inspection (gauging, coatings, materials, etc)

IV. Notes on repairs

V. Welding (preparation, electrodes, procedures, etc)

VI. Riveting

VII. Other information sources

VIII. Monograph for percentage of wastage in steel plates

1.2 Development over the Past Four Decades

Over the past several decades, the industry has made significant advances in ship construction and repair in the areas of marine ship design, construction, personnel training, materials and equipment. These advances have not only improved the cost and time effectiveness of vessel construction and repair but, more importantly, helped ensure the safety of ships, people and the environment.

Marine ship design has improved over the years to make ship construction and repairs more cost-effective, and more reliable. For example, MARPOL 73/78 as amended required oil carriers to be fitted with double hulls or an alternative design to protect the environment when the outer hull is damaged. Similarly, high tensile steels are used in designs allowing for reductions in plate thickness. Use of aluminum alloy superstructures can provide increased passenger accommodation on the same draft or be used to lower the center of gravity and improve stability.

In addition to ship design, training for personnel involved in the construction process is imperative to ensure quality control. In most cases, both Flag Administrations and Classification Societies now have stricter process inspection and testing requirements.

Technology in ship design has also been developing at a fast pace. New computer applications allow ship designers and approvers to significantly improve analyses of vessel designs by incorporating dynamic-based criteria for the scantlings, structural arrangements and details of ship structures.

With these advances in ship construction and repair, the marine industry has demonstrated an improved level of safety. As shown in Fig. 1-1, the total number of total vessel losses dropped from 200 in 1980 to less than 75 in 2009.

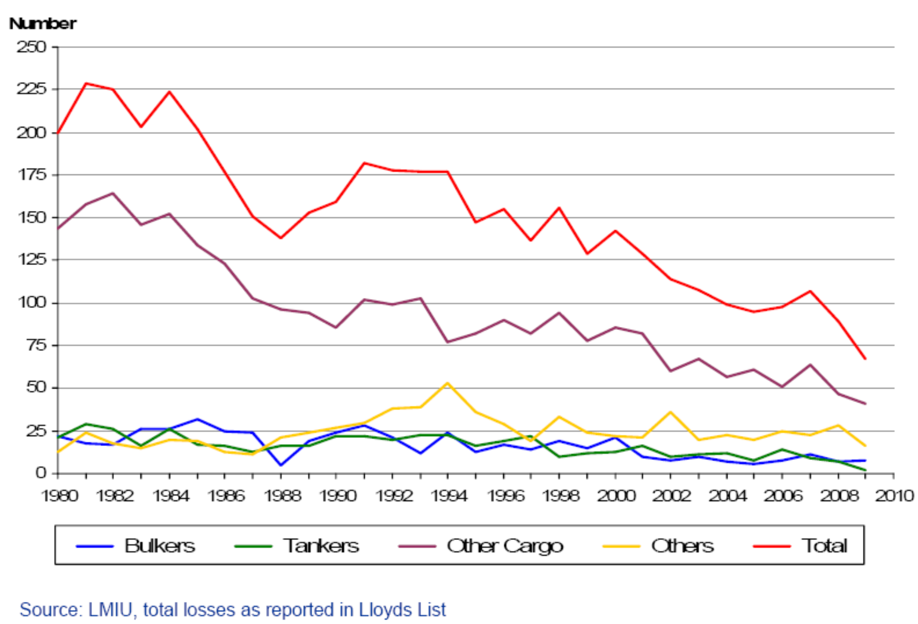


Figure 1-1 Number of total losses between 1980-2009 by main vessel types greater than 500 GT (IUMI 2009: Hull Casualty Statistics)

Even with these advances, structural fractures are still reported; however, some of these fractures can be attributed to operational and mechanical failures rather than design and construction failures. As shown in Figure 1-2, weather, grounding, fire/explosion, collision/contact and hull damage[1] are the main causes of vessel losses.

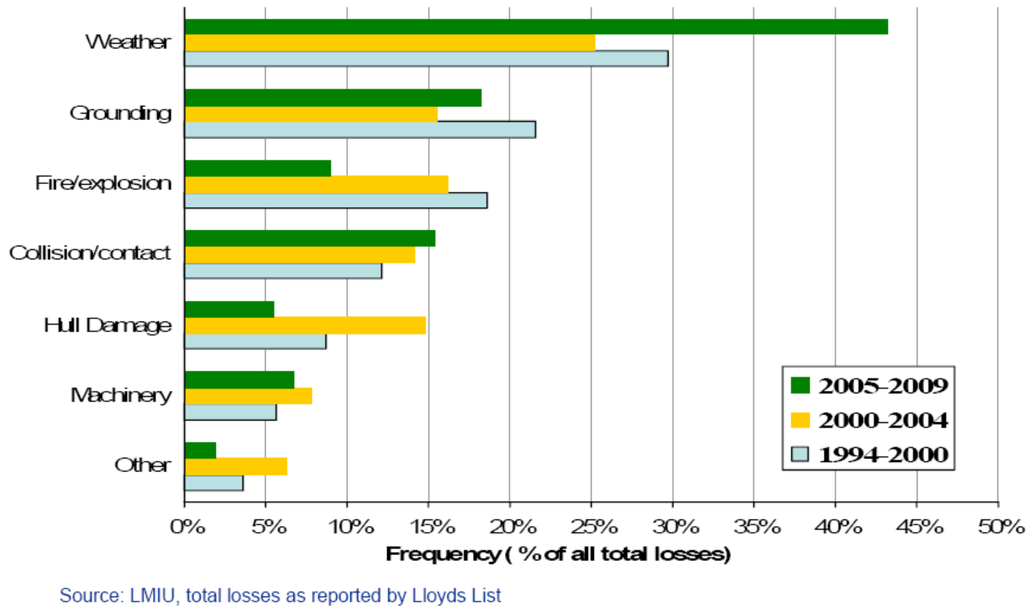


Figure 1-2 Number of total losses between 1980-2009 by cause for all vessel types greater than 500 GT (IUMI 2009: Hull Casualty Statistics)

It is important that information on ship structural design and construction are widely disseminated. It is also important that lessons learned from structural failures are used to update and improve requirements of the USCG, other Flag Administrations and Classification Societies for the design, construction and maintenance of ship hull structures. This should contribute to further reduction in structural failures.

[1] "Hull Damage" in chart includes loss of vessels due to fractures, buckling or other deformation, cracking or tearing, etc, by the Lloyds List. This category is referred to as "Hull Defect" in this report. See Table 3-1 in Chapter 3.

1.3 Scope of Work

This SSC project focuses on the marine industry practice of repairing fractures evaluating of the effect of a fracture on the structural integrity of the vessel.

It was agreed that the information or the deliverable of the project is to be applicable to seagoing steel vessels, including double hull oil carriers, container carriers, bulk carriers and general cargo vessels. However, it is generally applicable to barges, inland or Great Lakes vessels of similar structural design details.

The following six (6) tasks were proposed during the kick-off meeting.

Task 1	Repair Techniques
Task 2	Industry Experience with Fractures and Repairs
Task 3	Criticality of Affected Structures
Task 4	Fracture Criteria
Task 5	Selection of Repair Techniques
Task 6	Reporting and Project Management

Corrosion is not in the scope of work of this project. No attempt was made to address repairs for corrosion, riveting, or other topics covered in the NVIC 7-68. Numerous SSC reports on corrosion are available on the SSC website (www.shipstructure.org). Additional information and data on repair of corrosion damage is also available in the industry and applicable for NVIC 7-68 revision.

1.4 Organization of the Report

The report is organized slightly differently than the tasks list and is aligned to follow the contents of NVIC 7-68 that are relevant to fractures. The outcome of each task specified in Section 1.3 was gathered and laid out in the following sequence:

- Chapter 1– Background and introduction of this SSC project
- Chapter 2 – General guidance of fracture repairs that are currently applied in the industry. This chapter serves as the summary of the entire report and includes recommendations for steel hull repairs.
- Chapter 3 to 7 – Details and information that support the general guidance described in Chapter 2. The covered topics include:
    - technical background (Chapter 3),
    - industry experiences of fractures and fracture repairs (Chapter 4),
    - repair techniques (Chapter 7),

  - assigning criticality class of structural failures (Chapter 5), and
  - fracture threshold criteria (Chapter 6).
- Appendices A to E – Useful reference, including
  - material (Appendix A),
  - welding consumables (Appendix B),
  - industry experiences of fracture and fracture repair (Appendix C),
  - examples of fracture repair suggestions taken from IACS publications (Appendix D), and
  - a study on consequences of fractures (Appendix E)
- Attachments A to H – These documents complement this report.
  - Attachments A to B are copies of USCG documents that serve as easy reference.
  - Attachments D to G are the IACS recommendations for survey, assessment and repairs that represent the best industry practice.
  - Attachment H lists the typical terminology used by IACS members and can serve as a reference.

The following table indicates the contribution of each task to this report.

Table 1-1 Correlation between project tasks and chapters in report

Task	Chapter
Task 1 Repair Techniques	3, 7
Task 2 Industry Experience with Fractures and Repairs	4
Task 3 Criticality of Affected Structures	5
Task 4 Fracture Criteria	6
Task 5 Selection of Repair Techniques	2, 3, 4
Task 6 Reporting and Project Management	1 - 7

2 GENERAL GUIDANCE OF FRACTURE REPAIRS

During the determination of the type of fracture repair to be performed on a fracture found on a structural member, the Surveyor or inspector should be aware of factors which contribute to the decision-making process.

The chapter describes the flow of the process, along with the influencing aspects that could be included, and summarizes the application of the information detailed in Chapter 3 to 7 of this report.

2.1 General Principles

Only general principles can be stated for assessment and repair of fractures to steel hulls. It is impractical to provide, in advance, instructions to every single case of structural defects/damages because of the following facts:

- defects/damages vary from one case to another
- defect/damage may affect a variety of structural components, which are subjected to differing loads and operational condition, and
- consequences of defects/damages on safety and environments can be different.

2.2 General Guidance

There are three main stages in determining the remediation of a fracture: inspection of the fracture, evaluation of the fracture and consideration of repair options.

If the fracture is found during the inspection of the hull, the nature of the fracture and its location should be noted for evaluation purposes. These details may indicate the potential cause of the fracture and determine the criticality of the fracture.

At the evaluation phase, based on the information obtained during the inspection, the following are to be given proper consideration in order to determine the appropriate fracture repairs to be carried out:

- Potential consequences of a found fracture (or criticality of fracture)
- Causes and nature of fracture

Afterward, the team doing the examination would recommend the action to be taken; temporary repair or permanent repair. In cases where temporary repair is considered, the team should take into account the vessel's intended route and service and identify any potential risk.

Other important aspects that are to be considered are reporting and communications. These are, however, outside of the scope of the work of this study.

2.3 Location of Fractures

Fractures, if not caused by sudden large impact on the structure such as collision and grounding, are commonly found at stress concentration areas. Chapter 4 provides some illustrations of structural areas in commercial ships, namely oil carriers, bulk carriers and container carriers, where fractures due to high stress concentration have often been observed.

The location of a reported fracture may indicate the potential cause of the fracture and affects the accessibility of the fracture. Hence, these limit the type of repair work that can be performed in order to produce an efficient solution and prevent reoccurrence of fracture.

2.4 Criticality of Fractures

The method of assigning a criticality class to structural failures within certain structural members allows one to identify the importance of the member. This permits the more critical elements to be targeted ensuring that these elements have a lower probability of failure than less critical elements. The criticality is normally based on the effect to people, environment and serviceability, each of which can be affected differently by the different structural failure mechanisms.

Currently, the USCG defines three classes of structural failure in Critical Areas Inspection Plans (CAIP). Follow-up actions are dependent upon these classes. See Attachment B. In simplistic terms, Class 1 requires immediate repair, Class 2 permits postponed repair, and Class 3 requires no corrective action but the affected structure is to be inspected later.

However, the three classes of structural failure are developed for single hull oil carriers and classing a failure using this scheme may lead to an arguable conclusion. As part of this project, a generic scheme has been developed that is intended to be applied to assign criticality of fractures of various ship types in a consistent manner and to provide recommendations for appropriate and timely corrective action. In essence, this scheme uses three levels of criticality class; “High”, “Medium”, “Low” (see Figure 2-1).

- The “High” criticality class requires immediate repair.
- The “Medium” criticality class allows postponed repair.
- The “Low” criticality class requires monitoring but no repair.

The criticality classes “High”, “Medium”, “Low” take into account the intended purpose of a structural member and its impact to the safety of the vessel, life and environment. The types of recommendations in this newly developed scheme are similar to the action categories for Class 1, Class 2 and Class 3 in the USCG CAIP.

The steps are illustrated in Figure 2-1. Chapter 5 and Appendix E provide further details on assignment of criticality class of structural fractures.

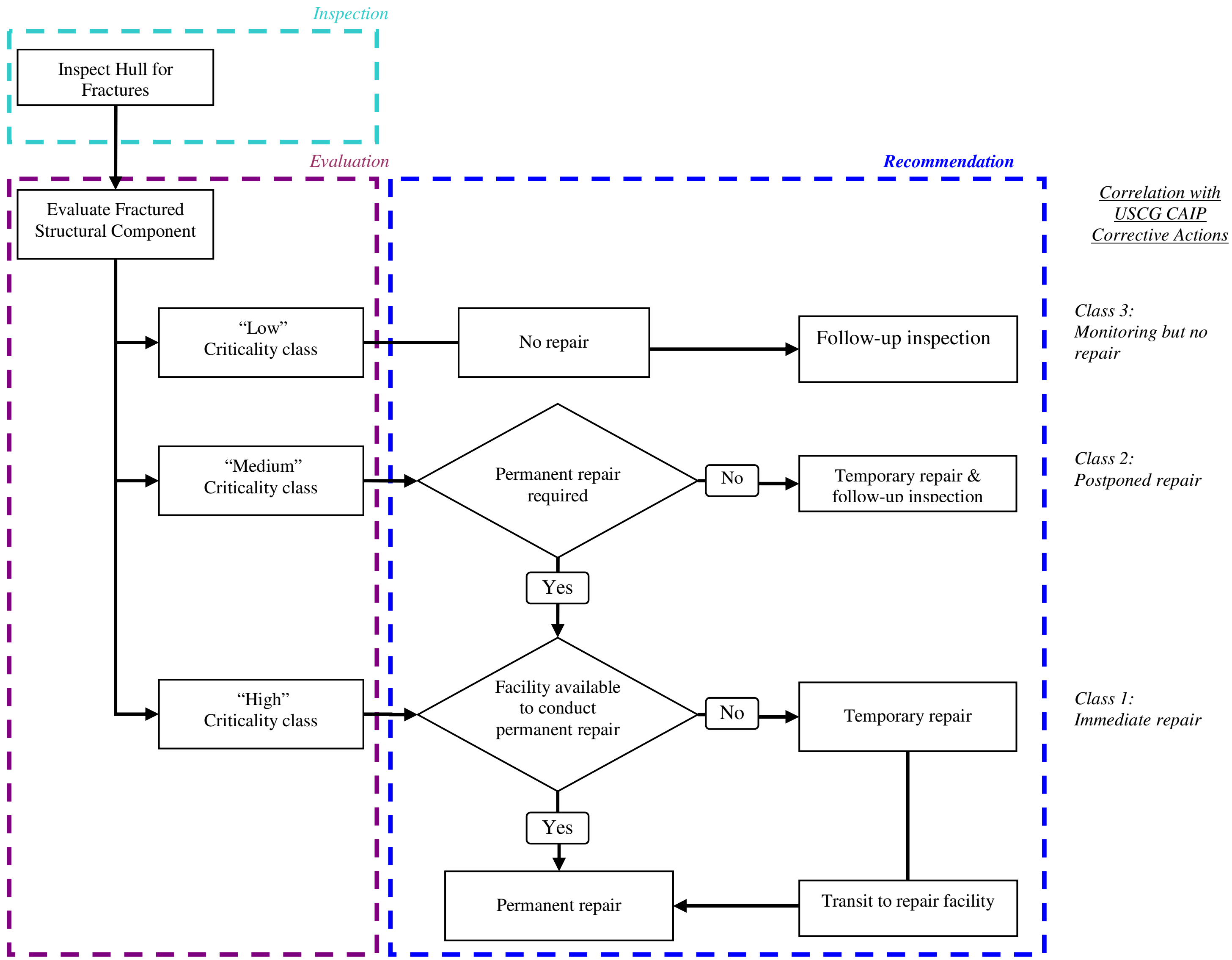


Figure 2-1 Major steps determination of criticality of structural component

2.5 Fracture Threshold Criteria

Currently in the marine industry, the relationship between the size of a fracture and its impact on the safety of the affected structure is often discussed. The extent of fracture may also determine the repair option that is adequate to restore the ideal condition of the member.

In Chapter 6, available fracture mechanics were reviewed to establish possible threshold criteria.

2.6 Fracture Repair Option

The type of repair technique to be performed as a fracture solution depends solely on the cause of the fracture and the necessity of immediate corrective action to restore the normal operation, or even the strength of the vessel. The ultimate goal of a fracture repair is to eliminate the cause of the fracture. However, there might be restrictions in fracture repair options depending on the circumstances of when and where the fracture was found.

"Crop and renewal" and "gouge and reweld" appear to be the most commonly used types of fracture repair. See the statistical studies in Appendix C. "Insert" is also commonly performed and is sometimes considered as "crop and renewal" as it can be a full or partial replacement of plate/panel of a structural section.

In some cases, the repair work may not address the underlying cause of the fracture and will eventually result in the same fracture. The Inspector/Surveyor should also be aware that strengthening of a member through design modification may shift the stress concentration to a nearby member which can cause a new fracture.

Chapter 7 has details of fracture repairs that are currently being practiced in the industry. Repair work can be permanent or temporary. The former is carried out in order to comply with Classification or Flag Administration requirements. The latter is generally performed when permanent repair cannot be carried out at the time of inspection due to lack of appropriate facilities or skills. Repairs that are generally considered to be temporary include cement patching, doubler plating and the application of drill stops. For these types of repairs, the Flag Administration and Classification Society must be informed and permission is generally required prior to commencement of work.

IACS has published various publications summarizing the potential causes of structural failure and the associated recommended repairs, often permanent repairs, which will likely prevent the same problem from recurring. See Attachments C - G and examples in Appendix D.

Following are a few notes of guidance on hull repairs. Reference has been drawn from ABS and IACS publications.

- There is no need to recommend the renewal of an entire plate if only part of it is damaged. However, the owner may elect to do so anyway.

- Individual small fractures in plates may usually be repaired by veeing-out and rewelding if the fracture is a simple one. If the fracture consists of several branches in one plate or is of considerable length, say more than a third of the plate width, the plate should preferably be renewed.[2]

- Whenever possible, the origin of the failure should be sought (such as by locating the point where the fracture-surface chevrons point to, or come from).

2.7 Design Modification as Permanent Repair

Reinforcement or design modifications may be done in order to soften a stress-concentration "hard spot" or to remove a change-of-section "notch". Design modification may be the best repair to eliminate the cause of the fracture. However, this requires information on the cause of the fracture and is location-specific.

Partial renewal is permitted where the remaining portion of the structure is satisfactory and it can be accepted as a permanent repair. However, partial renewal is not recommended if plane angles or other shapes (rolled bars of constant cross section) are used for longitudinals, stiffeners or framing. The reason for this is the difficulty in obtaining consistent edge preparation of the flame cut remaining section to weld the renewal section to. If partial renewal is to be performed, fabricated or built-up structural sections (I-beams, T-sections, etc.) can be used where the web and flange were originally welded together.

[2] IACS Rec. 47 Part B Table 6.8 stated that welding repairs for fractures are limited to linear and not branched fracture with maximum 500mm in length.

3 TECHNICAL BACKGROUND

Technical background relating to the qualification of personnel carrying out the repair work and material requirements for replaced metal are among subjects briefly described in this chapter.

3.1 Terminologies

In Table 3-1, the definition for several survey terms specified by IACS and USCG are listed, along with the source of publications.

Table 3-1 IACS and USCG selected definitions of survey terms

	IACS		USCG	
	Definition	**Ref.**	**Definition**	**Ref.**
Crack	A fracture type discontinuity without complete separation characterized by a sharp tip and high ratio of length and width to opening displacement	Rec. 82 (3)	Originate in structural discontinuities	NVIC 7-68 IV(A) (3)
Hull Damage	Depends on the characteristic or cause. For example, cavitation damage, collision damage, contact damage, cumulative damage and erosion damage.	Rec. 82 (3)	Such as caused by grounding, collision, the employment of the vessel, etc	NVIC 7-68 II(A) (3)
Hull Defect	Includes weld defects, buckling and fractures	Rec. 96	Fracture, buckling or other deformation, cracking or tearing, weakening or failure of fastenings.	NVIC 7-68 II(A) (2)
Fracture	Propagation of a crack through the thickness of a material	Rec. 82 (3)	Start in localized, highly stressed areas. (start in a notch or sharp angle)	NVIC 7-68 IV(A) (1)

3.2 USCG, Class and Owner

A damage survey is usually made jointly with the Owner's representative, Underwriter's Surveyor, Repairer, the Classification Surveyor and a representative of the Flag Administration. Usually, the procedure is as follows: The damage is examined by the examining team and then the Class Surveyor makes recommendations as to the extent of repairs that will be required to retain Classification. The Administration Inspector may be satisfied with this or may add items, as will the Owner if the Owners feels entitled to more under the insurance coverage. The Underwriter’s Surveyor may then advise the Owner as to which items the Underwriter Surveyor thinks are or are not attributable to the alleged cause and which repairs are considered reasonable and necessary to place the vessel back into an equivalent condition as before the damage incident. The Owner then reviews these positions and places the work order with the Repairer, as deemed necessary.

The Classification Surveyor and the Flag Administration usually take the lead role in suggesting the appropriate action to avoid loss of Class. This is also to ensure conformance with the insurance policy and, in most circumstances, Administration regulations. Classification Societies may have requirements on documentation that should be maintained onboard for the lifetime of the vessel. For example, ABS rules state that survey report files and supporting documents should be kept on Enhanced Survey Program (ESP) [3] vessels. These documents consist of:

- Reports of structural surveys
- Condition evaluation report
- Thickness measurement reports
- Survey plan
- Main structural plans of cargo holds, cargo and ballast tank
- Previous repair history
- Cargo and ballast history
- Extent of use of inert gas plant and tank cleaning procedures
- Owners inspection report

Expanded Survey (ESDC)[4] vessels require only survey and thickness measurement reports to be maintained onboard for the lifetime of the vessels. In some cases, the Classification Society may be the only entity with access to additional structural drawings, historical information of vessel's structural conditions (survey record), and needed knowledge about repairs and the capabilities of the Repairer.

The Flag Administration and Classification Surveyor often recommend only the minimum necessary repairs to place the vessel back in compliance with Class. This however is not the same as putting the vessel back into the same condition as prior to a casualty.

3.3 Repair Plan

The Classification Society and/or Flag Administration Inspector often reviews and approves a detailed repair plan indicating the repair procedure prior to commencement of the work.

Elements that may be included in the repair plan are as follow:

1. Condition of the vessel
   Generally, the fractured area should be in compression. Whether to ensure a hog or a sag condition depends on the fracture location and orientation.

2. Repair guidelines

[3] ABS notation assigned to seagoing self-propelled oil carriers including combination carriers, bulk carriers and chemical carriers. See ABS *Rules for Building and Classing Steel Vessels*, 7-1-1/1.7 for detailed descriptions of ESP vessels.

[4] ABS notation assigned to general dry cargo vessel. See ABS *Rules for Building and Classing Steel Vessels*, 7-1-1/1.9 and 3.33 for detailed descriptions of ESDC vessels

Generally, welding and repairs should be in accordance with applicable Flag Administration regulations and policy guidance, Class Rules, IACS Recommendation 47 Shipbuilding and Repair Quality Standard Part B, applicable IACS Guidelines for Surveys, Assessment and Repair of Hull Structure for the particular vessel type, and any instructions received from Class and Flag Administrations technical offices.

3. Types of repair
    - Drill stopping the end of the fracture
      Among the factors that need to be considered is the location of the end of the fracture.

    - Threshold for crop and renewed versus gouge and reweld or re-design
      This will generally be left up to the Surveyor's discretion but could also be affected by the size of the damaged area, as there are limitations on size of cofferdams. Also, the Surveyor should review the vessel's previous repair history, as applicable, checking for similar fractures or multiple in-line transverse fractures repaired in the past.

    - Welding sequence
      Where applicable, the repair plan should detail the sequence of the repair welding, using good marine practice

    - Backing bar
      For repairs made afloat on the underwater body where the procedure used a backing bar, Class and/or Flag Administration policy generally does not accept leaving the backing bar in place for permanent repairs.

    - Post-repair examination
      The repair proposal should indicate the method that will be used to examine the exterior weld.

4. Nondestructive Testing (NDT)
    - Pre-repair
      Should consist of ultrasonic test (UT) and either liquid penetrant test (PT) or dye penetrant test for surface inspection to verify area clean-up, scale and rust removal, etc. Ends of fractures are to be located and marked. Examining similar/identical structural locations (port and starboard sides) may be required to determine the root cause.

    - During-repair
      After gouging, conduct PT or dye penetrant to confirm fracture removed. In addition, some one-sided weld procedures call for NDT using PT of the root pass.

    - Post-repair
      Post repair NDT is applicable for all types of repair. The NDT methods depend upon the type of ship, location of repairs, repair technique performed and quality control methods used.

Working conditions such as adequate accessibility, safety watch and equipment, tank preparation and ventilation are to be evaluated in order to facilitate sound repairs.

3.4 Material of Steel

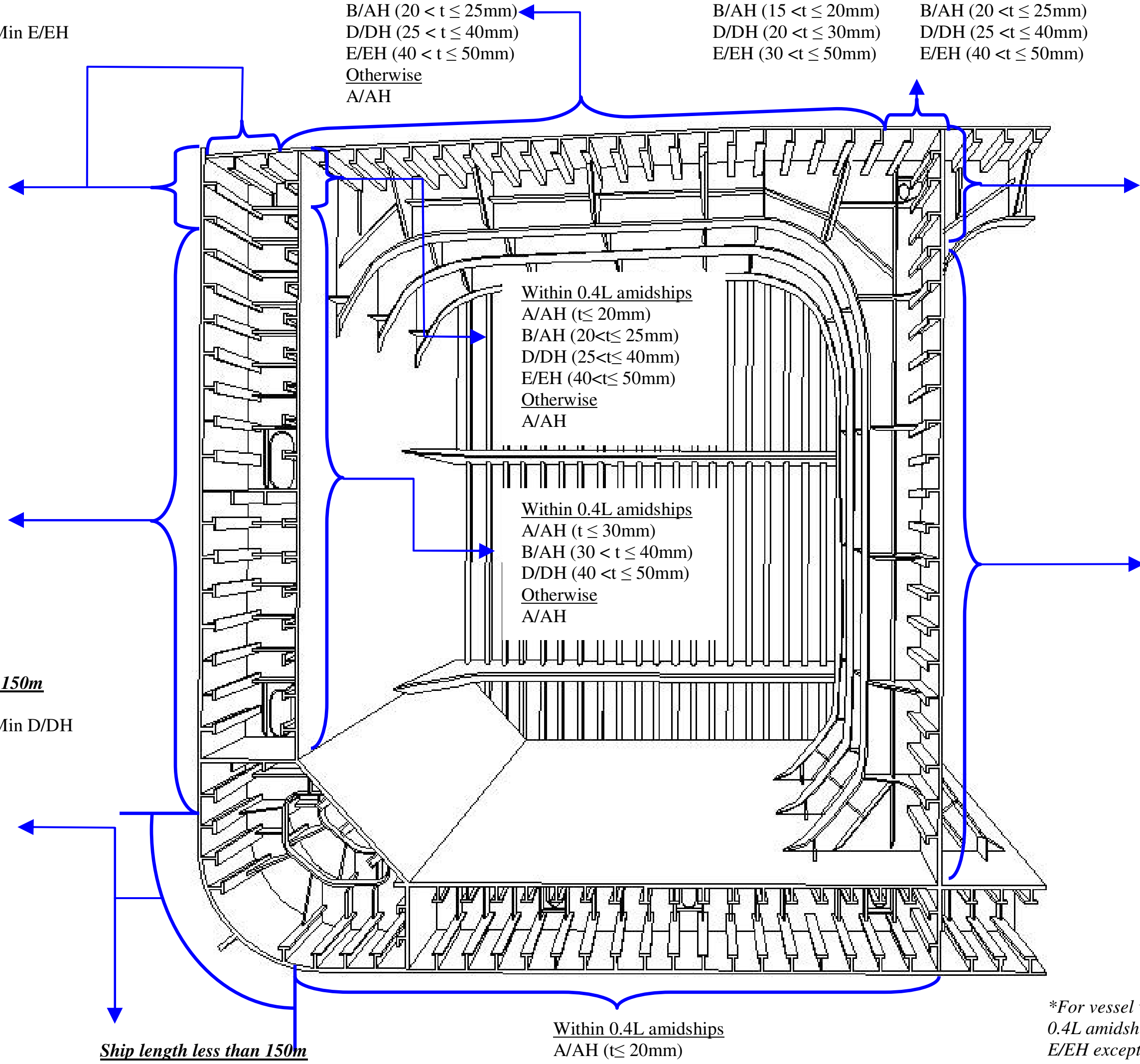
On all steel repairs, particularly extensive ones, the renewed material and scantlings need to be verified before work. This is especially important when welding is performed.

Replacement material is required to be of the same or higher grade as the original approved material. Materials of recognized national or international standards may be accepted by the Flag Administration and Classification Societies if the grade of the material is proved to be equivalent to corresponding requirements. Assessment of equivalency between material grades should include at least the following aspects:

- Heat treatment/delivery condition
- Chemical composition
- Mechanical properties
- Tolerances

IACS has tabulated the properties of various grades of steel in several documents. These tables are enclosed in Appendix A. Depending on the type and location of the structure on a vessel, the minimum required material grades may differ. Hence, the renewal material is to be verified to ensure it satisfies these minimum grades before commencement of repair. These requirements are also summarized in figure form as shown in Figure 3-1 to Figure 3-3 for illustration purpose

The replacement material specifications and extent of renewal must be clearly stated in the survey report. In cases where the original drawings are not available, scantling measurements on the opposite side of the ship or the damaged material itself are acceptable if the material is known. If steel of the desired size or grade is not available, the repair yard may be able to use an acceptable alternate. Generally, the characteristics of the alternative arrangement should match or exceed that of the originally proposed scheme and be approved by Flag Administration and Class Surveyor.



**For vessel with length exceeding 250m, within 0.4L amidship, minimum steel grade is to be E/EH except for bilge strake, D/DH. Single strakes are to have breadths not less than 800 + 5L (mm), need not be greater than 1800mm, unless limited by the geometry of the ship's design.*

Figure 3-1 Typical material grades for oil carrier structures

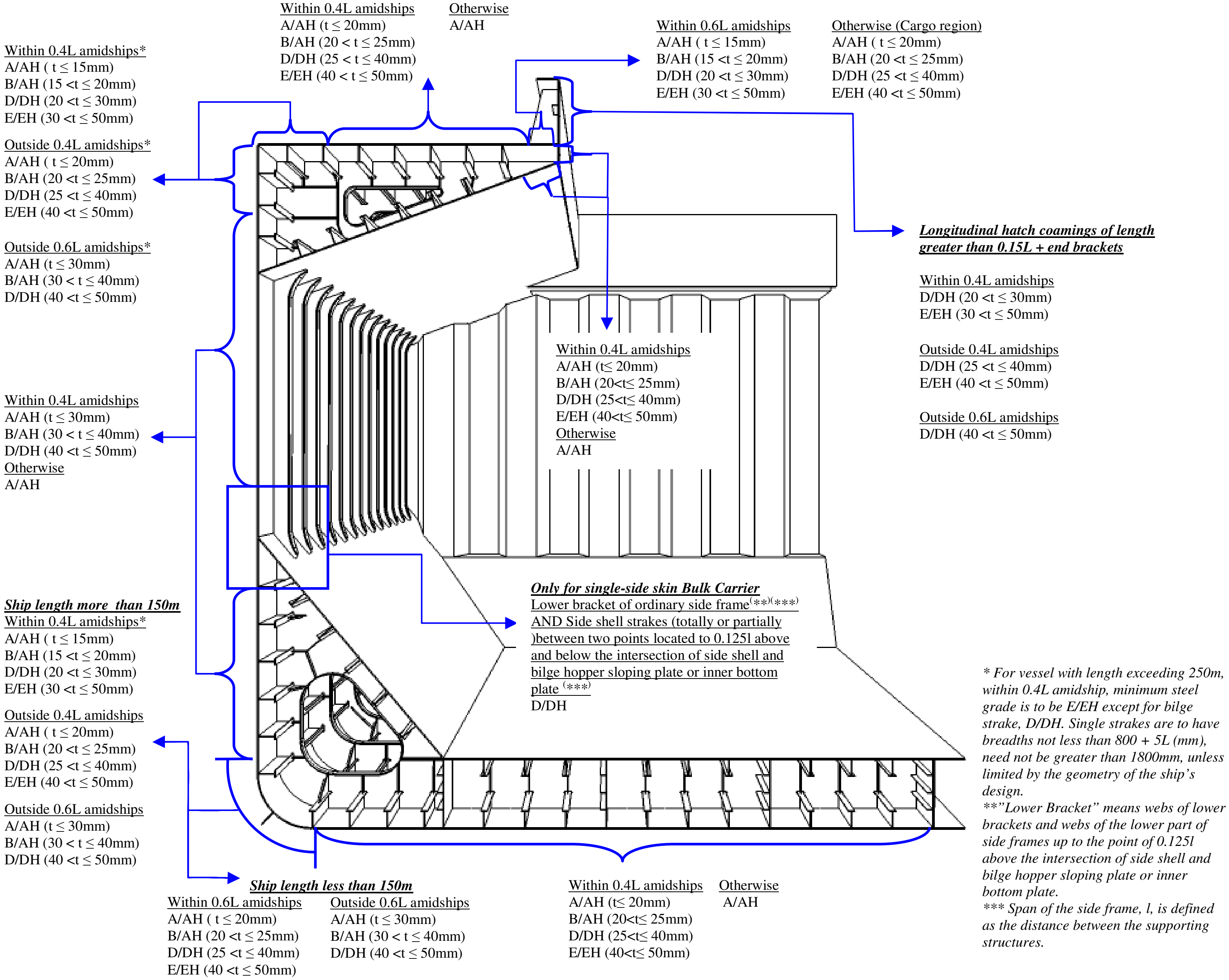


Figure 3-2 Typical material grades for bulk carrier structures

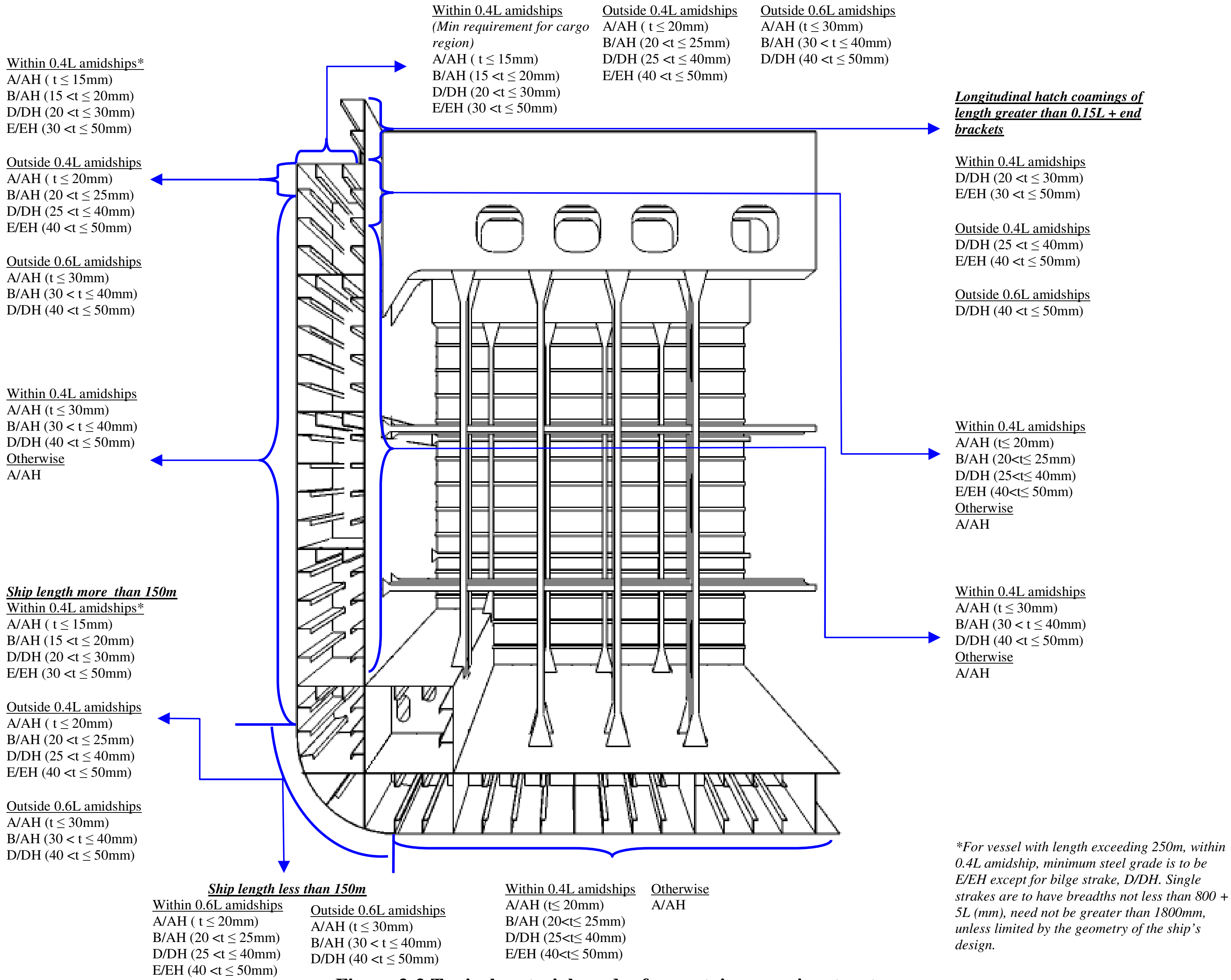


Figure 3-3 Typical material grades for container carrier structures

It is to be noted that the minimum material grades for ships with length more than 150m and having a single strength deck are generally to be B/AH for structures listed below:

- Longitudinal strength members of strength deck plating (within 0.4L amidships)
- Continuous longitudinal strength members above strength deck (within 0.4L amidships)
- Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck (within cargo region)

As a general guidance, IACS provides a list of acceptable welding consumables for various hull structural steel grades (see Appendix B). This table may be used as reference while deciding on filler metal for specific welding repair work.

Specific types of repair work may have limitations on the type of electrodes used. For example, while carrying out underwater welding, low-hydrogen electrodes are to be used if there is water backing.[P10]

3.5 Nondestructive Testing (NDT)

For determining the extent and method of NDT, the following aspects should be taken into account:

- Type of ship
- Location of repair (critical location based on Classification Societies' requirements)
- Welding procedures used (manual, semi-automatic, automatic)
- Quality control methods used
- Shipyard capability

The type of testing method for detecting weld surface imperfections is dependent on the weld joint type. IACS has a table describing the appropriate NDT method for different types of joints. This is applicable to butt welds with full penetration, tee, corner and cruciform joints with or without full penetration and fillet welds.

While inspecting a welded joint, Classification Societies generally recognize the test methods listed below:

- Radiography (RT)
- Ultrasonic (UT)
- Magnetic particle, (MT)
- Liquid penetrant (PT)

Similarly, as stated in the ABS *Guide for Nondestructive Inspection of Hull Welds* 2002, RT and UT are mainly used for internal inspection while MT or PT can mainly be carried out during surface inspection.

Table 3-2 Applicable NDT methods for testing of weld joints [P19]

WELD JOINT	PARENT MATERIAL THICKNESS	APPLICABLE TESTING METHODS
Butt welds with full penetration	Thickness ≤ 10 mm	VT, PT, MT, RT
	Thickness > 10 mm	VT, PT, MT, UT, RT
Tee joints, corner joints and cruciform joints with full penetration	Thickness ≤ 10 mm	VT, PT, MT
	Thickness > 10 mm	VT, PT, MT, UT
Tee joints, corner joints and cruciform joints without full penetration and fillet welds	All	VT, PT, MT, UT[1]
VT = Visual Testing, PT = Liquid Penetration Testing, MT = Magnetic Particle Testing, UT = Ultrasonic Testing, RT = Radiographic Testing		

Note: 1. UT can be used to monitor the extent of penetration in tee, corner and cruciform joints.

In IACS Rec. No. 20, each type of NDT method is described. Details such as preparation of weld surface, control of temperature and limitation of the methods are included. In addition, acceptance criteria after the NDT are specified for each method.

3.6 Qualification of Welders and NDT Personnel

Repair work and NDT are to be performed by personnel with the capability to provide adequate quality in accordance with relevant standards and requirements. The information included in this subchapter is normally verified while planning or executing a repair plan.

3.6.1 Welders

On vessels maintained in Class, welders are to be qualified in accordance with the Classification Society's requirements or recognized national or international standard, e.g., EN281, ISO 9606, ASME Section IX, ANSI/AWS D1.1. Any other standards are to be evaluated by the Classification Society. Repair yards and workshops should maintain records of welder's qualifications and, when required, furnish valid approved certificates. [P10]

Welding operators using fully mechanized or fully automatic processes generally need not pass approval testing, provided that production welds made by the operators are of the required quality. However, operators are to receive adequate training in setting or programming and operating the equipment. Records of training and production test results shall be maintained on individual operators' files and records, and be made available to the Classification Society and/or Flag Administration Inspector (USCG) for inspection when requested. [P10]

3.6.2 NDT Operators

Personnel performing nondestructive examination are to be certified to a recognized international or national qualification scheme. There are three levels of qualification.

IACS requires operators to have a grade equivalent to Level II qualification of ISO 9712, SNT-TC-1A, EN 473 or ASNT Central Certification Program (ACCP). Operators with Level I qualification may perform the test under the supervision of personnel with Level II or III qualification. [P19]

Personnel responsible for the preparation and approval of NDT procedures should be qualified according to a nationally recognized scheme with a grade equivalent to Level III qualification of ISO 9712, SNT – TC – 1A, EN 473 or ASNT Central Certification Program (ACCP). [P19]

The roles of each level are described in the ABS *Guide for Nondestructive Inspection of Hull Welds,* 2002, and as detailed below.

NDT Level I

An individual certified to NDT Level I may be authorized to:

- Set up equipment
- Carry out NDT operations in accordance with written instructions under the supervision of Level II or III personnel
- Perform the tests
- Record condition and date of the tests
- Classify, with prior written approval of a Level III, the results in accordance with documented criteria, and report the results.

An individual certified to Level I is not to be responsible for the choice of the test method or technique to be used.

NDT Level II

An individual certified to NDT Level II may be authorized to perform and direct NDT in accordance with established or recognized procedures. This may include:

- Defining the limitations of application of the test method for which the Level II individual is qualified
- Translating NDT codes, standards, specifications and procedures into practical testing instructions adapted to the actual working conditions
- Setting up and verifying equipment settings
- Performing and supervising tests

- Interpreting and evaluating results according to applicable codes, standards and specifications
- Preparing NDT instructions
- Carrying out or supervising all Level I duties
- Training or guiding personnel below Level II
- Organizing and reporting results of NDT

NDT Level III

An individual certified to NDT Level III may be authorized to direct any operation in the NDT methods for which he is certified. This may include:

- Assuming full responsibility for an NDT facility and staff
- Establishing and validating techniques and procedures
- Interpreting codes, standards, specifications and procedures
- Designating the particular test methods, techniques and procedures to be used for specific NDT work
- Interpreting and evaluating results in terms of existing codes, standards, and specifications
- Managing qualification examinations, if authorized for this task by the certification body
- Carrying out or supervising all Level I and Level II duties

An individual certified to Level III shall have:

i) sufficient practical background in applicable materials, fabrication and product technology to select methods and establish techniques and to assist in establishing acceptance criteria where none are otherwise available

ii) a general familiarity with other NDT methods

iii) the ability to train or guide personnel below Level III

Records of operators and their current certificates are to be kept and made available whenever requested by the Class Surveyor[P10] or Flag Administration Inspector (USCG).

4 ABS AND INDUSTRY EXPERIENCES WITH FRACTURES

Fractures are most likely to occur in zones of high stress concentrations. A study of ABS survey records was conducted to analyze the occurrence of fractures on ABS-classed vessels from information stored in ABS Survey Manager. This data was gathered with the intention of combining it with other similar data from IACS and MCA Consultants, Inc to help draw conclusions and identify problem areas within certain vessel types. The statistical data presented in Appendix C of this report is partly derived from the ABS Survey Manager library and covers reports for a limited time period of eight years.

While completing the statistical analysis, it was determined that the level of detail contained in the ABS survey findings was not comprehensive enough to draw meaningful conclusions. Basic information related to affected compartment, structures, and age of vessel, at the time of finding, were listed. However, details regarding cause, length, repair method, and affected members were not always provided as these are not required to be recorded by the Surveyor, and are optional.

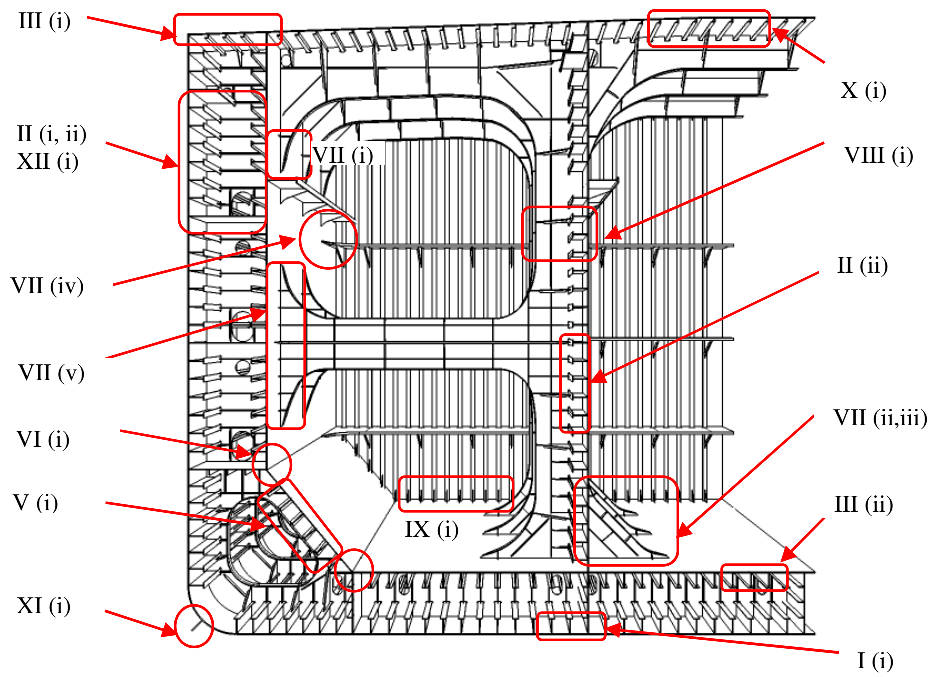
For the above reasons, a review of external consultant data and IACS documents were used to supplement ABS data and to determine structural areas prone to fractures in each of the vessel types, namely oil carriers, bulk carriers and container carriers. The following tables were prepared to graphically highlight the major areas of concern for each vessel type based on this data. Tables 4-1, 4-2 and 4-3 show the major areas of concern, typical locations of fractures and a brief description of the affected members.

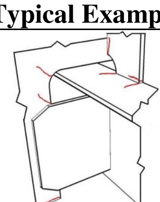
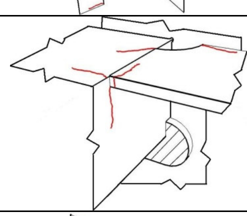
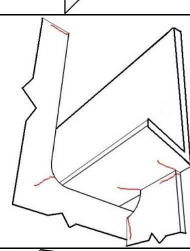
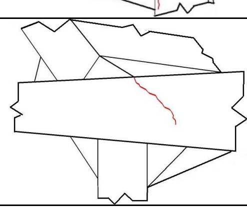
It should be noted that data from general cargo vessels were not considered in this study because of the large variation in designs and cargo types. There is also limited data on this type of vessel in the ABS in-house database.

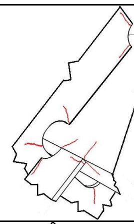
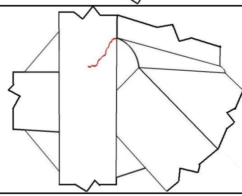
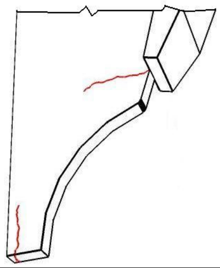
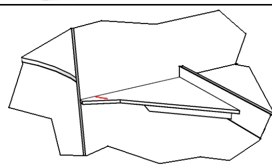
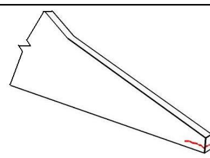
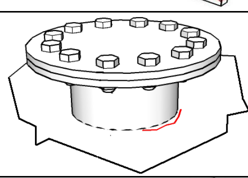
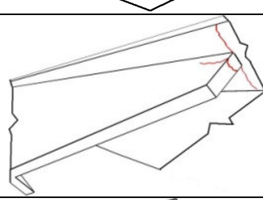
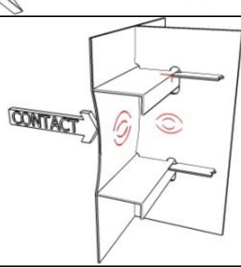
4.1 Areas Prone to Fractures in Oil Carriers

Table 4-1 Structural areas prone to fractures: oil carriers

Structural Areas Prone to Fractures in Oil Carriers



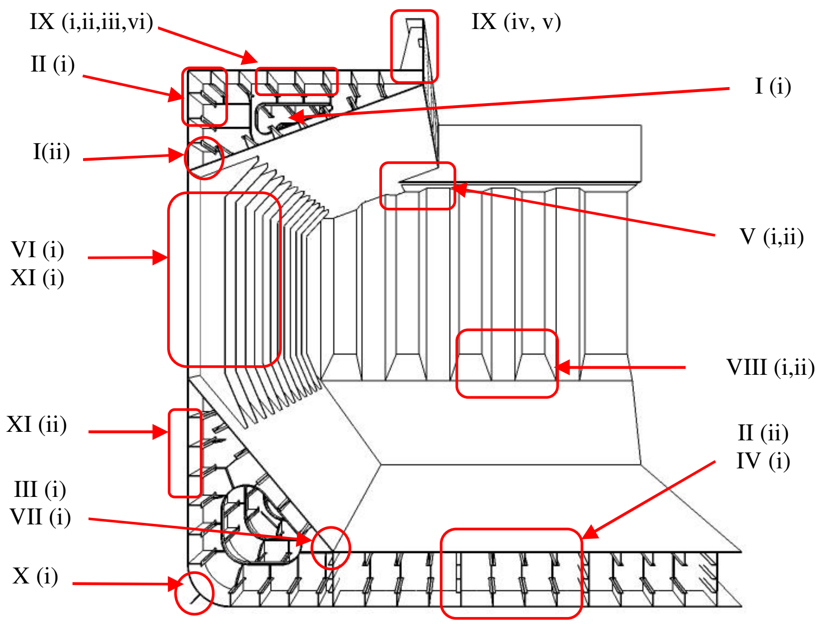
Area	Typical Example	Description
I		i. Fracture at connection of bottom longitudinal to vertical stiffener of transverse floor and transverse web (L and T shape)
II		i. Fracture at the connection of side shell long. to vertical web plating and transverse bulkhead (L and T shape) ii. Fracture at connection of longitudinal BHD longitudinal (L and T shape) to vertical web and transverse bulkhead in way of longitudinal BHD
III		i. Fracture at connection of deck longitudinal (L and T shape) to vertical web plate and vertical stiffener ii. Fracture at connection of inner bottom longitudinal to vertical stiffener on inner floor (or transverse bulkhead)
IV		i. Fracture in the lower hopper knuckle joint between inner bottom and hopper plate (in way of transverse web)

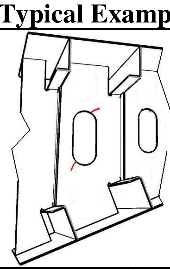
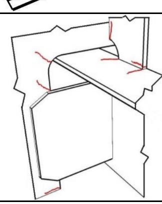
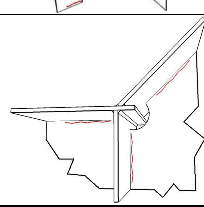
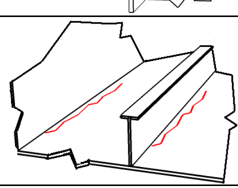
V		i. Fracture at the connection of hopper plating long. to transverse bulkhead (L and T shape)
VI		i. Fracture in the inner hull longitudinal BHD at the connection of hopper plating to inner skin
VII		i. Fracture at connection of deck transverse bracket toe in way of inner hull longitudinal BHD. ii. Fracture at vertical web longitudinal BHD bracket toe in way of tank top iii. Fractures at end bracket in way of longitudinal BHD (on center line BHD) iv. Fracture at connection of horizontal girders of transverse bulkhead to longitudinal bulkhead or inner skin in way of bracket toe v. Fractures at the end connection of cross tie to inner hull longitudinal BHD.
VIII		i. Fracture in connection of transverse bulkhead stringer to transverse web frames and longitudinal bulkhead (or centerline bulkhead)stringer
IX		i. Fracture at end connection of transverse bulkhead longitudinal to inner bottom.
X		i. Corrosion and fractures around deck penetrations
XI		i. Fracture at connection of bilge keel to bilge plating
XII		i. Contact damage to side shell plating, side longitudinal, vertical web, horizontal girder, transverse bulkhead

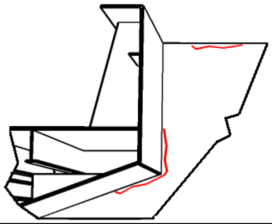
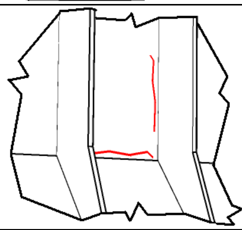
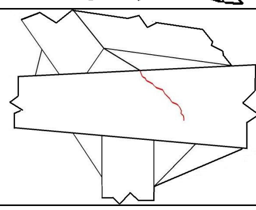
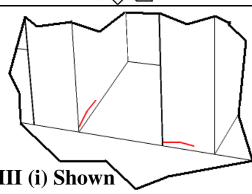
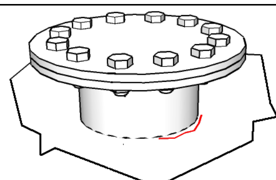
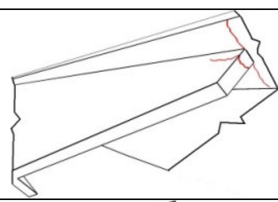
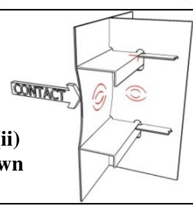
4.2 Areas Prone to Fractures in Bulk Carriers

Table 4-2 Structural areas prone to fractures: bulk carriers

Structural Areas Prone to Fractures in Bulk Carriers



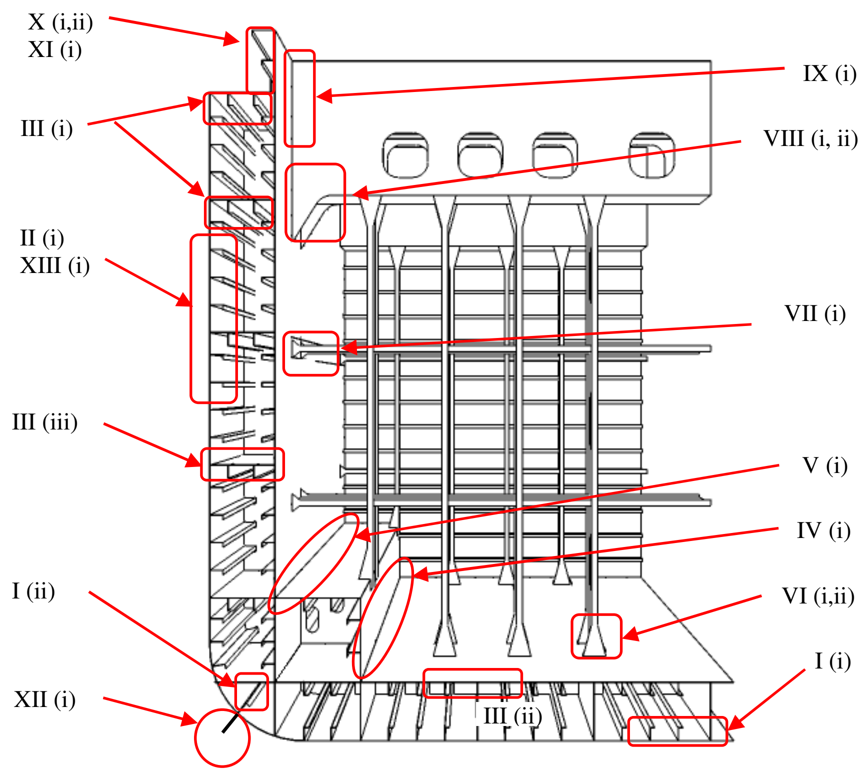
Area	Typical Example	Description
I		i. Fractures around lightening holes/manholes in transverse bulkhead ii. Fractures in transverse brackets in Top Side Tank (TST)
II		i. Fractures in longitudinal at transverse web frame or bulkhead (particularly, lowest longitudinal in Top Side Tank) ii. Fractures in inner bottom longitudinals, and bottom longitudinals
III		i. Fractures in weld connection of floors in way of hopper/inner btm
IV		i. Fractures in bottom plating alongside girder or bottom longitudinal

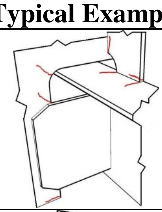
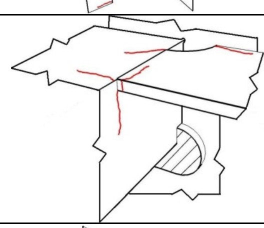
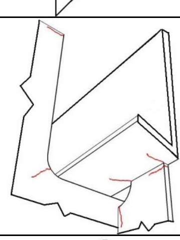
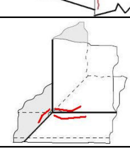
V		i. Fractures in corrugated bulkhead at topside tank connection ii. Fractures in hatch end beam in way of hatch side coaming
VI		i. Fracture in side shell plating alongside shell frame and hopper sloping plating
VII		i. Fractures in the hopper knuckle joint between inner bottom and hopper plating
VIII	 **VIII (i) Shown**	i. Fractures at connection of lower stool to inner bottom/hopper slope plate ii. Fractures in corrugated bulkhead at intersection of shredder plates
IX	 **IX (i) Shown**	i. Deformation / fractures in deck plating around bollard / tug bit ii. Fractures in deck plating around access manholes iii. Deformation / fractures in deck plating near crane foundations, and deck penetrations iv. Fractures in hatch coaming top plate v. Fracture in toes of hatch coaming termination bracket vi. Deformation / fractures in welded seam between think and thin deck plating
X		i. Fracture at connection of bilge keel to bilge plating
XI	 **XI (ii) Shown**	i. Contact damage to side shell plating, hold frame, transverse bulkhead ii. Contact damage to side shell plating, side longitudinal, vertical web, horizontal girder, transverse bulkhead

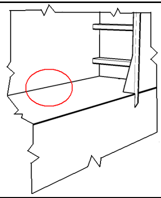
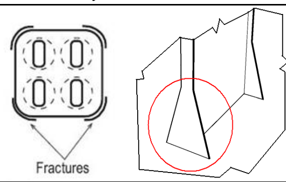
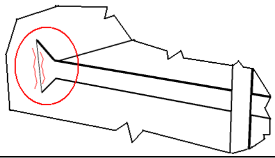
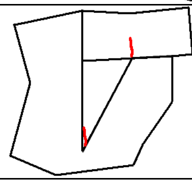
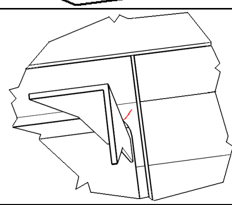
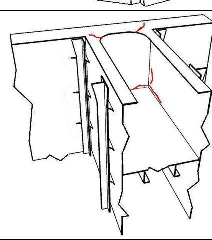
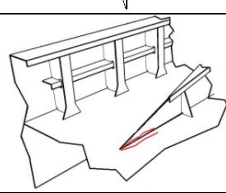
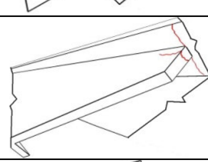
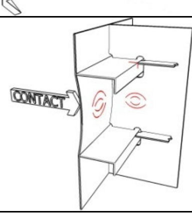
4.3 Areas Prone to Fractures in Container Carriers

Table 4-3 Structural areas prone to fractures: container carriers

Structural Areas Prone to Fractures in Container Carriers



Area	Typical Example	Description
I		i. Fracture at connection of bottom longitudinal to vertical stiffener of transverse floor and transverse bulkhead (L and T shape) ii. Fracture at connection of Bilge longitudinal to Transverse web (L and T shape)
II		i. Fracture at the connection of side shell longitudinal to vertical web plating and transverse bulkhead (L and T shape)
III		i. Fracture at connection of Upper and Second deck longitudinal to Vertical web and transverse bulkhead (L and T shape) ii. Fracture at connection of inner bottom long. to vertical stiffener on inner floor and transverse bulkhead (L and T shape) iii. Fracture and deformation in stringer in-way of cutouts for vertical stiffeners and access cut-outs
IV		i. Fracture and deformation at connection of Inner bottom plating (Tank top) to Side longitudinal bulkhead in way of web frames.

V		i. Fractures and deformation at connection of Longitudinal bulkhead and Stringer deck in way of web frames
VI		i. Fracture and deformation in tank top (inner bottom) in way of container sockets ii. Fracture at connection of Cellular bulkhead (N.T.) to Inner bottom plating (Tank top)
VII		i. Fracture at connection of Cellular bulkhead (N.T.) to Longitudinal bulkhead (Inner skin)
VIII		i. Fracture at connection of Box transverse (N.T.) to Longitudinal bulkhead (Inner skin) ii. Fracture in deck girder
IX		i. Fractures and deformation in cell guide connections to bulkhead structure
X		i. Fracture at connection of Hatch coaming top plate to Box transverse ii. Fracture at connection of Hatch side coaming to Box transverse
XI		i. Fracture at connection of Hatch side coaming to Upper deck
XII		i. Fracture at connection of bilge keel to bilge plating
XIII		i. Contact damage to side shell plating, side longitudinal, vertical web, horizontal girder, transverse bulkhead

4.4 Conclusions

The charts shown above indicate the fracture sensitive locations and can be used as reference for Surveyors or inspectors. The statistical analysis carried out provided limited information upon which to draw any conclusions on common causes of fracture or selection of repair method. Repair method is influenced by factors such as the criticality of the fracture and availability of resources like repair facilities and necessary skills.

5 CLASSIFYING STRUCTURAL FAILURES

Structural failures need to be classified based on the criticality of the damaged structure in order to recommend timely and appropriate corrective action. This is an important contribution to the safety of the vessel, on-board personnel and environment, and minimizes disruptions in normal vessel operation.

This chapter reviews the USCG CAIP scheme of classing structural failures and proposes a new scheme for assigning criticality class of structural components for various ship types.

5.1 USCG CAIP Scheme for Classing Structural Failures

The USCG Critical Areas Inspection Plans (CAIP) program presents a scheme for classing structural failures to guide reporting and corrective actions.[P5]

"Class 1 Structural Failure:

During normal operating conditions, either

(1) a visible, through thickness fracture of any length in the oiltight envelope of the outer shell where threat of pollution is a factor or,

(2) a fracture or buckle which has weakened a main strength member to the extent that the safety of the vessel to operate within its design parameters is compromised.

Action: Immediate corrective action must be initiated by the operator with approval of the cognizant OCMI. Temporary repairs may be permitted to allow the vessel to safely transit to a repair facility.

Class 2 Structural Failure:

A fracture or buckle within a main strength member which does not compromise the safety of the vessel to operate within its design parameters and does not create a threat of pollution either by location or containment.

Action: Necessity for corrective action shall be evaluated and agreed upon between the vessel operator and OCMI when the failure is found. Temporary repairs until the next scheduled repair period may be authorized.

Class 3 Structural Failure:

Any fracture or buckle which does not otherwise meet the definition of a Class 1 or 2 structural failure or a fracture which might normally be considered a Class 2 but is determined not to be detrimental to the strength or serviceability of the effected main hull structural member

Action: Corrective action or notification to the OCMI is not required. Shall be noted for the record, monitored by the operator if deemed desirable and addressed at the next regularly scheduled repair period."

Paragraph 5.G.2.a gives definition of paragraphs 5.G.2.b and 5.G.2.c:

"(1) outer shell: the side shell and bottom plating of a vessel including the bow and stern rakes of barges. [5]

(2) oiltight envelop: that portion of the outer shell in way of cargo oil tanks and the vessel's bunker/fuel, lube oil and slop tanks, exclusive of the clean ballast tanks.

(3) main strength members: those structural members which provide primary longitudinal strength to the hull and those transverse structural members which directly contribute to support longitudinal strength members. Such members include the strength deck plating; tank top plating; the center vertical keel; underdeck, side and bottom longitudinal stiffeners; internal longitudinal bulkheads and stiffeners; deep web frames and girders; transverse bulkheads and girders; and associated bracketing connecting the aforementioned longitudinal and transverse structural members."

From the definitions above, classifying failure of a main strength member as Class 1 or Class 2 structural failure depends on the impact to safety of the vessel and potential threat of pollution. In some cases, this may cause indecisive action as the potential impact is debatable. Hence, a scheme which considers potential consequences of a structural component's failure, taking account its intended function and location of a structural component is needed.

Moreover, this scheme was developed for single hull oil carriers and needs to be revised so that it is applicable to double hull oil carriers as well. There is also a need for a generic scheme in order to classify structural failure for other vessel types given that consequences of structural failure would vary with the design and type of intended cargo.

Due to the reasons mentioned above, the project team attempted to develop "criticality class" charts by adapting an IACS approach introduced in 2006.

[5] Does not include main deck.

5.2 Generic Scheme for Assigning Criticality Classes

IACS Common Structural Rules for Double Hull Oil Tankers, January 2006 "Background Document, Section 2 – Rule Principles" presents a schematic diagram of the "criticality class" for structural components in the cargo region. This classification facilitated the selection of acceptance criteria and capacity models such that the more critical components have stricter requirements and hence a lower probability of failure.

The approach outlined above was modified to meet the scope of this study. During the development process, a typical cargo block design was considered for each vessel type, namely oil carriers, bulk carriers and container carriers. General cargo vessels were not considered for the exercise due to the large variations in design.

The criticality of each structural component in the cargo region was evaluated based on loss of intended function (containment or providing strength) upon failure with respect to consequences to People (P), Environment (E) and Serviceability (S). One of the three criticality classes, "high", "medium" or "low", was assigned to each consequence category to facilitate the evaluation. Definition of each criticality class is shown in Table 5-1.

Table 5-1 Definition of Criticality Class

Criticality Class	Description
High	For structural components where failure may imply high potential for fatality or human injury, significant environmental pollution or ship going out of service
Medium	When failure may imply medium potential for human injury, medium environmental pollution or impairment of ship serviceability
Low	When failure may imply low potential for human injury, minor environmental or impairment of ship serviceability

A combined criticality class was established for each structural component to simplify the assessment process. This may be used to recommend appropriate and timely corrective action. Typical recommendations are listed in Table 5-2.

Table 5-2 Recommendations of repairs based on the criticality class of a fracture

Combined Criticality	Recommendation at Repair
High	Initiate immediate corrective action
Medium	Evaluate necessity for corrective action when failure is found. Conduct temporary repair and monitor vessel's condition until permanent repair is carried out
Low	No immediate corrective action required. Needs to be monitored and reexamined at next scheduled inspection.

Details of the development process are included in Appendix E. Table 5-4 summarizes the structural components in double hull oil carriers, single skin bulk carriers and container carriers with "high" combined criticality class (see Figures E-2, E-3 and E-4 in Appendix E, respectively).

Table 5-3 Structural components with "High" criticality class of fractures

		Ship Types		
		Double Hull Tankers	**Single Skin Bulk Carriers**	**Container Carriers**
Structural hierarchy	**Global**	Hull Girder	Hull Girder	Hull Girder
	Major	Deck Side Structure Bottom Structure Longitudinal Bulkhead Transverse Bulkhead Fore/Aft End Transverse Bulkhead	Deck Topside Tank Side Structure Hopper Tank Bottom Structure Corrugated Transverse Bulkhead	Main Deck Side Structure Bottom and Bilge Structure Transverse Bulkhead
	Primary	Deck Panel Deck Girders Deck Transverse Inner Skin Panel Side Shell Panel Inner Bottom Panel Bottom Shell Panel Longitudinal Bulkhead Panel Transverse Bulkhead Panel	Deck Panel Hatch Coaming Hatch Cover Side Panel Hold Frame Bilge Shell Panel Inner Bottom Panel Bottom Shell Panel	Deck Panel Hatch Corner Hatch Coaming Hatch Coaming Corner Inner Bottom Panel Bottom and Bilge Panel
	Local			Deck Longitudinal Deck Plate Side and Top Coaming Plate

Table 5-4 shows a structural hierarchy (for each vessel type) of four levels: "Global", "Major", "Primary" and "Local". These levels were defined on the basis of a review of the structural boundaries of components (see Table 5-3 for descriptions).

A "top-down" approach is followed, starting from the hull girder (highest level) to individual plates and stiffeners (lowest level). The combined criticality class at a given level is always set to be equal or higher than the combined criticality class at the next lower level.

Table 5-4 Structural Hierarchy

Location of item in structural hierarchy	Structural component	Description
Global	This represents the top level in the hierarchy	
	Hull girder	
Major	This represents the 2nd level in the hierarchy Major components are bounded by bulkheads or the shell envelope	
	Major elements	This represents the major structural components 1 Deck 2 Bottom structure (combined bottom shell and inner bottom) 3 Side structure (combined side shell and inner side) 4 Longitudinal bulkhead (inner or centerline) 5 Transverse bulkhead 6 Topside tank 7 Hopper tank 9 Hatch coaming 10 Hatch cover
Primary	This represents the 3rd level in the hierarchy Girders are bounded by bulkheads or shell envelope Stiffened panels are bounded by girders/bulkheads	
	Girders	Collective term for primary support members including DB girders, bulkhead stringers, deck transverses, floors, etc.
	Stiffened panels	The plating and attached stiffeners/longitudinals of deck, bulkheads, etc.
Local	This represents the lowest level in the hierarchy Local components are usually bounded by girders and stiffener spacing	
	Stiffeners or longitudinals	This represents a single stiffener/plate combination comprising the stiffener profile and attached plate flange. Brackets are also included in this group.
	Plates	This is the plating between adjacent stiffeners/longitudinals or the web plate of girders.

5.2.1 Criticality Class Charts

Criticality charts were developed for double hull tankers, single skin bulk carriers and container carriers. These charts are attached in Appendix E, Figure E-2 to Figure E-4.

The following section briefly describes how to interpret and use the criticality charts in a real life scenario.

Criticality Class Color Code

In the criticality class charts, the criticality classes are represented using three different colors as shown in Figure 5-1.

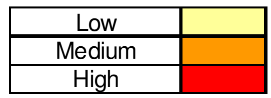


Figure 5-1 Criticality Class Color Code

Criticality Class Block

Individual structural components are presented by a criticality class block where the first row states the name of the structure, the second row showing criticality class with respect to consequences to People (P), Environment (E) and Serviceability (S) using the color code mentioned above and the third row is the combined criticality class for the structural component.

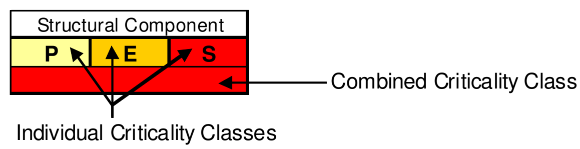


Figure 5-2 Criticality Class Block Definition

Case Studies

The use of criticality class charts are examined using two sample fracture reports from the ABS survey database. The recommendations identified using criticality class charts for Case 1 and Case 2 were found to correspond to those of the attending Surveyors.

Case 1 Fractures found on bottom structure of double hull oil carrier

Survey Finding:

1. Fracture length approximately 5 inch found on 1st ***bottom longitudinal*** *counting from inboard from longitudinal swash bulkhead.*

2. Fracture extended from aforementioned item no. 1 into ***bottom shell plate*** *port and starboard side of bottom longitudinal as follows;*

a. Starboard two fractures of length approximately 10 inches length.

b. Port side two fractures approximately 12 inches and 8 inches in length and not joined.

Fractured structural members: bottom longitudinal, bottom shell plate.

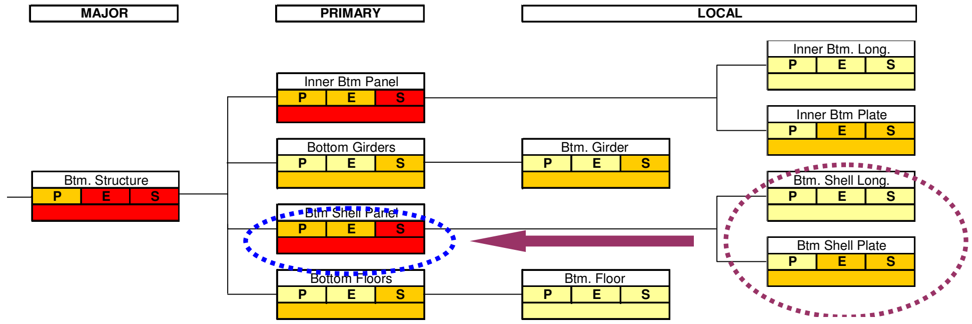


Figure 5-3 Evaluation of Case 1 using criticality class chart for double hull oil carrier (Figure reproduced from Figure E-2 in Appendix E)

As shown in Figure 5-3, fractures were found on both structural components in the "Local" level (bottom shell longitudinal and bottom shell plate). This indicates that it is a panel issue as both stiffener and plating are affected. Hence, the combined criticality class to be considered is of the structural component in the "Primary" level (bottom shell panel)

In Figure 5-3, the combined criticality class of "Bottom Shell Panel" is "Red", i.e., "High". Therefore, using Table 5-2, it is recommended to "initiate immediate corrective action". According to the fracture report, the following recommendation was made and repair completed within the same survey.

"The affected shell plate and bottom longitudinal to be cropped and partly renewed to the satisfaction of attending surveyor."

<u>Case 2 Fractures found on deck structure of container carrier</u>

Survey Finding: *The **deck plate** was found to be fractured in two (2) locations with an approximate length of 300 mm.*

*The fractures propagated into the **inner side plate** approximately seventy-five (75) mm, and the **longitudinal coaming** approximately fifty (50) mm on the port side.*

Fractured structural members: deck plate, inner side plate and longitudinal coaming.

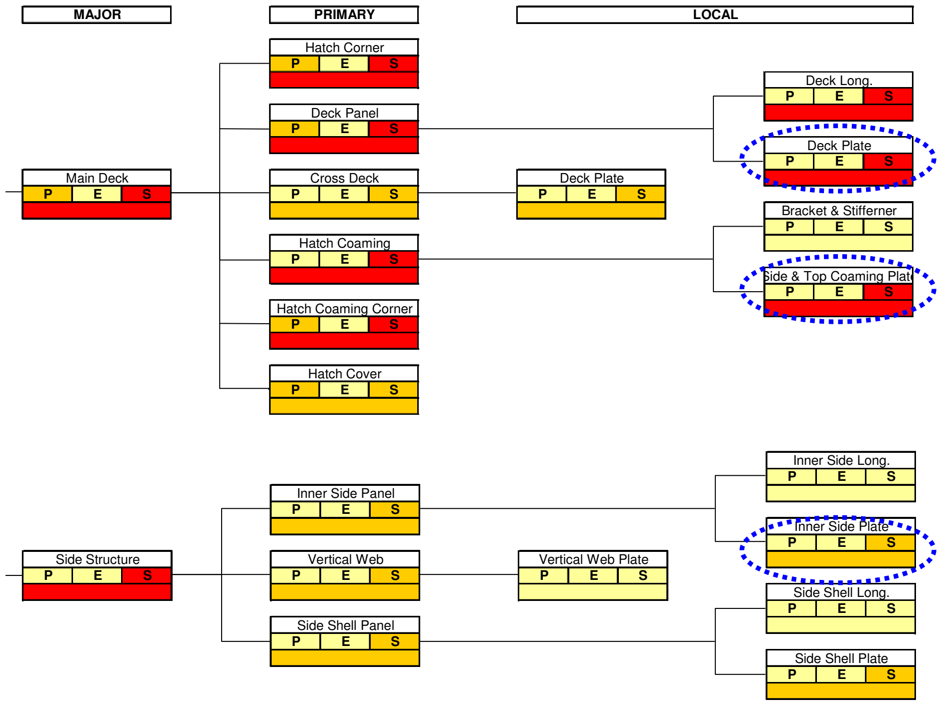


Figure 5-4 Evaluation of Case 2 using criticality class chart for container carrier (Figure reproduced from Figure E-4 in Appendix E)

From Figure 5-4, the fractured structural components are found at the “Local” level (deck plate, side and top coaming plate and inner side plate).

Two of the three structural components (deck plate and side and top coaming plate) have a “High” combined criticality class, represented by the red color. From Table 5-2, this suggests initiation of immediate corrective action. Inner side plate has a combined criticality of “Medium”, represented by the orange color, and requires evaluation of necessity for immediate corrective action as in Table 5-2. The assessment of the damage condition of the inner plate may be performed by an on-site surveyor, who based on his best judgment, determines the need of immediate corrective action.

According to the fracture report, the following recommendation was made and repair completed within the same survey.

“The fractures need to be gouged and rewelded for a temporary repair. The repair shall be conducted by ABS certified welders utilizing ABS grade certified materials to the satisfaction of the attending Surveyor.”

5.3 Conclusions

The developed criticality class charts present an alternative method to classify structural failure based on the criticality of the affected structural component and to recommend timely and appropriate corrective action.

Potential impact of structural failure on the consequence categories (People, Environment, and Serviceability) are evaluated by taking into account the function of the structural component.

Hence, the generic scheme developed for assigning criticality classes can be extended to other vessel types if typical designs and threat of pollution of the intended cargo are known.

The criticality charts are meant to be used as a reference tool. On-site personnel should also take into consideration the cause and nature of the fracture (size and direction) in order to conclude appropriate fracture solution, i.e., repair techniques.

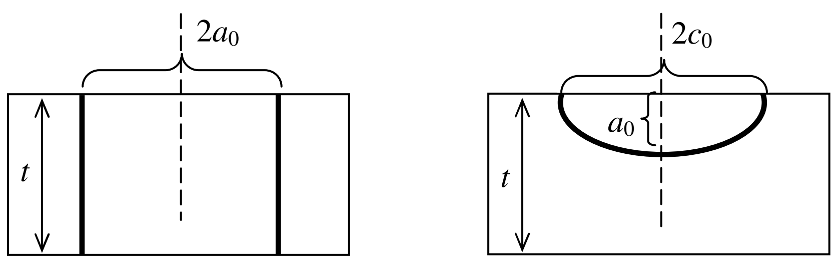
6 FRACTURE THRESHOLD CRITERIA

One question that field inspectors frequently encounter is whether a found fracture of a certain size (length and depth) will become a threat to the safety of the vessel during the following voyage(s). It is desirable to establish threshold criteria for fracture size (length) that can be used to make decisions about the follow-up actions (i.e., immediate and deferred repairs) depending upon the size of found fractures.

6.1 Fracture Mechanics

The fracture mechanics approach (FM) has been recognized as well-suited for predicting the remaining service life of fractures. Fracture mechanics is the field of mechanics concerned with the study of the formation and propagation of fractures (or cracks) in materials. It applies analytical and experimental solid mechanics to calculate the driving force on a crack and the material's resistance to fracture.

Two types of analytical models of fracture mechanics are found to be relevant to fractures typically seen in ship structures, through-thickness cracks and surface cracks for flat steel plates. See Figure 6-1. However, in most cases, through-thickness cracks and edge cracks may be more critical as they normally propagate at a faster rate compared to surface cracks.



(a) through-thickness crack (b) surface crack

Figure 6-1 Typical fracture mechanics models for ships

The general procedure of FM calculations is illustrated in Figure 6-2 . The main components of fracture mechanics calculation are:

- A model for fracture and fracture propagation
- Loads
- Structural responses
- Fracture resistance

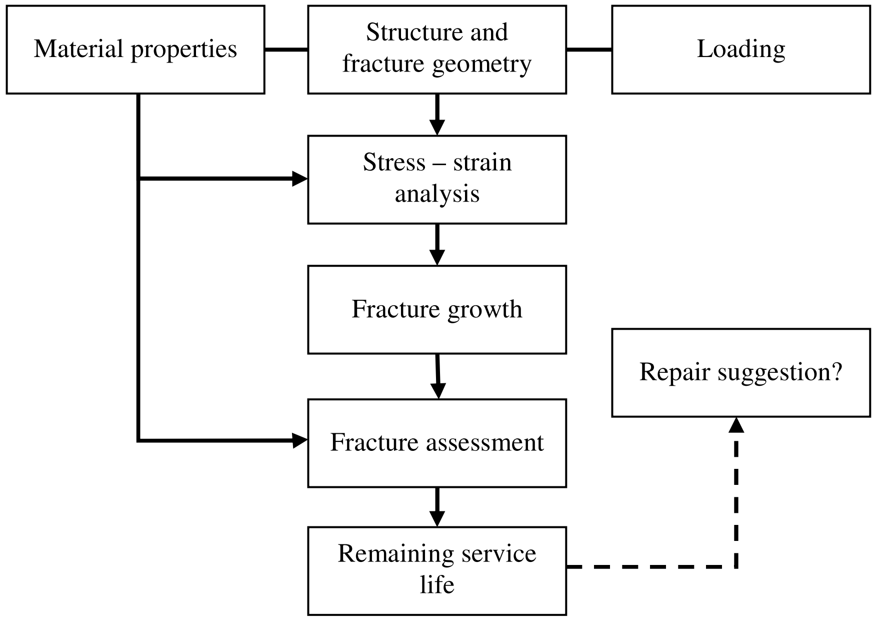


Figure 6-2 Fracture Mechanics Calculations

6.2 Fracture Mechanics Methodology Specified by USCG CAIP

The USCG NVIC 15-91, CH-1 describes a procedure for fracture mechanics calculations. Owners and operators of vessels required to maintain CAIPs may apply this procedure to calculate the remaining service life of assumed cracks in a TAPS tanker. Depending upon the calculation results, the owner and operator are allowed to modify the required CAIP intervals. Application of fracture mechanics was allowed for demonstrating that the Class 2 and 3 fractures will not propagate into the critical length in the proposed time interval.

This CAIP FM methodology consists of the following steps:

- identify specific details of cracks
- characterize the geometry of the crack with use of appropriate crack models
- determine a representative value for the fracture toughness of the steel plates
- estimate the equivalent root mean squared stress range to which a vessel is subject to
- calculate the resultant crack propagation life
- propose a reasonable CAIP examination interval

6.3 Industry Standard for Fracture Mechanics Calculations

Since the release of USCG CAIP, there has been extensive research and development devoted to further FM technology. Several industry standards and guidelines have been established for performing fracture mechanics calculations[6]:

- British Standard Institute 7910: 2005, Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures
- American Petroleum Institute Recommended Practice 579, Fitness-For-Service

FM analysis procedures provided by BS7910 and API579 are similar and can be briefly summarized as follows:

a) identify specific details of cracks

b) characterize the geometry of the crack with use of appropriate crack models

c) establish fatigue loading spectrum to which the crack is subjected to

d) calculate the resultant crack propagation life based on specific acceptance criteria

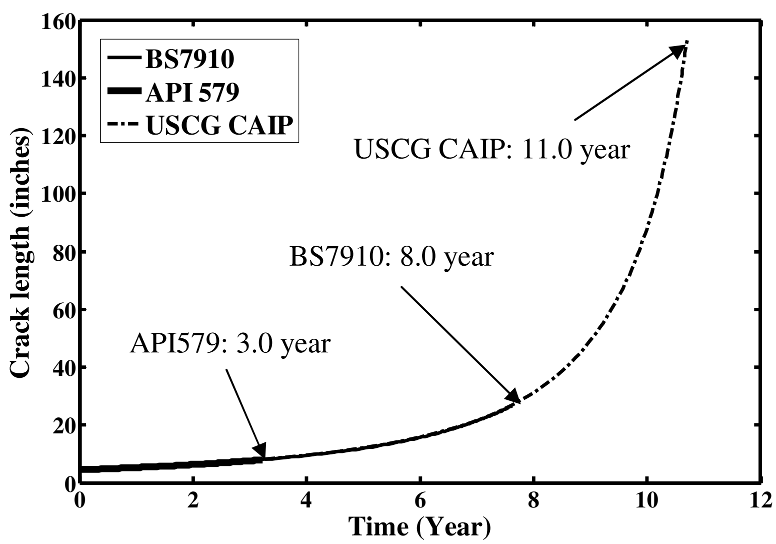


Figure 6-3 Prediction of crack propagation and remaining service of a 4.5-inch crack using BS 7910, API579 and USCG CAIP

Figure 6-3 shows an example of the prediction of the remaining service life of a through-thickness crack based on BS7910, API579, and USCG CAIP. In this example, the initial crack length is 4.5 inches and the equivalent stress range is 2.96 ksi. As shown in the figure, BS7910, API579, and USCG CAIP predict the same path

[6] IACS is not listed as it has no standard procedures for fracture mechanics calculations.

of crack propagation, and the BS7910 and API579 approaches predict shorter remaining service compared to the USCG CAIP approach. This difference is due to the criteria for determining the critical crack size.

6.4 Research on Fracture Mechanics Applications

The fracture mechanics approach has seen great improvement during the last 50 years. At present, it is widely used to predict the crack propagation and the remaining service life prediction in many industries.

Crack propagation approach

Paris' law has been widely accepted as a practical engineering tool for predicting crack propagation. The formulae given by industry standards and guidelines, such as, BS 7910 and API 579, can be used for the calculation of stress intensity factor range (ΔK).

Criteria for fracture failure

Fracture failure criteria are primarily based on fracture toughness, crack tip opening displacement or angle, energy release rates, *J*-integral, and the tearing modulus, etc. Fracture instability is assumed to occur when the stress intensity factor reaches the critical stress intensity factor. Alternatively, the critical crack tip opening angle (CTOA) or displacement (CTOD) at a specified distance from the crack tip is also considered suitable for determining the onset of fracture instability.

In addition, the through-thickness criterion and several criteria published in industry standards, e.g., BS7910 Levels 1 and 2, have been widely accepted by engineers.

Projects of the Ship Structure Committee (*SSC*)

Since the first Ship Structure Committee report 'Causes of cleavage fracture in ship plates', SSC has been working on exploring the fracture mechanism and developing fracture control approaches and guidance for ship structures. During 1946-1975, many projects (e.g., SSC 1, 131, 143, 248, 251, 75symp16) were carried out by SSC to develop an understanding of the factors that contribute to the brittle behavior of mild steels and the relevant micro-mechanisms of fracture. These research programs initiated the International Conference on Fracture in Swampscott, Massachusetts in 1959 with subsequent conferences to follow and ultimately gave impetus to the International Journal of Fracture in 1965.

From 1976 to 1986, SSC continued work on this subject through a series of projects (e.g., SSC 256, 276, 307, 328, SSC-81symp14) to investigate crack propagation and fracture control in structural steels, and fracture criteria for ship steels, and so on. After 1986, SSC broadened the research on fracture mechanics-based reliability assessment, maintenance of ship structures, and damage tolerance analysis (e.g., SSC 337-1, 402, 409, SSC-91symp06, 91symp08). Recent SSC projects (e.g., SSC 429-430, 448) were focused on fracture toughness of ship steels, rapid solution for stress intensity factors, and fracture behavior of aluminum components, etc.

6.5 Challenges

As illustrated by the example calculation, the fracture mechanics approach seems to have matured for predicting crack propagation in a practical manner. The current need is to establish a generic fracture mechanics procedure that can be used consistently for various marine fracture problems. The USCG CAIP approach may need to be updated to reflect the state-of-the-art technology on both FM and structural designs. Some of the challenges are discussed below.

Fracture toughness

Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture. Fracture toughness is usually determined from one of following:

- measured linear-elastic plane strain fracture toughness KIC or
- correlations from Charpy V-notch impact test data (CVN)
- conversions from CTOD or CTOA
- conversions from J–integral which is a line or surface integral that encloses the crack front from one crack surface to the other, used to characterize the local stress-strain field around the crack front

The material's fracture toughness plays an important role in the assessment of fracture resistance. Unfortunately, in the marine industry, there is no established minimum value of fracture toughness based on which the fracture resistance can be evaluated. Complicating the situation is that limited lab test data (such as K_{IC}, J or CVN values) shows a high level of variation, which makes it difficult to derive minimum values of fracture toughness for a generic FM calculation.

Fatigue loading

Ideally, loads for fracture mechanics calculation should reflect the vessel's trading route and season. It is preferable to use measured fatigue loading. However, such load information is not available in most cases. A practical alternative is to use design loads, which are defined and specified in ship design rules (such as IACS CSR, ABS SafeHull, etc).

If a specific season and intended known route are to be considered in the evaluation, which may often be the case, the design loads need to be adjusted for the considered season and route. In general, basis of design loads is to assume that the vessel will be trading in the North Atlantic for 20 to 25 years.

Criteria for fracture failure

The fracture resistance is often expressed as a maximum limit to the length or depth of a crack. It is a result of considerations of two aspects:

- Geometry: A surface crack will continue to grow in the depth direction until the crack tip/front reaches a certain depth, often 85-100% the plate thickness.
- Fracture resistance: A crack grows until the stress intensity factor reaches the critical stress intensity factor which is determined by the fracture toughness.

As shown in the example in Fig.6-3, criteria for fracture failure have an evident impact on the estimated remaining service lives. There is still a need to define appropriate failure criteria with sufficient safety margin for determining the fracture failure for marine applications.

Stress concentration

Stress concentrations occur at structural discontinuities, e.g., gross discontinuities, misalignment and deviation from intended shape, or local discontinuities such as welds, holes, notches, etc. The effects of stress concentrations must be taken into account in the FM analysis

Safety factor

The USCG NVIC 15-91 specifies a minimum safety factor of 2.5 for determining the extended CAIP internal. This safety factor needs to be reevaluated once the generic FM procedure is established.

6.6 Summary and Recommendations

The fracture mechanics approach can be used for evaluating whether a fracture of a certain size on a certain part of a ship will develop to threaten structural integrity during the intended voyage(s).

The fundamental theory of the fracture mechanics approach has matured. Extensive experience has been gained by applying FM to various practical problems from many industries. The established industry standards provide a solid basis for its application to the marine industry. However, performing the approach requires basic knowledge or background on FM. Hence, calculations should be carried out by skilled professionals or by the engineering office.

Caution should be applied when performing FM analysis on a crack found on a corroded plate. Corrosion is generally an uneven process. Corrosion will, in general, reduce cross-sectional area resulting in an increase in the field stress. In addition, corrosion will result in local stress concentrations which may provide sites from which cracks may propagate. It is possible that fracture toughness properties may degrade in the presence of corrosion. All these factors may result in quicker propagation of a crack and less remaining service life.

The limited study in this project seems to suggest that the FM method specified in USCG CAIP is comparable to the more refined FM procedure specified in BS 7910. However, there are still many technical challenges. There is a need for establishing a standard procedure that defines all the needed parameters, including the loads and fracture resistance. Therefore, further study is required to determine the need of revision of the USCG CAIP.

7 FRACTURE REPAIR TECHNIQUES

Gap analysis of the details of repair methods documented in USCG NVIC 7-68 and IACS publications were carried out and the results are discussed in Section 7.1. Sections 7.2 to 7.4 provide a general background and introduction of commonly practiced repair techniques on steel vessels. Aluminum structures are not considered. These include criteria or requirements such as heating and moisture constraints.

7.1 Gap Analysis

USCG NVIC 7-68 allows the following repair methods:

- Cropping and renewing
- Insert plates
- Welded doubler plates
- Welding (drill stop was briefly discussed in "welding" subsection)
- Riveting

More recent industry practices of steel hull repairs can be found in the series of IACS recommendations:

- Repair quality standard for existing ships (IACS Rec. No. 47, Part B)
- Double hull oil tankers – Guidelines for surveys, assessment and repair of hull structures (IACS Rec. No. 96),
- Guidelines for surveys, assessment and repair of hull structures – Bulk carriers (IACS Rec. No. 76),
- Container ships – Guidelines for survey, assessment and repair of hull structures (IACS Rec. No. 84)
- General cargo ships – Guidelines for surveys, assessment and repair of hull structures (IACS Rec. No. 55).

These documents (Attachments C, D, E, F, and G) are commonly used as the basis for assessment and repair of steel commercial ships. Table 7-1 compares repairs specified in USCG NVIC 7-68 and IACS Rec. No. 47. Other publications such as the following were also frequently used as reference.

- Guidance Manual for Maintenance of Tanker Structures (Tanker Structure Co-operative Forum (TSCF) and International Association of Independent Tanker Owners (INTERTANKO))
- Guidelines for the Inspection and Maintenance of Double Hull Tanker Structures (TSCF)

Table 7-1 Guidance on repair techniques in USCG NVIC 7-68 and IACS Rec. No. 47, Part B

Repair Technique	USCG NVIC 7-68		IACS Recommendation No. 47, Part B		Notes
	Paragraph	Descriptions	Paragraph	Descriptions	
Crop & Renew	IV (E)	- Sufficient material for sound attachment of new metal - Alignment - Sufficient clearance	6.2, 6.4, 6.5	- Size, welding sequence, etc - Illustrations included.	
Gouge & Reweld	IV (A)(5), V	- Location of repair work - Temperature depending on steel - Filler metal - Edge preparation - Welding sequence and procedure - Welding defects and prevention methods - NDE for weld testing/verification	5	- Welding consumables (IACS UR W17) - Temperature control (preheating and drying out)	
			6.1	- General welding standards	
			6.8	- Welding repairs for cracks (Preparation, sequence, etc) - Finish and NDE (IACS Rec. No. 20)	
			6.9	- Grinding of shallow cracks	
Design Modifications	*Not Available*	*Not Available*		- IACS documents suggestion of fracture repair depending on vessel type, cause of fracture, affected structure and extend of fracture. (IACS Rec. No.55, 76, 84, 96)	Need to include "design modification" in the revision of NVIC 7-68 TSCF listed options of design modification. Decision of fracture solution depends on cause and location of fracture.
Insert Plate	IV (C)	- Inserts covering at least one frame space - Amount of fractured material to be cut out - Edge preparation and shipfitting - Procedure to minimize locked-in stress - Restrictions of patch plate	6.2, 6.4	Details same as renewal of plates	
Doubler Plate	IV (D)	- Where doubler plate can be used - Brief guide on drilling end of cracks before repair work proceed.	6.3	- Applicable onto plating over 5mm thick - Size of doubler plate - Edge preparation, Weld size and material, slot welding	
Underwater Welding (include water backed welding)	*Not Available*	*Not Available*	5.3, 6.1	- Applicable to normal and higher strength steel with specified yield strength not exceeding 355MPa and local repairs only. - Low-hydrogen electrodes or welding process - Temperature	- Increasingly popular, mostly as temporary repair.

Repair Technique	USCG NVIC 7-68		IACS Recommendation No. 47, Part B		Notes
	Paragraph	**Descriptions**	**Paragraph**	**Descriptions**	
Drill Stop	IV (A)(5)	- General procedure on drill stopping - Precautions on specific structural locations	*Not Available*	*Not Available*	- Rule of thumb definition of the size of drill hole. - Stop hole drilling information documented in Guidance Manual for Maintenance of Tanker Structures by TSCF and INTERTANKO [P33] can be used as reference.
Riveting	VI	- Application restrictions - Hole preparation - Potential problem with rivets	*Not Available*	*Not Available*	- Rarely used in modern commercial ships
Cement Patching	*Not Available*	*Not Available*	*Not Available*	*Not Available*	- Often used to temporarily seal breached tanks

Table 7-2 is a checklist of the specific recommendations indicated in both documents. For example, USCG NVIC 7-68 describes the procedure of cropping and renewing with general statements and IACS Rec. No. 47, Part B includes material specifications, procedures and testing or verification approaches.

Direct comparison of the information detailed in both documents can be used as a reference while updating the USCG NVIC 7-68. For details that are not covered in USCG NVIC 7-68, IACS materials can be added in the new version. For fields that are described in both documents, guidelines in USCG NVIC 7-68 can be updated by incorporating IACS recommendations.

Table 7-2 Specific guidance/recommendations checklist stated in USCG NVIC 7-68 and IACS Rec. No. 47, Part B

		USCG NVIC 7-68	IACS Rec. No. 47, Part B	Remark
Crop & Renew	Material		√	NVIC 7-68 gave very general statements. "There should be sufficient clearance…", " The new portion should be in good alignment with adjoining old…" IACS provided illustration and tables to be used as references.
	Temperature			
	Procedure	√	√	
	Limitations/Restrictions			
	Testing/Verification		√	
Gouge & Reweld	Material	√	√	Both provide guidelines in all aspects. IACS gives more detailed instructions.
	Temperature	√	√	
	Procedure	√	√	
	Limitations/Restrictions	√	√	
	Testing/Verification	√	√	
Design Modification	Material			This technique is subjective and not considered as a repair technique. IACS has guidelines and examples in separate documents that are vessel type specific.
	Temperature			
	Procedure			
	Limitations/Restrictions			
	Testing/Verification			
Insert Plate	Material	√	√	NVIC 7-68 indicates the precautions and methods that are required to reduce stress concentrations
	Temperature			
	Procedure	√	√	
	Limitations/Restrictions	√		
	Testing/Verification		√	

		USCG NVIC 7-68	IACS Rec. No. 47, Part B	Remark
Doubler Plate	Material		√	NVIC 7-68 only indicates where doubler plate is applicable and its serving purpose.
	Temperature			
	Procedure		√	
	Limitations/Restrictions	√		
	Testing/Verification		√	
Underwater Welding	Material		√	
	Temperature		√	
	Procedure		√	
	Limitations/Restrictions		√	
	Testing/Verification			
Drill Stop	Material			Additional information is available in Guidance Manual for Maintenance of Tanker Structures by TSCF and INTERTANKO [P33].
	Temperature			
	Procedure	√		
	Limitations/Restrictions	√		
	Testing/Verification			
Riveting	Material			
	Temperature			
	Procedure	√		
	Limitations/Restrictions	√		
	Testing/Verification			

It is to be noted that design modification is subjective. IACS has, however, guidelines and examples in separate documents that are vessel type-specific. This is discussed further in Section 7.4.

The following sections provide a general background and an introduction of each repair technique that is currently being used in the industry.

7.2 Welding

7.2.1 General

The working environment where welding is to take place has a significant effect on the weld quality. In IACS Rec. No. 47, Part B, Section 5.2 and Table 5.1, the appropriate temperatures of the steel plate depending on the plate thickness and how to ensure the dryness of the welding surroundings are provided as guidance.

In general, welding consumables exist in several groups. Each group of consumables' application correlates with the steel grades of the relevant structure. IACS UR W17 Table 1 listed the correlation of welding consumables to hull structural steels (see Chapter 3 and Appendix B).

7.2.2 Welding Procedures

The welding sequence should be arranged in such an order as to eliminate an unnecessary stress concentration. It is specified by IACS that welding procedures are required to be qualified in accordance with the procedures of the Classification Society or a recognized national or international standard such as EN288, ISO 9956, ASME Section IX and ANSI/AWS D1.1. For recognition of other standards, the procedure is to be submitted to the Classification Society for evaluation.

Any welding procedure is to be supported by a welding procedure qualification record, detailing the welding process, types of electrodes, weld shape, edge preparation, welding techniques and position. The welder performing the work should be qualified to perform the intended welding procedure. IACS Rec. 47, Part B includes details of welding sequences corresponding to the type of repair methods selected along with illustrations.

After the completion of the welding repair, the welds are to be tested or inspected using NDT (See Section 3.5).

7.2.3 Underwater Welding

Fractures found below the waterline can be repaired by inserting or gouging and rewelding.

While considering the possibility of carrying out underwater welding, the owner is to decide the extent, stresses, environmental and safety conditions since the safety of the vessel is his responsibility. The extent of repairs includes the following factors:[P33]

- 'built in' stresses(loading conditions, i.e., high longitudinal bending moments at repair location should be avoided),
- acceptance of openings in the hull at sea,
- structural strength during the repair work (avoid high stress concentration after removal of structural element),

- environmental and safety issues.

Cofferdams fitted by divers under the ship can be used while replacing plating in small areas such as ballast tanks on oil carriers. The size of the cofferdam is limited by the size of the steel to be replaced. The cofferdam can also be used while performing welding work inside a hull to avoid rapid cooling of the weld; for example, replacement of shell stiffeners without replacing shell plating. [P33]

Environmental issues will not only affect the weld quality, but also the safety of the repairer. Movement of the ship should be limited throughout the repair work.[P33]

All completed welds are to be checked through NDT, specifically ultrasonic or radiograph testing.

Welding on internal hull plating below the waterline of vessels afloat is only allowed for local repairs on normal and higher strength steels with specified yield strength not exceeding 355 MPa.[P10] Approval of this work is on a case-by-case basis. Hence, a repair plan is generally required and is to be submitted to the Classification Society and/or Flag Administration before the repair is performed.

Welding against water backing may lead to reduced elongation and toughness in weld metal and heat-affected zones of the base metal caused by relatively rapid quenching which can lead to hydrogen entrapment. Procedure qualification testing is to be carried out to qualify for welding against water backing. Therefore, specific repair requirements such as base metal type and thickness preheating procedure, dryness control of repair site, and low hydrogen weld consumables are to be reviewed by the Classification Society and/or Flag Administration. [P10]

7.3 Repair Techniques

7.3.1 Crop and Renew

While replacing a structure, the same scantlings and strength properties (as built per drawings – original scantlings) material are generally recommended. For special cases where material with lower properties is considered, approval of the Classification Society and/or Flag Administration is required (see Section 3.4).

The following conditions are to be examined before this type of work is carried out. These are stated in NVIC 7-68 and currently remain applicable.

- Sufficient material in the remaining portion of the member to permit sound attachment of the new metal.

- Good alignment with adjoining old portion. Special attention may be required for new material in way of flanges.

- Sufficient clearance to permit good quality welds.

- If the attachment of the member to the adjoining plating is by riveting, the joint will have to be checked for tightness and corrected as necessary after completion of welding.

The typical procedure of carrying out this repair is illustrated in Figure 7-1. Welding procedures, edge preparations and size of new metal are specified in IACS Rec. No. 47 Part B (see Attachment C).

7.3.2 Gouge and Reweld

Rewelding is normally considered a temporary repair and performed on linear and not branched fractures that have length less than 500mm.[P10.] This type of repair involves removing surface fractures by grinding or other suitable applications and welding the grinded surface. When the work is completed, NDT is essential to ensure the quality of the weld.

IACS Rec. No. 47, Part B Section 6.9 provides the suggested procedure for performing this type of repair, both for shallow cracks found in weld and on surface of plate. See Figure 7-2 for the basic steps of the work.

7.3.3 Insert Plates

The technique of using insert plates in repair work is similar to the crop and renew. It generally involves partial replacement of plate, panel or deep web of a structural section. The work of inserting plate is to be performed in such a way that stress caused by welding is minimized. This can be achieved through adopting an appropriate welding procedure and selecting the ideal size of insert plate.[P33] IACS Rec. No. 47 Part B provides limitations and requirements in terms of material and procedures, such as the size of the insert plate and the sequence of welding.

7.3.4 Doubler Plates

Doublers are normally accepted as a temporary repair. There are suggested procedures for carrying out this type of work. Studies were also carried out to establish design and limitations of doubler plate repairs. More information can be found in IACS Rec. No. 47, Part B (see Attachment C) and SSC-443 Design Guidelines for Doubler Plate Repairs of Ship Structures. For example, slot weld throats may be required for a doubler extending over several supporting elements and corners of the doublers are to be rounded.

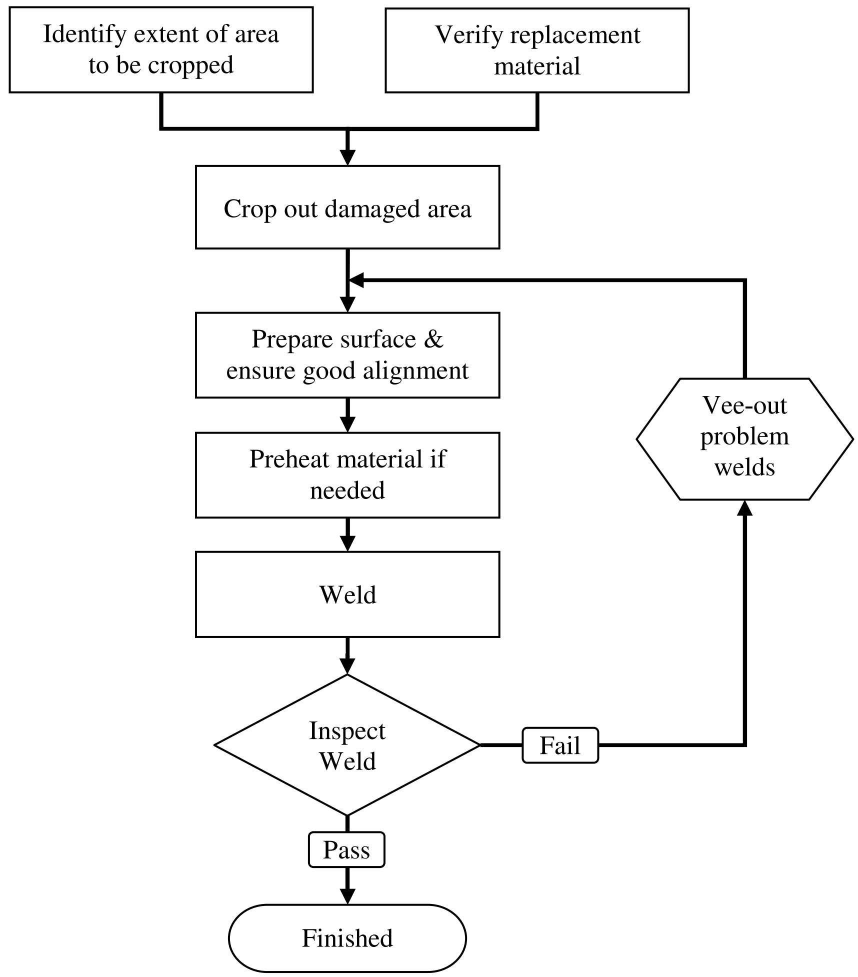


Figure 7-1 Crop and renew

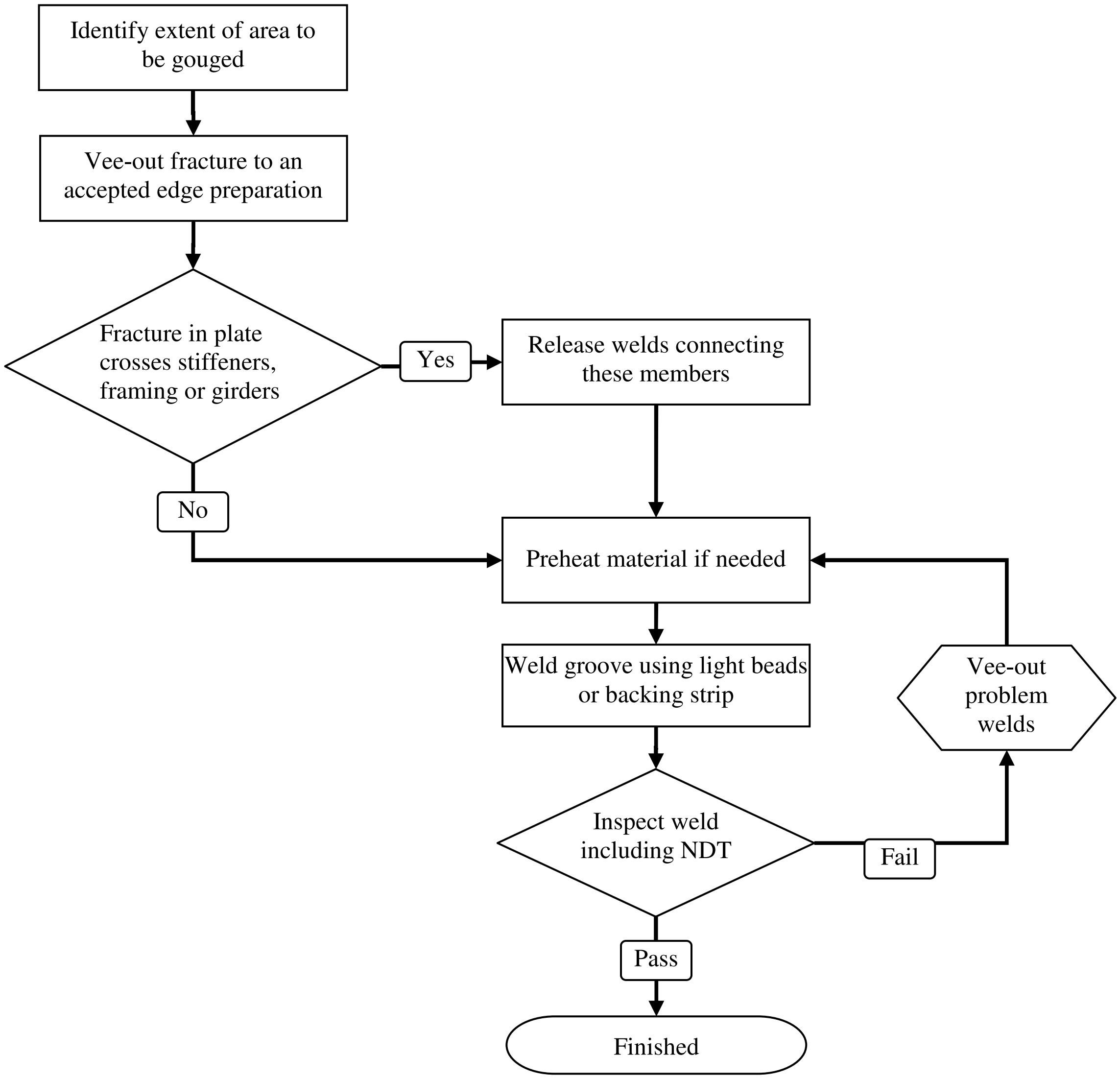


Figure 7-2 Major steps of gouge and reweld

7.3.5 Drill Stop

A simple and economic way to retard or even to stop the growth of a fracture in structural components that cannot be replaced immediately is to drill a hole at the tip of the fracture. This method has been widely used in many industries. Its principle is to transform a tip into a blunt notch and in this way to reduce the stress concentration effect. Research has been carried out in the past several years to determine the appropriate stop holes location and adequate stop hole size to prevent further propagation of a fracture.

In general, the location of a tip is to be verified using NDT methods prior to repair. USCG Navigation and Vessel Inspection Circular No.7-68/IV/A/(5)/(a) (1968) indicates that "*locate the ends of the crack, and approximately two plate thicknesses beyond the end, drill a hole to prevent its extension. The use of dye penetrant or other NDT method is desirable to locate the ends of the crack or to insure the crack does not extend beyond the holes.*". Repair records indicated that different practices are currently adopted in the industry. Some repairers drilled a stop hole half the diameter of the stop hole away from the tip of the fracture, while others positioned the stop hole at the end of the fracture[P33]. See Figure 7-3. The repair process should be witnessed by a Class Surveyor and/or a Flag Administration Inspector.

A practical rule of thumb has been that for steel plates 0.5 ~ 1.0 inch in thickness, the diameter of a stop drilling hole is 0.5 ~ 2.0 times the plate thickness. Instances of a stop hole in thicker plate, say greater than two inches, are rare. In addition, formulation for determination of the minimum diameter of a stop hole is documented in SSC-425 "Fatigue Strength and Adequacy of Weld Repairs", and results of the study indicate that the equation may be conservative. For practical applications, the approaches for determining the adequate size of the stop hole are believed to be not mature and extensive, and further in-depth study is needed.

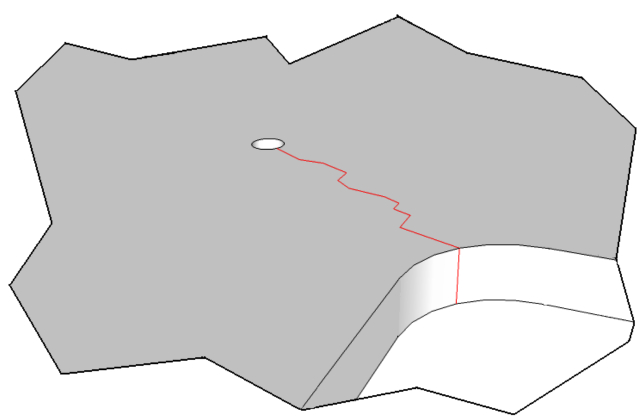


Figure 7-3 Drill stop at tip of fracture after location of tip is verified using NDT

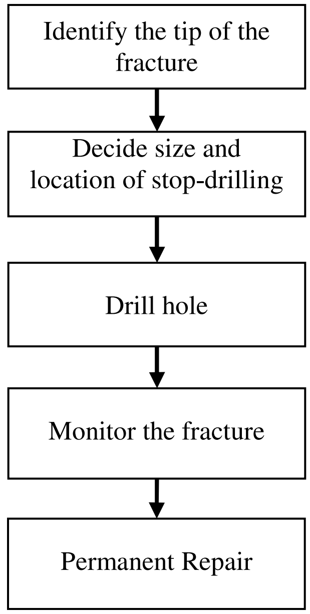


Figure 7-4 Major steps of stop-drilling

7.3.6 Riveting

Riveting is generally performed on vessels operating in the US Great Lakes where vessels may be over 50 years old. This is a complicated and high-cost procedure.

This type of repair technique is carried out either to repair deteriorated rivets or when replacing steel plating. When a rivet on a vessel is found to be deteriorating, the strength of the joint is affected. This is normally determined by inspecting the head and countersunk point of the joint.

During the work, rivet holes are to be checked for alignment and counter-sinking before driving rivets. The inspection on the bolting up is generally the responsibility of the repair yard. The Surveyor or inspector is to check all faying surfaces of plates and frames with a feeler of 0.15”. Any poorly fayed joints are unacceptable.

In some specific cases, riveted and welded plate connections are replaced in kind. For example, bilge and shear strakes are riveted and strakes in between may be welded. Welding work should be performed prior to riveting if possible to prevent weld shrinkage from shearing or slackening the rivets. Welds should also be at least 300mm away from rivet. Ring welding is a temporary fix and is not recommended at highly stressed locations.

If a riveted strake is installed to prevent propagation of hull fracture, i.e., a crack arrestor, the riveted seam is not to be welded. Welding such a plate will eliminate the purpose of the crack arrestor. Therefore, the function of a strake of plating should be determined prior to commencement of repair work.

The work finish is to be tested by water or air test for leak inspection after visual inspection of the rivets and weld quality. Rivets are to be checked for split or burnt heads, excess point overlap and tightness through hammering. Caulking may be used to repair any unsealed rivets but excessive caulking or flattening of rivets should be avoided. Rivets are to be renewed if caulking is found to be excessive. However, a slight "weep" should to be left alone.

7.4 Design Modification

If a fracture recurs due to the presence of a stress concentration, the best repair solution is to eliminate the cause of the stress concentration. This will very likely involve a design modification.

The following are common practices in the industry for this type of repair method.[P31,P32,P33]

- Enhance scantling in size and/or thickness and/or steel grade
- Add brackets
- Add stiffeners
- Add lugs, collar plates or closing plates to cut-outs
- Change structural configuration by applying soft toe, new face plate, radius change, etc.
- Increase welding or full penetration welding locally
- Dressing bead on fillet weld
- Grinding of welding surface
- Peening of surface in way of weld heat-affected zone

Design modification is often recommended though it is not considered a "repair". An appropriate design modification for a fractured structural member depends on the cause of fracture and location of the member. However, fractures found on vessels within five years of service, are most likely caused by a design issue, assuming the structure concerned was fabricated under proper supervision and manufacturing specifications are adhered to. The Design or Engineering office should be contacted.

IACS Recommendations which are vessel type-specific, e.g., IACS Rec. No. 55, 76, 84 and 96, contain suggestions for fracture repair based on the nature and location of fracture, i.e., stress concentration area.

7.5 Recommendations

Steel vessel repair technology has improved over the years to ensure not only cost and time effective performance, but also reliable and safe operation for both personnel and vessels.

As each repair technique mentioned above serves a specific purpose, particular skills, environmental constraints and facilities to produce sound structural repair or “close-to-as-built” standard may be required.

Based on the comparison table in Table 7-1 and checklist in Table 7-2, USCG NVIC 7-68 could be revised accordingly to include recommended industrial standards practiced by most organizations in the industry.

Appendix A. Steel Grades and Properties Specified by IACS

Table A-1 Properties of standard steel grades[P21]

Grade	Yield Strength ReH (N/mm^2) min.	Tensile Strength Rm (N/mm^2)	Elongation ($5.65\sqrt{S_0}$) A5 (%) min.	Charpy V-notch Impact Test						
				Test Temp. TC (°C)	Minimum Average Impact Energy (J)					
					$t \le 50$		$50 < t \le 70$		$70 < t \le 100$	
					Longl.	Trans.	Longl.	Trans.	Longl.	Trans.
A	235	400-520	22	+20	-	-	34	24	41	27
B				0	27	20				
D				-20						
E				-40						
A32	315	440-570	22	0	31	22	38	26	46	31
D32				-20						
E32				-40						
F32				-60						
A36	355	490-630	21	0	34	24	41	27	50	34
D36				-20						
E36				-40						
F36				-60						
A40	390	510-660	20	0	39	26	46	31	55	37
D40				-20						
E40				-40						
F40				-60						

Table A-2 Material classes and grades for ships in general P20

<table>
<tr><th colspan="2" rowspan="2">Structural Member Category</th><th colspan="3">Material Class</th><th colspan="2">Material Grade</th></tr>
<tr><th>Within 0.4L</th><th>Outside 0.4L</th><th>Outside 0.6L</th><th>Within 0.4L</th><th>Outside 0.4L</th></tr>
<tr><td rowspan="3">Secondary</td><td>Longitudinal bulkhead strakes (excluding those under Primary Category)</td><td rowspan="3">I</td><td rowspan="8">-</td><td rowspan="8">-</td><td rowspan="15">-</td><td rowspan="8">A/AH</td></tr>
<tr><td>Deck plating exposed to weather (excluding those under Primary or Special Category)</td></tr>
<tr><td>Side plating</td></tr>
<tr><td rowspan="5">Primary</td><td>Bottom plating (including keel plate)</td><td rowspan="5">II</td></tr>
<tr><td>Strength deck plating (excluding those under Special Category)</td></tr>
<tr><td>Continuous longitudinal members above strength deck (excluding hatch coamings)</td></tr>
<tr><td>Uppermost strake in longitudinal bulkhead</td></tr>
<tr><td>Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank</td></tr>
<tr><td rowspan="9">Special</td><td>Sheer strake at strength deck</td><td rowspan="5">III</td><td rowspan="3">II</td><td rowspan="3">I</td><td rowspan="7">-</td></tr>
<tr><td>Stringer plate in strength deck</td></tr>
<tr><td>Deck strake at longitudinal bulkhead (excluding deck plating in way of inner-skin bulkhead of double-hull ships)</td></tr>
<tr><td>Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations</td><td>II
(Min Class III within cargo region)</td><td>I
(Min Class III within cargo region)</td></tr>
<tr><td>Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers combination carriers and other ships with similar hatch opening configurations</td><td>III</td><td>II
(Within cargo region)</td></tr>
<tr><td>Bilge strake in ships with double bottom over the full breadth and length less than 150m*</td><td>II</td><td>II</td><td>I</td></tr>
<tr><td>Bilge strake in other ships</td><td rowspan="3">III</td><td rowspan="3">II</td><td rowspan="3">I</td></tr>
<tr><td>Longitudinal hatch coamings of length greater than 0.15L</td><td colspan="2" rowspan="2">(Not to be less than D/DH)</td></tr>
<tr><td>End brackets and deck house transition of longitudinal cargo hatch coamings</td></tr>
</table>

Note:

(*) Single strakes required to be of Class III within 0.4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.

Table A-3 Minimum material grades for ships with length exceeding 150m and single strength deck[P20]

Structural Member Category	Material Grade
Longitudinal strength members of strength deck plating	B/AH within 0.4L amidships
Continuous longitudinal strength members above strength deck	B/AH within 0.4L amidships
Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck	B/AH within cargo region

Table A-4 Minimum material grades for ships with length exceeding 250m[P20]

Structural Member Category	Material Grade
Shear strake at strength deck	E/EH within 0.4L amidships
Stringer plate in strength deck	E/EH within 0.4L amidships
Bilge strake	D/DH within 0.4L amidships

Note: Single strakes required to be of Grade E/EH and within .4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.

Table A-5 Minimum material grades for single-side skin bulk carriers subjected to SOLAS regulation XII/6.5.3[P20]

Structural Member Category	Material Grade
Lower bracket of ordinary side frame (*), (**)	D/DH
Side shell strakes included totally or partially between the two points located to 0.125*l* above and below the intersection of side shell and bulge hopper sloping plate or inner bottom plate (**)	D/DH

Note:
(*) The term "lower bracket" means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125l above the intersection of side shell and bulge hopper sloping plate or inner bottom plate.
(**) The span of the side frame, l, is defined as the distance between the supporting structures.

Table A-6 Minimum material grades for ship with ice strengthening[P20]

Structural Member Category	Material Grade
Shell strakes in way of ice strengthening area of plates	B/AH

Table A-7 Material grade requirements for Classes I, II and III[P20]

<table>
<tr><th>Class</th><th colspan="2">I</th><th colspan="2">II</th><th colspan="2">III</th></tr>
<tr><th>Thickness (mm)</th><th>MS</th><th>HT</th><th>MS</th><th>HT</th><th>MS</th><th>HT</th></tr>
<tr><td>t ≤ 15</td><td rowspan="4">A</td><td rowspan="6">AH</td><td rowspan="2">A</td><td rowspan="3">AH</td><td>A</td><td rowspan="2">AH</td></tr>
<tr><td>15 < t ≤ 20</td><td>B</td></tr>
<tr><td>20 < t ≤ 25</td><td>B</td><td rowspan="2">D</td><td rowspan="2">DH</td></tr>
<tr><td>25 < t ≤ 30</td><td rowspan="3">D</td><td rowspan="3">DH</td></tr>
<tr><td>30 < t ≤ 35</td><td rowspan="2">B</td><td rowspan="3">E</td><td rowspan="3">EH</td></tr>
<tr><td>35 < t ≤ 40</td></tr>
<tr><td>40 < t ≤ 50</td><td>D</td><td>DH</td><td>E</td><td>EH</td></tr>
</table>

Appendix B Welding Consumables

Table B-1 Correlation of welding consumables to hull structural steels[P22]

Grades of welding	**Hull structural steel grades**											
Consumables (see note)	A	B	D	E	A32 /36	D32 /36	E32 /36	F32 /36	A40	D40	E40	F40
1, 1S, 1T, 1M, 1TM, IV	X											
1YS, 1YT, 1YM, 1YTM, 1YV	X			X[2)]								
2, 2S, 2T, 2M, 2TM, 2V	X	X	X									
2Y, 2YS, 2YT, 2YM, 2YTM, 2YV	X	X	X		X	X						
2Y40, 2Y40S, 2Y40T, 2Y40M, 2Y40TM, 2Y40V	1)	1)	1)		X	X		X	X			
3S, 3T, 3M, 3TM, 3V	X	X	X	X								
3Y, 3YS, 3YT, 3YM, 3YTM, 3YV	X	X	X	X	X	X	X					
3Y40, 3Y40S, 3Y40T, 3Y40M, 3Y40TM, 3Y40V	1)	1)	1)	1)	X	X	X		X	X	X	
4Y, 4YS, 4YT, 4YM, 4YTM, 4YV	X	X	X	X	X	X	X	X				
4Y40, 4Y40S, 4Y40T, 4Y40M, 4Y40TM, 4Y40V	1)	1)	1)	1)	X	X	X	X	X	X	X	X
1) see note d) 2) see note e)												

NOTES:

a) When joining normal to higher strength structural steel, consumables of the lowest acceptable grade for either material being joined may be used.

b) When joining steels of the same strength level but of different toughness grade, consumables of the lowest acceptable grade for either material being joined may be used.

c) It is recommended that controlled low hydrogen type consumables are to be used when joining higher strength structural steel to the same or lower strength level, except that other consumables may be used at the discretion of the Society when the carbon equivalent is below or equal to 0.41%.When other than controlled low hydrogen type electrodes are used, appropriate procedure tests for hydrogen cracking may be conducted at the discretion of the Society.

d) The welding consumables approved for steel Grades A 40, D 40, E 40 and/or F 40 may also be used for welding of the corresponding grades of normal strength steels subject to special agreement with the Classification Society

e) When joining higher strength steels using Grade 1Y welding consumables, the material thicknesses should not exceed 25 mm.

A Publication and ABS Acceptance of Filler Metals to AWS Specifications

A table of the latest AWS specifications at the time of this printing is given on the following pages. It is recommended that all submittals for AWS approval be to the latest specification. In cases where a particular AWS standard has been reissued, the need for requalification of an approved filler metal will be governed by the following:
In instances where a new AWS specification is essentially unchanged, no new testing is required. At the manufacturer's request, new certificates will be issued indicating the appropriate change in code designations.

Table B-2 AWS specifications

In instances where the new AWS specification has been significantly revised, additional testing will be required, where needed, to conform to the new requirements. New certificates will then be issued to indicate compliance with the newly issued AWS classification. Specification for AWS Classification	
Carbon Steel Electrodes for Shielded Metal Arc Welding	A5.1:2004
Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding	A5.2:2007
Aluminum and Aluminum Alloy Electrodes for Shielded Metal Arc Welding	A5.3:1999
Stainless Steel Electrodes for Shielded Metal Arc Welding	A5.4:2006
Low Alloy Steel Electrodes for Shielded Metal Arc Welding	A5.5:2006
Covered Copper and Copper Alloy Arc Welding Electrodes	A5.6:2008R
Copper and Copper Alloy Bare Welding Rods and Electrodes	A5.7:2007
Filler Metal for Brazing and Braze Welding	A5.8:2004
Bare Stainless Steel Welding Electrodes and Rods	A5.9:2006
Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods	A5.10:1999
Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding	A5.11:2005
Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting	A5.12-98
Surfacing Electrodes for Shielded Metal Arc Welding	A5.13:2000
Nickel and Nickel Alloy Bare Welding Electrodes and Rods	A5.14:2005
Welding Electrodes and Rods for Cast Iron	A5.15-90
Titanium and Titanium Alloy Bare Welding Rods and Electrodes	A5.16:2007
Carbon Steel Electrodes and Fluxes for Submerged Arc Welding	A5.17-97
Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding	A5.18:2005
Magnesium Alloy Welding Electrodes and Rods	A5.19-92R
Carbon Steel Electrodes for Flux Cored Arc Welding	A5.20:2005
Bare Electrodes and Rods for Surfacing	A5.21:2001
Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding	A5.22-95
Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding	A5.23:2007
Zirconium and Zirconium Alloy Bare Welding Electrodes and Rods	A5.24:2005
Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding	A5.25-97
Carbon and Low Alloy Steel Electrodes and Fluxes for Electrogas Welding	A5.26-97

Low Alloy Steel Electrodes for Gas Shielded Metal Arc Welding	A5.28:2005
Low Alloy Steel Electrodes for Flux Cored Arc Welding	A5.29:2005
Consumable Inserts	A5.30:2007
Fluxes for Brazing and Braze Welding	A5.31-92
Welding Shielding Gases	A5.32-97
Nickel-Alloy Electrodes for Flux Cored Arc Welding	A5.34:2007

The above specifications are available from World Engineering Xchange, Ltd., 2671 W 81 St., Hialeah, FL 33016, USA; tel: 888-935-3464, 305-824-1177; fax: 305-826-6195; www.aws.org/standards .

Filler Metal Comparison Chart ABS-AWS

The AWS filler metals listed on the following pages are those which are considered, based on past experience, to be acceptable and meet the minimum Bureau requirements for the indicated grade. Comparisons have been made separately for manual electrodes, wire-flux, and wire-gas combinations.

Table B-3 Manual electrodes grades comparison between AWS and ABS

Manual Electrodes		
ABS **Filler Metal Grade**	**Acceptable** **AWS Classification**	**Suitable for ABS** **Hull Structural Steel Grade**
Ordinary Strength		
1	AWS A5.1-04 E6010, E6011, E6027 E7015, E7016, E7018, E7027, E7028, E7048 E7016-1, E7018-1	A to 12.5mm (0.5 in.) Inclusive
2	AWS A5.1-04 E6010, E6011, E6027 E7015, E7016, E7018, E7027, E7028, E7048 E7016-1, E7018-1	A, B, D
3	AWS A5.1-04 E6010, E6011, E6027 E7015, E7016, E7018, E7027, E7048 E7016-1, E7018-1	A, B, D, E
Higher Strength		
2Y	AWS A5.1-04 E7015, E7016, E7018, E7028, E7048 E7016-1, E7018-1 AWS A5.5-06 E8016-C3, E8018-C3	AH, DH
3Y	AWS A5.1-04 E7016-1, E7018-1 AWS A5.5-06 E8016-C3, E8018-C3	AH, DH, EH

Notes:

1. Electrode classifications E6012, E6013, and E7014 may be used for Grade 1 single pass fillet applications for the attachment of stiffening members in non-structural applications.

2. Electrode classification E7024 may be used for Grade 1 single pass fillet applications in the flat and horizontal welding positions for attachment of stiffening members. In the case of barges for river, bay, and sound service, the E7024 electrode may also be used for single pass lap joints. Acceptability of E7024 electrodes in both cases is contingent on procedure tests being conducted in the shipyard for the particular brand of electrode to demonstrate that adequate penetration and elongation are achieved. Macro test and longitudinal fillet weld guided bend tests are to be included for each size electrode to be used in production. Welding current should be controlled and periodic production tests should be carried out to ensure that adequate weld quality is maintained.

3. Electrode classification E6020 may be used for Grade 1 fillet applications without supplementary testing.

4. For ABS H40 higher strength hull structural steel having 390N/mm^2 (40kgf/mm^2, 57,000 psi) yield strength, the above filler metal grades may be used provided each fabricator carries out a procedure test to ensure that required strength and toughness will be obtained in production.

Table B-4 Wire flux combination grades comparison between AWS and ABS

Wire-Flux Combinations			
ABS Filler Metal Grade	**Acceptable AWS Classification**		**Suitable for ABS Hull Structural Steel Grade**
	AWS A5.17-97	AWS A5.23-07	
Ordinary Strength			
1	F6A0X, F6A2X, F6A4X F6A6X, F7A0X, F7A2X F7A4X, F7A6X		A to 12.5mm (0.5 in.) inclusive
2	F6A0X, F6A2X, F6A4X F6A6X, F7A0X, F7A2X F7A4X, F7A6X		A, B, D
3	F6A2X, F6A4X, F6A6X F7A2X, F7A4X, F7A6X		A, B, D, E
Higher Strength			
1Y	F7A0X, F7A2X, F7A4X F7A6X	F7A0X, F7A2X, F7A4X F8A0X, F8A2X, F8A4X	AH to 12.5mm (0.5 in.) inclusive
2Y	F7A0X, F7A2X, F7A4X F7A6X	F7A0X, F7A2X, F7A4X F8A0X, F8A2X, F8A4X	AH, DH
3Y	F7A2X, F7A4X F7A6X	F7A2X, F7A4X, F8A2X, F8A4X	AH, DH, EH

Notes:

1. The letter X represents the various electrode chemistry designations such as EL8, EM15K, etc.

2. Wire-flux classification F6AZX may be used for Grade 1 applications, and F7AZX and F8AZX may be used for grade 1Y applications provided that the average Charpy V-Notch impact value of the weld metal meets Bureau requirement for the pertinent grade as indicated in the ABS *Rules for Steel Vessels Part 2 Appendix 2 Tables 1 and 2*.

3. Electrodes approved to AWS grades not requiring impact testing may be used for Grade 1 fillet application for the attachment of stiffening members in non-structural applications. They may be specially approved for welding of stiffening members on structural applications. Such approval is contingent on procedure tests being conducted at the shipyard. These tests should be equivalent to those specified for E7024 electrodes as in Note 2 of Appendix B—Manual Electrodes.

4. For ABS H40 higher strength hull structural steel having 390N/mm^2 (40kgf/mm^2, 57,000 psi) yield strength, the above filler metal grades may be used provided each fabricator carries out a procedure test to ensure that the required strength and toughness will be obtained in production.

Table B-5 V-3 wire-gas combinations grades comparison between AWS and ABS

V-3 Wire-Gas Combinations			
ABS Filler Metal Grade	**Acceptable AWS Classification**		**Suitable for ABS Hull Structural Steel Grade**
	AWS A5.18-05	AWS A.5.20-05 (See Note 1)	
Ordinary Strength			
1	ER70S-2, ER70S-3 ER70S-6, ER70S-7	E6XT-1, E6XT-5 E6XT-6, E6XT-8	A to 12.5mm (0.5 in.) inclusive
2	ER70S-2, ER70S-3 ER70S-6, ER70S-7	E6XT-1, E6XT-5 E6XT-6, E6XT-8	A, B, D
3	ER70S-2, ER70S-6 ER70S-7	E6XT-6 E6XT-8, E7XT-5 E7XT-6, E7XT-8	A, B, D, E
Higher Strength			
1YA	ER70S-2, ER70S-3 ER70S-6, ER70S-7	E7XT-1, E7XTG-6 E7XT-5, E7XT-8	AH to 12.5mm (0.5 in.) inclusive
2Y	ER70S-2, ER70S-3 ER70S-6, ER70S-7	E7XT-1, E7XT-6 E7XT-5, E7XT-8, E7XT-9, E7XT-12	AH, DH
3Y	--	E7XT-1J, E7XT-9J, E7XT-12J	AH, DH, EH

Notes:

1. Electrode classifications of AWS A5.20-05 that meet the minimum Bureau requirements for grades 1YA, 2Y, and 3Y are also acceptable for Bureau grades 1, 2, and 3, respectively.

2. Electrode classifications ER70S-4, ER70S-5, ER70S-G, E7XT-4, E7XT-7, E7XT-11, and E7XT-G which do not require impact testing may be used for welding ordinary and higher strength steels provided that the average Charpy V-Notch impact value of the weld-metal meets the Bureau requirement for the pertinent grade as indicated in the ABS *Rules for Steel Vessels Part 2 Appendix 2 Tables 1 and 2*.

3. Electrode classifications E6XT-4, E6XT-7, E6XT-11, and E6XT-G may be used for welding ordinary strength steel provided that the average Charpy V-Notch impact value of the weld metal meets the Bureau requirement for the pertinent grade as indicated in the ABS *Rules for Steel Vessels Part 2 Appendix 2 Tables 1 and 2*.

4. Electrode classifications E7XT-2, E7XT-3, E7XT-10, and E7XT-GS that do not specify all weld metal tensile requirements may be specially approved for fillet weld applications.

5. Electrodes approved to AWS grades not requiring impact testing may be used for Grade 1 fillet application for the attachment of stiffening members in non-structural applications. They may be specially approved for welding of stiffening members on structural applications. Such approval is contingent on procedure tests being conducted at the

shipyard and should be equivalent to those specified for E7024 electrodes as in Note 2 of Appendix B—Manual Electrodes.

6. For ABS H40 higher strength hull structural steel having 390N/mm^2 (40kgf/mm^2, 57,000 psi) yield strength, the above filler metal grades may be used provided each fabricator carries out a procedure test to ensure that the required strength and toughness will be obtained in production.

Appendix C Industry Experiences With Fracture Repairs

C.1 Data Sources and Data Analysis

The ABS survey reports spanning seven years from 2002 to 2008 were pooled to form an in-house database. The survey reports relating to fractures of hull structures were extracted from this database. These reports were further broken down into categories of ship types, location and frequency of fractures, fracture lengths, and repairs. When considered necessary, data from external sources was used to augment data from ABS survey reports in this study of general trends.

For this report, the focus is on data of large commercial ships, i.e., oil carriers, bulk carriers, container carriers, etc (10k DWT and above). It should be noted that this snapshot fracture study was based mostly on ABS records for the time span indicated above. To help put this into context, data is also presented on the world fleet of commercial ships. The trends found in this study provide some information on fracture experiences and fracture repairs. The world fleet experience may differ from the above due to class and owner operation profiles.

All data is used and presented here anonymously to protect confidentiality.

ABS Eagle Survey Manager System

The ABS Survey Manager system is a database and reporting system that is in use worldwide by ABS Surveyors. The application is divided into several modules that together provide the means for collection and maintenance of vessel data for which ABS provides services. ABS Surveyors started to use the Survey Manager system for electronic recording of survey findings in 2002.

Query of fracture reports

The Surveyor records in the Survey Manager system during the period of 2002 to 2008 were queried to extract the survey findings related to fractures to structures.

1. Steel vessels were selected, and records of offshore units were not considered.
2. Survey reports that have key words of “fracture” or “crack” were extracted from the ABS O2K system.
3. Oil carriers and bulk carriers with deadweights greater than 10,000 tonnes and container carriers with a capacity greater than 10 TEU were included in this report.

This query returned about 20,000 individual reports.

These fracture reports were then filtered to remove duplicate reports and findings not pertaining to structures.

Data tagging and data analysis

After an initial review, reports were filtered and manually tagged with the following details:

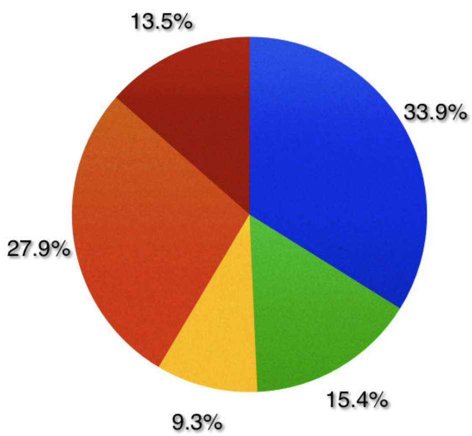
- Vessel type & category
- Age of vessel at time of fracture report
- Compartment
- Structural locations
- Fracture details (i.e., length, if available)
- Cause of fracture (if available, otherwise consider to be due to wear and tear)
- Repair type and details (if available)

Charts and tables were used to illustrate the trends in reported fractures.

C.2 ABS and World Fleets of Commercial Ships

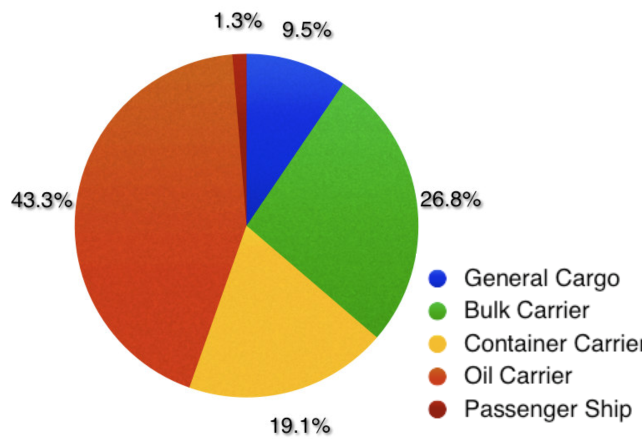
The world fleet of commercial ships is presented in order to provide a basis for comparing the analyzed records with all trading vessels.

Table 3-1 and Figure 3-1 show the vessel size breakdown of the world fleet of commercial vessels. The information was taken from Lloyd's Register Fairplay, July 2009. There were a total of 50,503 vessels in the world fleet.



(a) World fleet (50,503 vessels)

(Lloyd's Register Fairplay 2009)



(b) ABS Fleet (2,717 vessels)

(ABS Record book Dec 2009)

Figure C-1 Vessel size breakdown by vessel number

Table C-1 World & ABS fleet breakdown

Vessel Type	World Fleet		ABS Fleet	
	Number of Vessels	Percent of World Fleet	Number of Vessels	Percent of ABS Fleet
General Cargo	17104	33.87	259	9.53
Bulk Carrier	7787	15.42	728	26.79
Container Carrier	4678	9.26	520	19.14
Oil Carrier	14095	27.91	1174	43.31
Passenger Ship	6839	13.54	36	1.33

The number of ABS-classed vessels at the end of 2009 was 10,842. From the ABS fleet, only 2717 vessels were either general cargo, bulk carrier, container carrier, oil carrier or passenger ship.

C.3 Oil Carriers

C.3.1 ABS and world oil carrier fleets

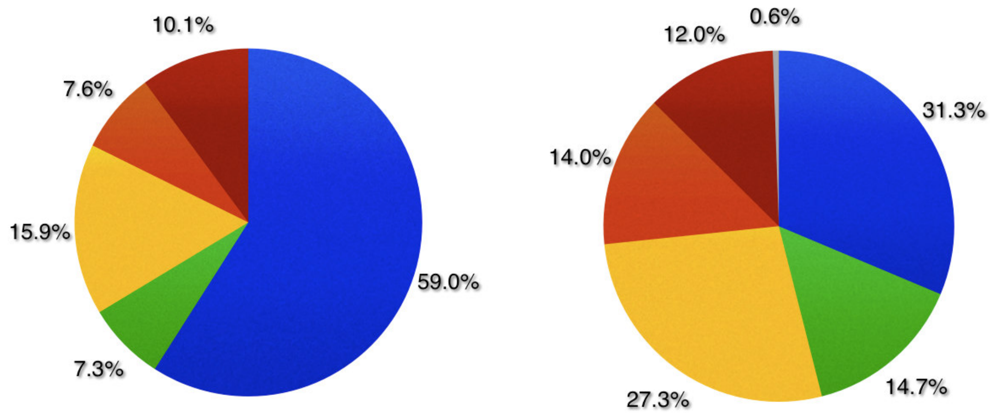
Oil carriers are ordinarily split into six size categories based on their deadweight tonnage as follows:

Figure C-2 Size categories of oil carriers

Size profile

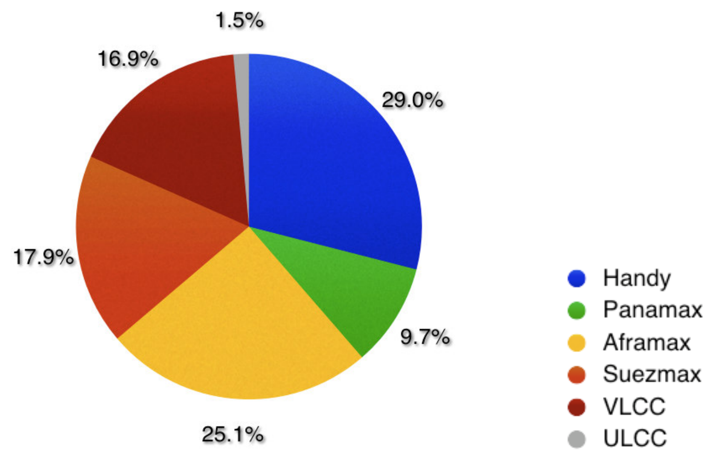
The world fleet contains nearly twice the percentage of Handy-sized vessels compared to the ABS fleet. The analyzed ABS oil carriers have a representative size breakdown when evaluated against the entire ABS oil carrier fleet. See Figures 3-3.

Approximately 29% of the analyzed ABS oil carriers are of 60,000 DWT (Handy) or less and over 63% are under 120,000 DWT (Handy, Panamax, Aframax).



(a) World fleet (5348 vessels) (Clarkson Research Services, March 2010)

(b) ABS fleet (1065 vessels) (ABS Record book Dec 2009)



(c) Analyzed ABS Fleet

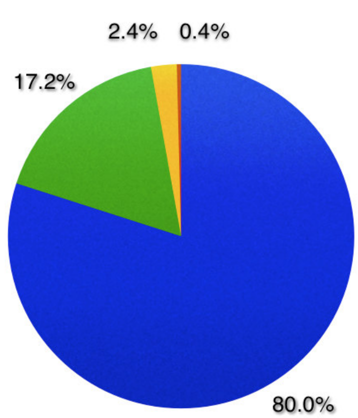
Figure C-3 Size profile of oil carriers

Oil carriers built since the early 1990's are mostly double hulls. Those built before 1990 are mostly single hulls.

Age profile

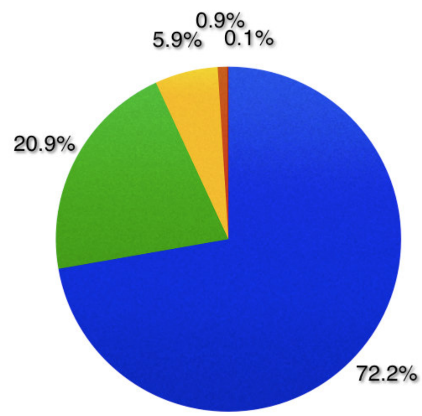
80% of the world oil fleet is less than ten years of age; moreover, 50% are less than five years of age and have only been subject to limited survey as the 1st renewal survey is conducted after five years. The average age of the world oil carrier fleet across all size categories is seven years with the youngest vessel size categories being VLCC vessels.

The analyzed ABS oil carrier fleet has an average age of 18 years. Over one-third of the vessels were in the 10 to 20-year age range. One-quarter of the analyzed oil carrier were less than 10 years of age, compared to 80% of the world fleet.



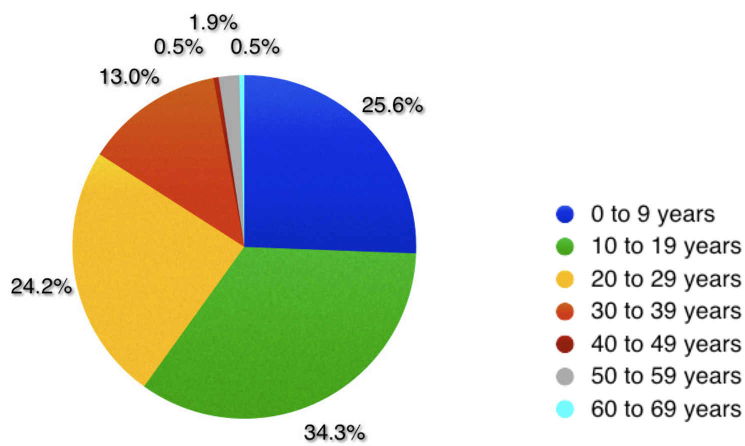
(a) World Fleet (1932 vessels)

(Lloyd's Register Fairplay 2009)



(b) ABS Fleet (1065 vessels)

(ABS Record book Dec 2009)



(c) Analyzed ABS Fleet

Figure C-4 Age profile of oil carriers

C.3.2 Fractures reported in oil carriers

Vessel age when fractures were reported

The distribution of reported fractures over the ship's life for each ship size category is given in the following table and figure. The age range in which most fractures were reported is 15-19 years.

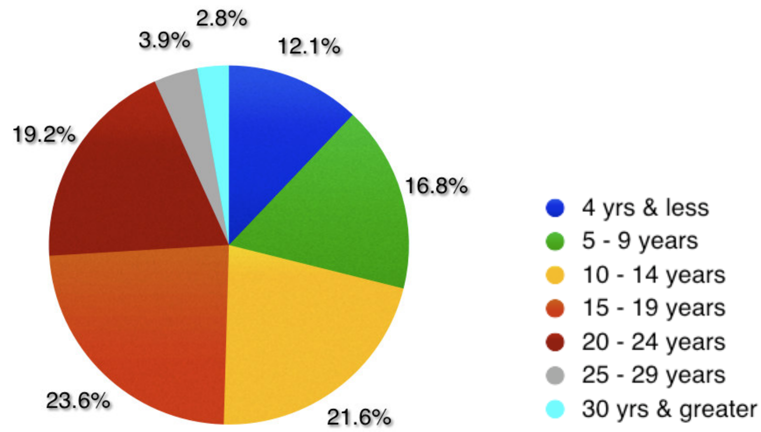


Figure C-5 Vessel age when fractures were reported

Table C-2 Vessel age at time of report

Age	Vessel Size						
	Handy (29.0%)	Panamax (9.7%)	Aframax (25.1%)	Suezmax (17.9%)	VLCC (16.9%)	ULCC (1.4%)	Total / Sample
4 years and less	5.07%	40.00%	16.33%	9.93%	13.33%	12.50%	12.08%
5 – 9 years	5.43%	11.43%	13.15%	28.48%	30.91%	37.50%	16.82%
10 – 14 years	14.13%	5.71%	31.47%	14.57%	29.70%	0.00%	21.56%
15 – 19 years	22.46%	28.57%	13.55%	45.03%	20.00%	25.00%	23.59%
20 – 24 years	38.04%	14.29%	19.52%	0.66%	6.06%	0.00%	19.19%
25 – 29 years	5.80%	0.00%	5.98%	1.32%	0.00%	25.00%	3.95%
30 years and greater	9.06%	0.00%	0.00%	0.00%	0.00%	0.00%	2.82%

Vessel age of different vessel size when fractures were reported

In Handy-size vessels, the age range with most fractures was not reported until the vessel was between 20 and 24 years of age. However, in Panamax-size vessels, 40% of reported fractures occurred in the first five years of the vessel's life.

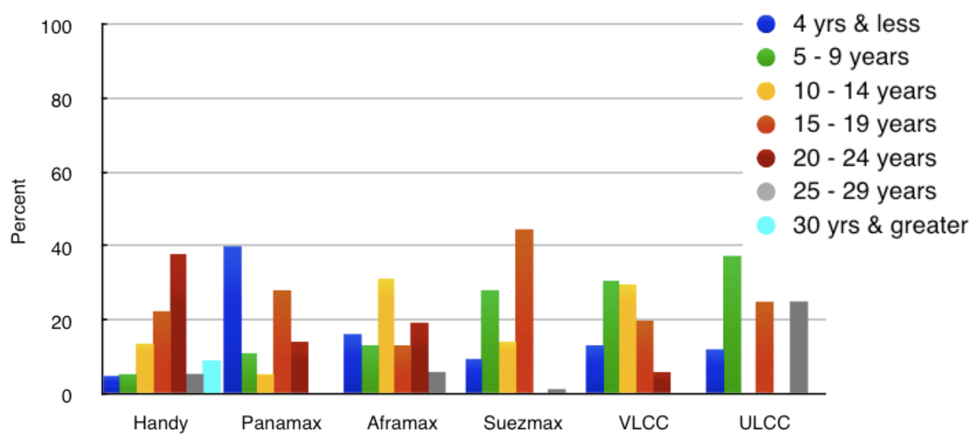


Figure C-6 Vessel age when fracture reported

Fracture reports by compartment

Overall, 43.2% of the reported fractures have been recorded in the ballast tank. Cargo tanks represented another major portion, making up 35.2% of the reported fractures. All other compartments accounted for 11.6% of reported fractures.

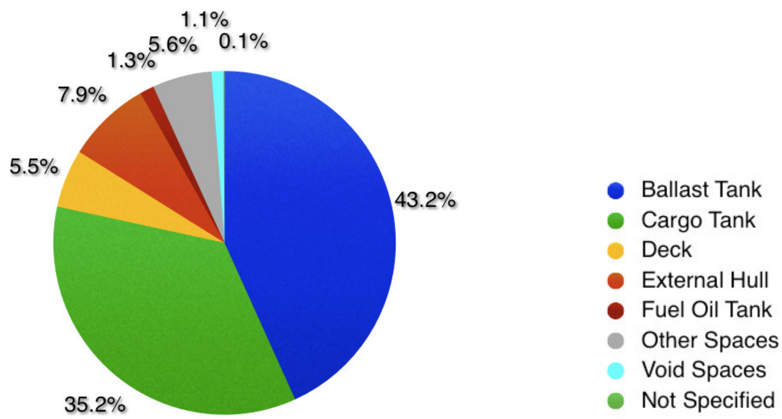


Figure C-7 Oil carriers: Fracture report by compartment

Table C-3 Oil carriers: Fracture report by compartment and vessel size

Compartment	Vessel Size						
	Handy (29.0%)	Panamax (9.7%)	Aframax (25.1%)	Suezmax (17.9%)	VLCC (16.9%)	ULCC (1.4%)	Total
Ballast Tank	38.71%	40.00%	41.43%	46.71%	49.40%	75.00%	43.23%
Cargo Tank	40.86%	17.14%	40.64%	32.89%	25.00%	0.00%	35.16%
Deck	5.38%	8.57%	4.78%	9.87%	2.38%	0.00%	5.49%
External Hull	6.45%	22.86%	7.17%	4.61%	10.71%	25.00%	7.95%
Fuel Oil Tank	2.87%	0.00%	0.00%	1.32%	1.19%	0.00%	1.34%
Other Spaces	5.02%	8.57%	5.58%	4.61%	7.14%	0.00%	5.60%
Void Spaces	0.36%	2.86%	0.40%	0.00%	4.17%	0.00%	1.12%
Not Specified	0.36%	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%

Fracture reports by compartment and vessel size

With an increase in size of the oil carriers, fractures were more likely to take place in the ballast tank, increasing from 38.7% of reports in Handy-size oil carriers to 75.0% in ULCCs. Fracture counts in cargo tanks appeared to be higher in cargo tanks for Handy and Aframax-size vessels, accounting for over 40% of their findings.

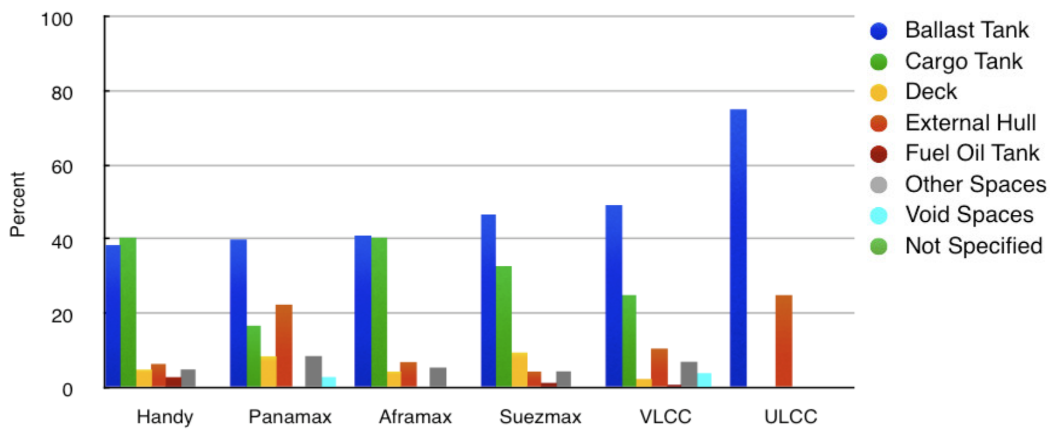


Figure C-8 Oil carriers: Fracture report by compartment and vessel size

Fracture reports by structure type

Overall, 39.0% of the reported fractures have been recorded in the sideshell, followed by 25.4% in the deck area and 18.4% in the inner bottom. Together, these account for 82.8% of the reported fractures.

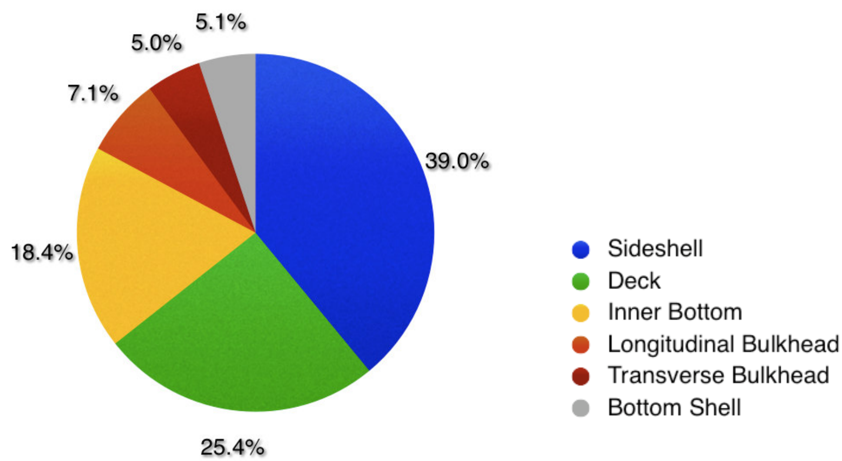


Figure C-9 Oil carriers: Fracture report by structure type

Table C-4 Oil carriers: Fracture report by structure type and vessel size

Structures Type	Vessel Size						
	Handy (29.0%)	Panamax (9.7%)	Aframax (25.1%)	Suezmax (17.9%)	VLCC (16.9%)	ULCC (1.4%)	Total
Sideshell	38.82%	47.62%	36.09%	31.40%	47.87%	100.00%	39.01%
Deck	17.11%	19.05%	31.36%	36.36%	17.02%	0.00%	25.35%
Inner Bottom	25.66%	4.76%	16.57%	12.40%	22.34%	0.00%	18.44%
Longitudinal Bulkhead	9.21%	0.00%	5.33%	11.57%	3.19%	0.00%	7.09%
Transverse Bulkhead	5.26%	9.52%	2.96%	4.96%	7.45%	0.00%	4.96%
Bottom Shell	3.95%	19.05%	7.69%	3.31%	2.13%	0.00%	5.14%

Fracture reports by structure and vessel type

Clearly, fracture reports in the sideshell are the most widely reported. However, Suezmax-size vessels have slightly more fracture reports for the deck area (36% in the deck compared to 31% in the sideshell). Fractures reports within the inner bottom account for over 20% of reports in Handy and VLCC-size vessels.

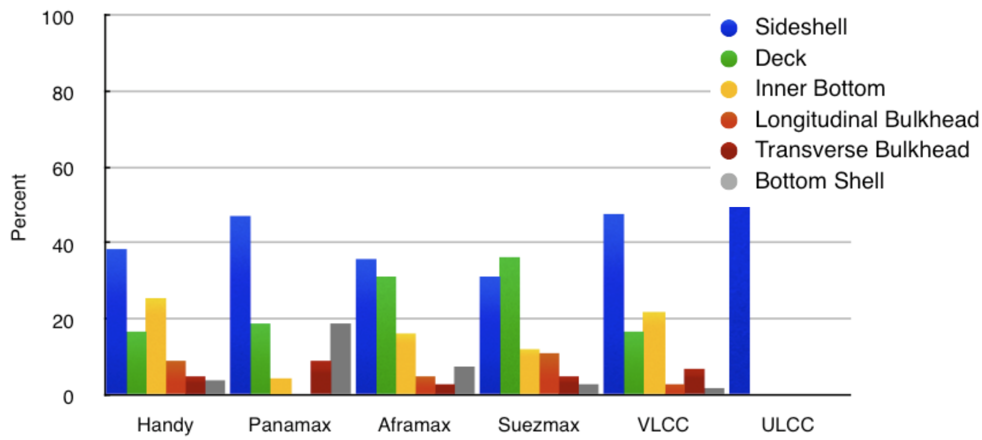


Figure C-10 Oil carriers: Fracture report by structure type and vessel size

Fracture reports by compartment and structure type

Table C-5 Oil carriers: Fracture report by compartment and structure type

	Ballast Tank	Cargo Tank	Deck	External Hull	FO Tank	Void Spaces	Other Spaces	Total
Sideshell	47.93%	26.56%	9.52%	67.31%	57.14%	66.67%	26.09%	39.01%
Deck	10.33%	36.98%	90.48%	3.85%	14.29%	16.67%	21.74%	25.35%
Inner Bottom	22.31%	22.40%	0.00%	9.62%	0.00%	0.00%	8.70%	18.44%
Longitudinal Bulkhead	9.09%	7.81%	0.00%	0.00%	0.00%	0.00%	13.04%	7.09%
Sideshell	4.13%	4.69%	0.00%	0.00%	28.57%	0.00%	30.43%	4.96%
Deck	6.20%	1.56%	0.00%	19.23%	0.00%	16.67%	0.00%	5.14%

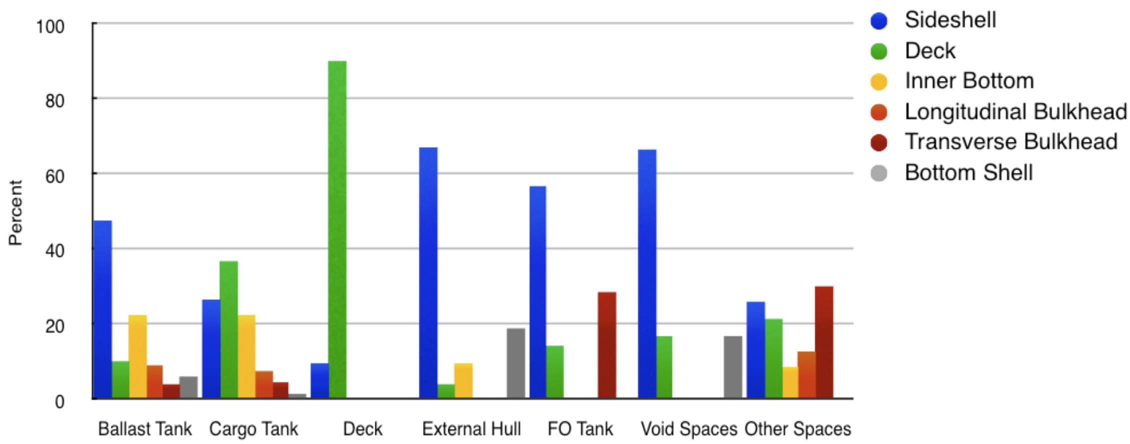


Figure C-11 Oil carriers: Fracture report by compartment and structure type

Reported Fracture length

Fracture length was reported in less than 20% of ABS oil carrier survey reports. This is because Surveyors are not required to record the fracture length in their reports.

The size range in which most cracks were discovered was 2.1 to 6.0 inches in length (34.8%). 27.8% of reported fractures were 0.0-2.0 inches in length. 37.3% of reported fractures were longer than 6.0 inches in length.

An external consultant was approached for a study on their records of fracture length in 10 TAPS (Trans-Alaska Pipeline Service) tankers. This external database shows that a large portion of reported fractures were in the range of 2.1 to 6.0 inches. It should be noted that this external consultant may have used different NDE and their visual inspections likely do not follow class procedure. As a result, it is not recommended to directly compare the recorded fracture length between ABS data and other data sources.

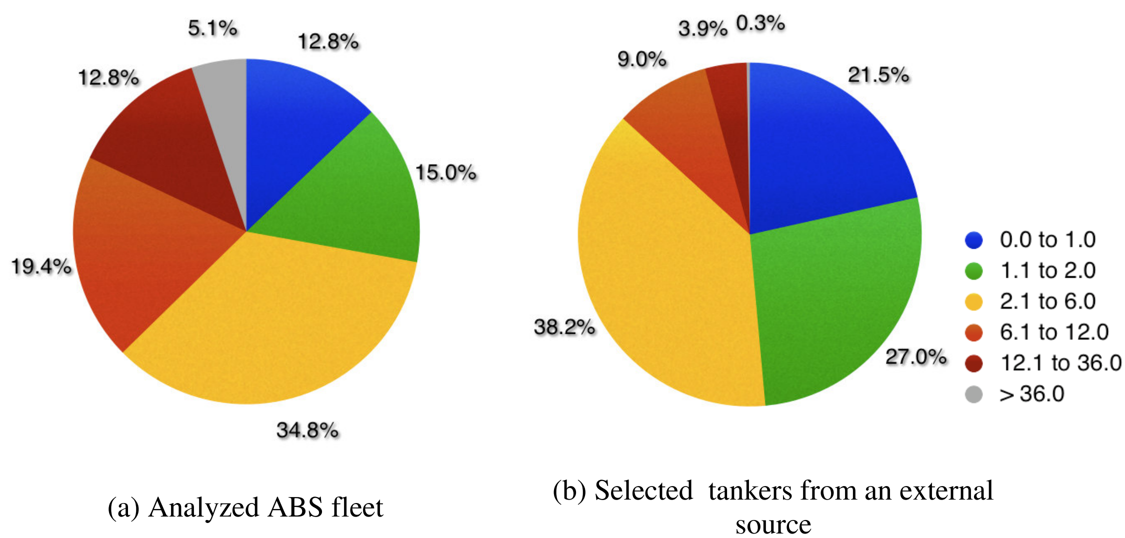


Figure C-12 Oil carriers: Reported fracture length (inches)

Table C-6 Oil carriers: Reported fracture length by vessel size

Length (inches)	Vessel Size						
	Handy (29.0%)	Panamax (9.7%)	Aframax (25.1%)	Suezmax (17.9%)	VLCC (16.9%)	ULCC (1.4%)	Total / Sample
0.0 to 1.0	20.19%	12.50%	8.57%	8.57%	5.45%	100.00%	12.82%
1.1 to 2.0	21.15%	0.00%	18.57%	8.57%	5.45%	0.00%	15.02%
2.1 to 6.0	34.62%	25.00%	24.29%	42.86%	45.45%	0.00%	34.80%
6.1 to 12.0	9.62%	50.00%	30.00%	14.29%	23.64%	0.00%	19.41%
12.1 - 36.0	9.62%	12.50%	11.43%	20.00%	16.36%	0.00%	12.82%
36.0+	4.81%	0.00%	7.14%	5.71%	3.64%	0.00%	5.13%

Reported fracture length by vessel size

For Handysize, Suezmax and VLCC's, the majority of reported fracture lengths were in the range of 2.1 to 6.0 inches in length, while the data on Panamax and Aframax showed more fractures in the 6.1 to 12.0 inch length. Statistically, few fracture lengths were recorded for ULCC's, thus all fractures recorded were less than 1.0 inch.

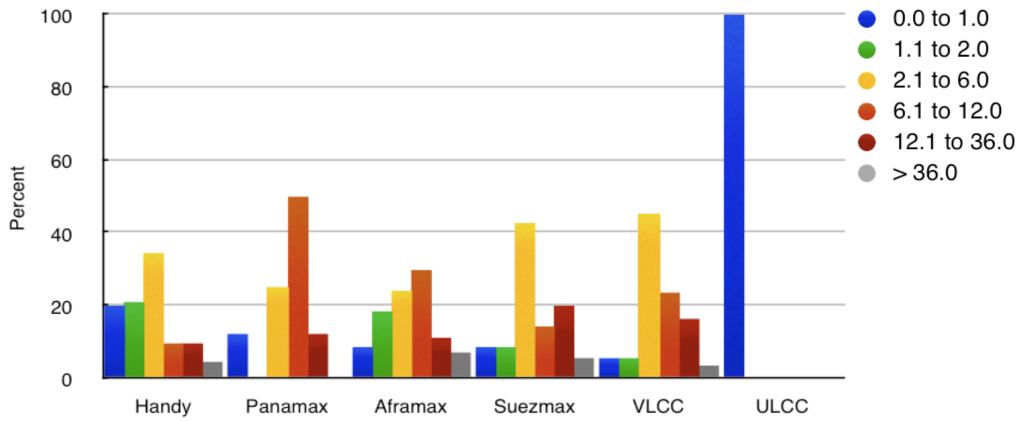
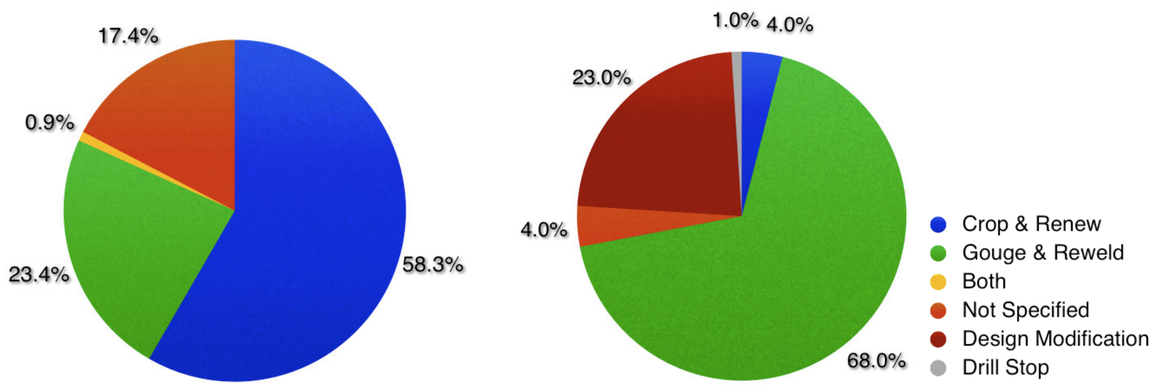


Figure C-13 Oil carriers: Reported fracture length by vessel size

Fracture repairs

Crop and renew is the most widely used repair method (58.3%).

Further study on repairs to the ten TAPS tankers reveals that gouge and reweld was commonly used (68%), followed by design modifications (23%) and crop and renewal. It is to be noted that repair involving insert plates is included within crop and renew repairs.



(a) Analyzed ABS Data (b) Consultants Data

Figure C-14 Oil carriers: Repair recommendations

Causes of reported fractures

The majority of reported fractures were structural failures (95.6%). All other fractures account for fewer than 5% of reports.

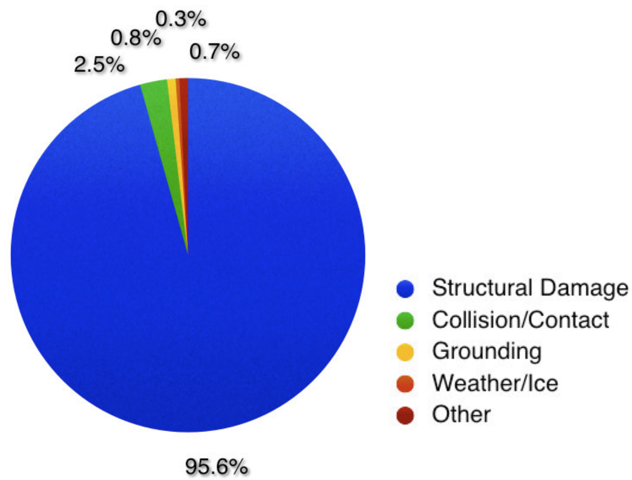


Figure C-15 Oil carriers: Cause of reported fractures

C.4 Bulk Carriers

7.5.1 ABS and world bulk carrier fleets

Bulk carriers are ordinarily split into four size categories based on their deadweight tonnage as follows:

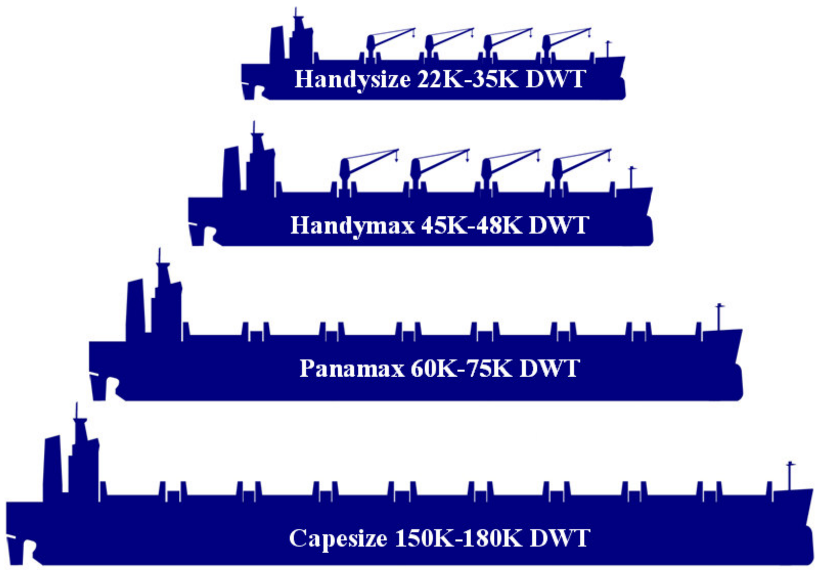
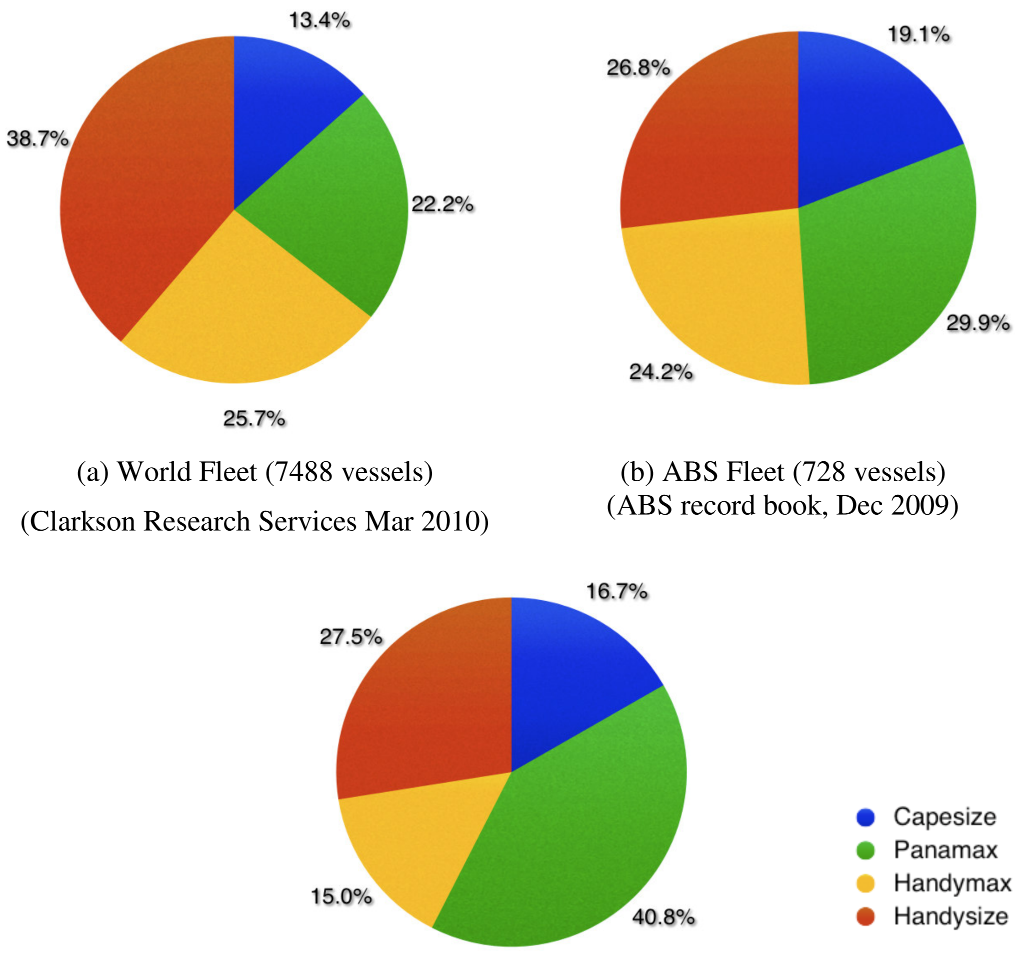


Figure C-16 Size categories of bulk carriers

Size profile

Overall, the analyzed ABS fleet included a larger percentage of smaller-sized vessels than the world fleet. The world fleet contains a larger percentage of Handymax and Handy-size vessels, while the ABS fleet has a greater percentage of Capesize and Panamax-size vessels.

From the analyzed ABS fleet, approximately 41% of the vessels were in the Panamax-size category, and Handysize vessels accounted for over 27% of vessels.



(a) World Fleet (7488 vessels)
(Clarkson Research Services Mar 2010)

(b) ABS Fleet (728 vessels)
(ABS record book, Dec 2009)

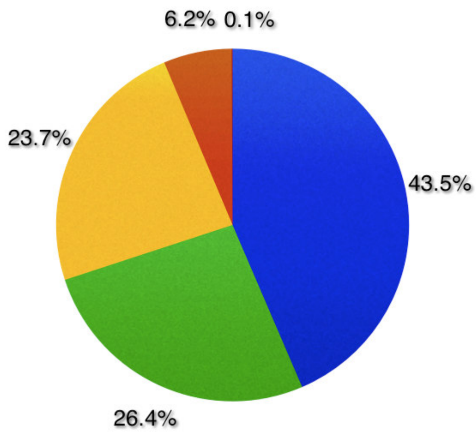
(c) Analyzed ABS Fleet

Figure C-17 Size profile of bulk carriers

Great Lakes bulk carriers were not included in this study.

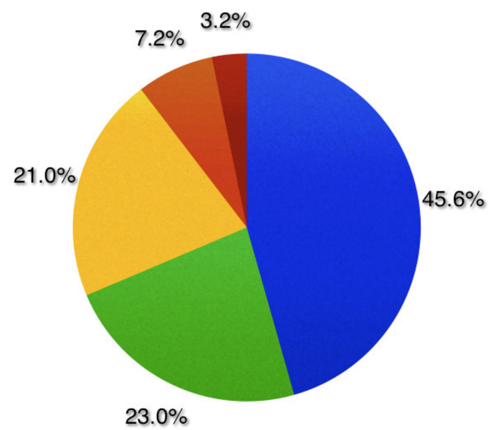
Age profile

The analyzed ABS bulk carrier fleet has an average age of 18 years. Over 90% of the fleet is less than 30 years of age and 54% of the fleet is less than 20 years of age.



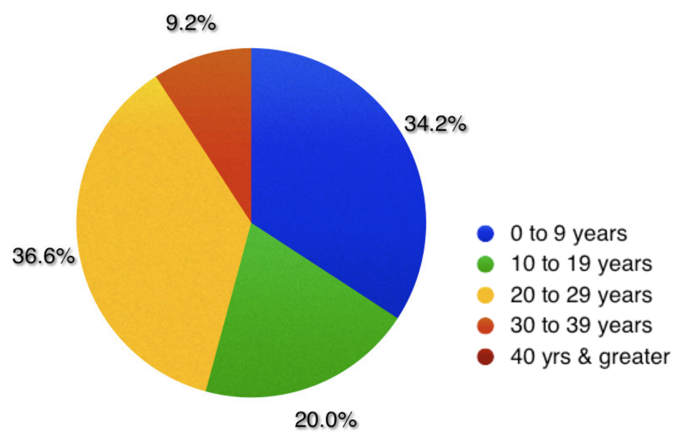
(a) World Fleet (5635 vessels)

(Intercargo Benchmarking BC 2009-10)



(b) ABS Fleet (728 vessels)

(ABS Record book Dec 2009)



(c) Analyzed ABS Fleet

Figure C-18 Age profile of bulk carriers

C.5 Fracture reported in bulk carriers

Vessel age when fractures were reported

The distribution of reported fractures over the ship's life for each ship size category is given in the following table and figure. The majority of fractures (51.24%) were reported when the vessel was between five and nine years of age.

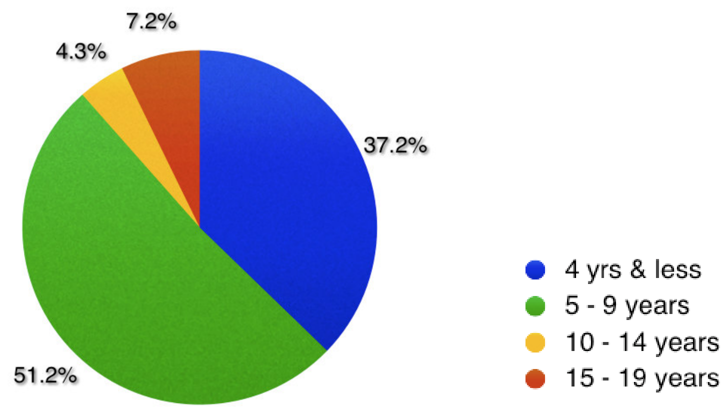


Figure C-19 Vessel age at time of report

Table C-7 Vessel age at time of report

Vessel Age	Handysize	Handymax	Panamax	Capesize	Total
4 years and less	37.63%	46.81%	44.79%	25.00%	37.25%
5 – 9 years	45.16%	46.81%	42.94%	66.43%	51.24%
10 – 19 years	2.15%	2.13%	6.75%	3.57%	4.29%
20 – 29 years	15.05%	4.26%	5.52%	5.00%	7.22%

Fracture reports by compartment

Overall, 39.9% of the reported fractures have been recorded in the ballast tank. The highest percentage of reports was recorded in Capesize bulk carriers with 55.93% of all fracture reports being found in the ballast tanks.

The cargo hold represented one-third of all reports. Reports in the ballast tank dominated for all vessel categories, except Panamax-size vessels where the majority of reports were for the cargo hold.

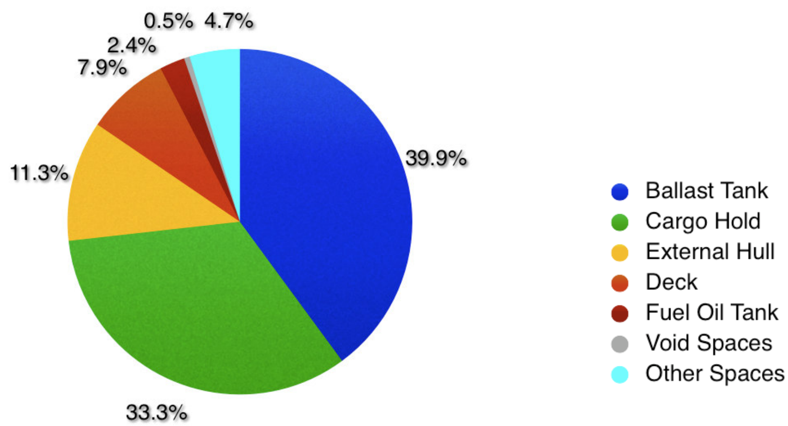


Figure C-20 Bulk carriers: Fracture reports by compartment

Table C-8 Bulk carriers: Fracture report by compartment and vessel size

Compartment	Vessel Size				
	Handysize	Handymax	Panamax	Capesize	Total
Ballast Tank	37.04%	47.62%	25.90%	55.93%	39.90%
Cargo Hold	34.57%	16.67%	46.76%	22.88%	33.33%
External Hull	13.58%	14.29%	15.11%	4.24%	11.29%
Deck	11.11%	7.14%	5.04%	9.32%	7.87%
Fuel Oil Tank	1.23%	7.14%	2.16%	1.69%	2.36%
Void Spaces	0.00%	4.76%	0.00%	0.00%	0.52%
Other Spaces	2.47%	2.38%	5.04%	5.93%	4.72%

Fracture reports by compartment and vessel size

With an increase in the size of bulk carriers, fractures were more likely to take place in the ballast tank, increasing from 37.04% of reports in Handy-size oil carriers to 55.93% in Capesize. Fracture counts in cargo tanks appeared to be higher in cargo tanks for Panamax-size vessels, accounting for over 46.76% of their findings.

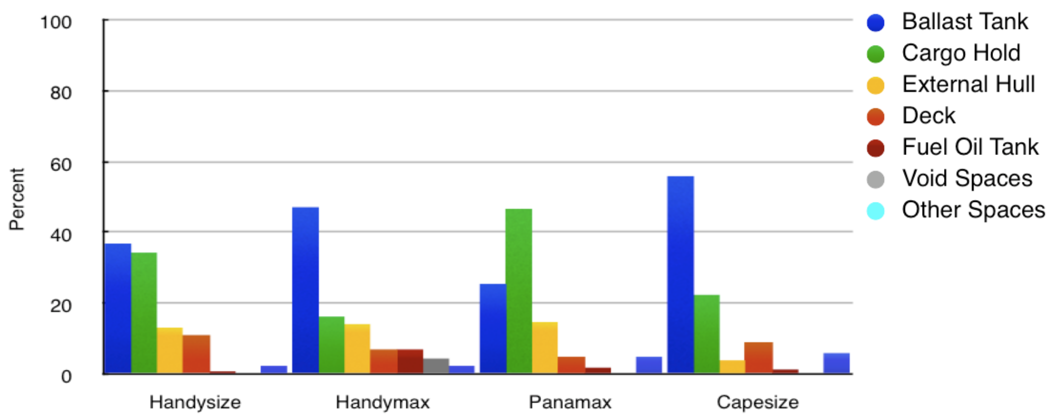


Figure C-21 Bulk carriers: Fracture report by compartment and vessel size

Fracture reports by structure type

Overall, 31.8% of the fracture reports have been recorded in the sideshell, followed by 20.4% of reports in the deck area, and 19.5% in the bottom shell. Together, these account for 71.8% of the reported fractures.

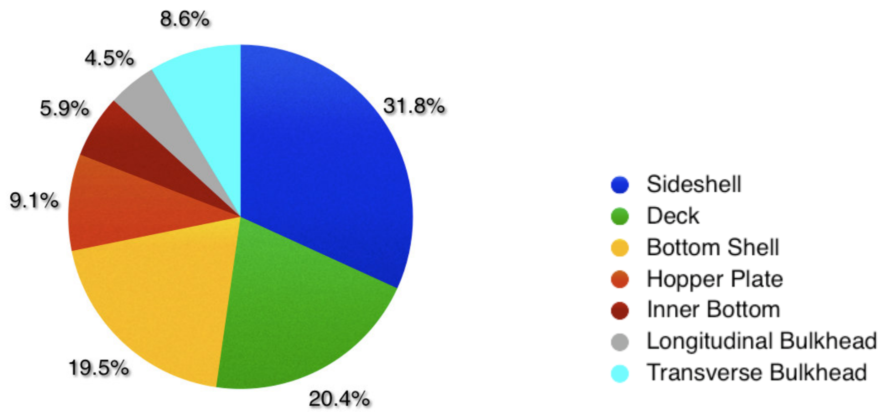


Figure C-22 Bulk carriers: Fracture report by structure type

Table C-9 Bulk carriers: Fracture report by structure type and vessel size

Structure Type	Vessel Size				
	Handysize	Handymax	Panamax	Capesize	Total
Sideshell	34.78%	12.12%	19.18%	52.94%	31.82%
Deck	17.39%	6.06%	20.55%	29.41%	20.45%
Bottom Shell	4.35%	63.64%	24.66%	2.94%	19.55%
Hopper Plate	8.70%	6.06%	17.81%	1.47%	9.09%
Inner Bottom	4.35%	0.00%	10.96%	4.41%	5.91%
Longitudinal Bulkhead	17.39%	6.06%	0.00%	0.00%	4.55%
Transverse Bulkhead	13.04%	6.06%	6.85%	8.82%	8.64%

Fracture reports by structure type and vessel size

In Capesize vessels, more than half of all fracture reports have been for the sideshell and nearly one-third are reported in the deck area. Handymax-size vessels have a low percentage of findings in the sideshell with only 12.1% of their reports, and 63.6% recorded for the bottom shell.

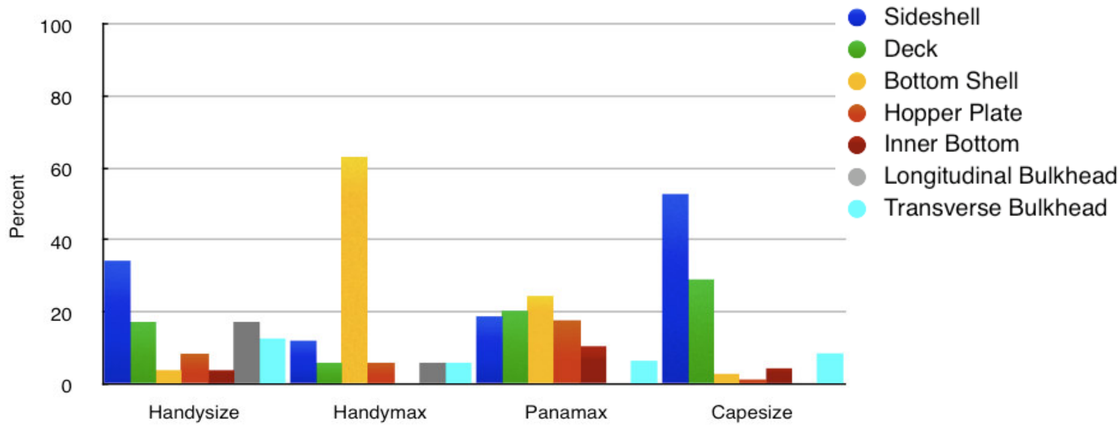


Figure C-23 Bulk carriers: Fracture report by structure type and vessel size

Reported fracture length

Fracture length was reported in less than 20% of ABS container carrier survey reports. This is because the Surveyor is not required to record the fracture length.

The majority of reported fractures were in the range of 2.1 to 6.0 inches in length (37.9%). 15.5% of reported fractures were 0.0-2.0 inch in length, and 56.5% of reported fractures were longer than 6.0 inches in length.

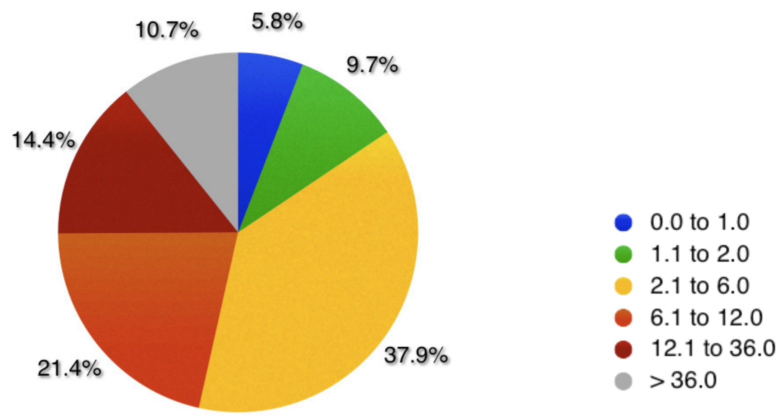


Figure C-24 Bulk carriers: Reported fracture length (inches)

Table C-10 Bulk carriers: Reported fracture length by vessel size

Fracture Length (inches)	Handysize	Handymax	Panamax	Capesize	Total
0.0-1.0	0.00%	0.00%	7.41%	9.52%	5.83%
1.1-2.0	7.14%	14.29%	7.41	14.29	9.71
2.1-6.0	35.71%	7.14%	42.86%	18.52%	9.52%
6.1-12.0	28.57%	42.86%	18.52%	9.52%	21.36%
12.1-36.0	21.43%	21.43%	12.96%	9.52%	14.56%
>36.0	7.14%	14.29%	11.11%	9.52%	10.68%

Reported fracture length by vessel size

In Handymax-size vessels, 42.9% of reported fractures were in the range of 6.1 to 12.0 inches in length.

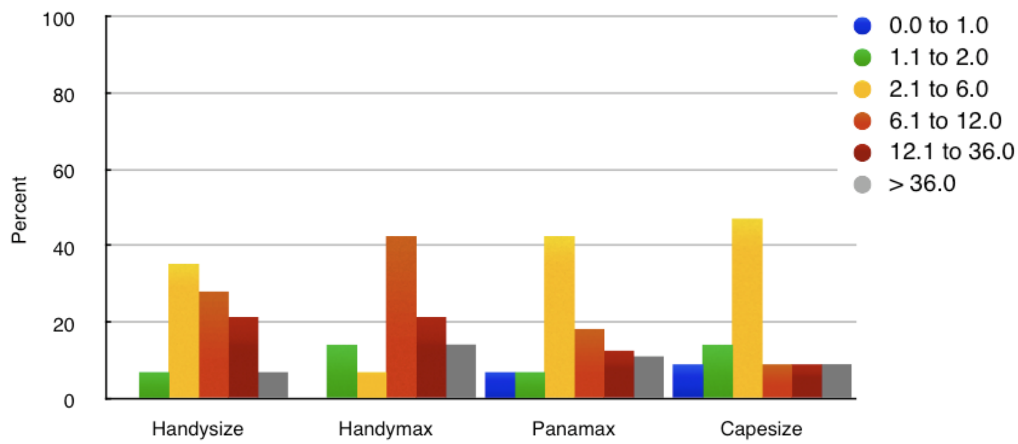


Figure C-25 Reported fracture length by vessel size category

Repairs
Crop and renew is the most commonly recommended repair method at 44%, followed by gouge and reweld at 20%. Over one-third of all bulk carrier fracture reports did not list a repair recommendation. It is to be noted that repairs involving insert plates are included within crop and renew repairs.

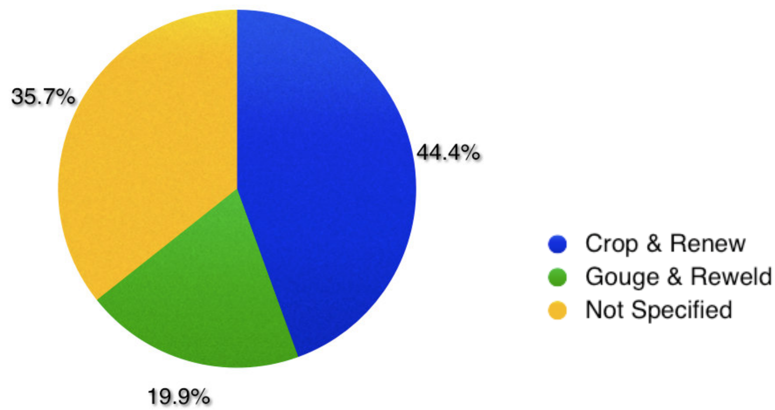


Figure C-26 Bulk carriers: Repair recommendations

Causes of reported fractures

Overall, 92.7% of findings are recorded as structural failures. All other causes account for just over 7% of the reports.

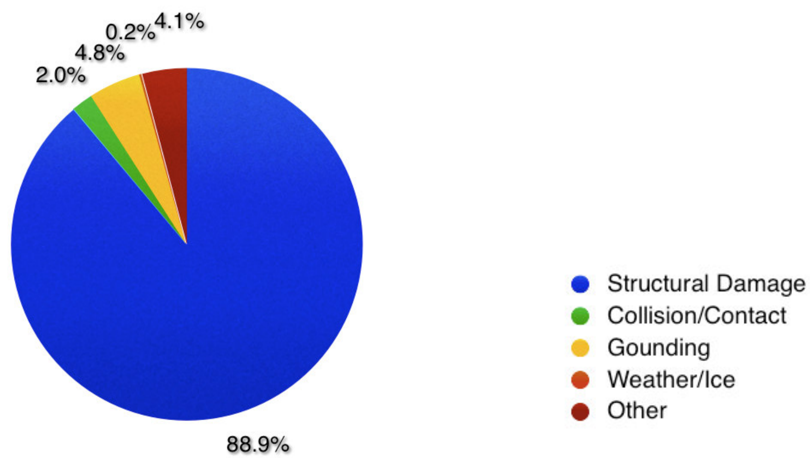


Figure C-27 Bulk carriers: Cause of reported fractures

C.6 Container Carriers

7.5.2 ABS and world container carrier fleets

Container carriers are ordinarily split into six size categories based on their design TEU as follows:

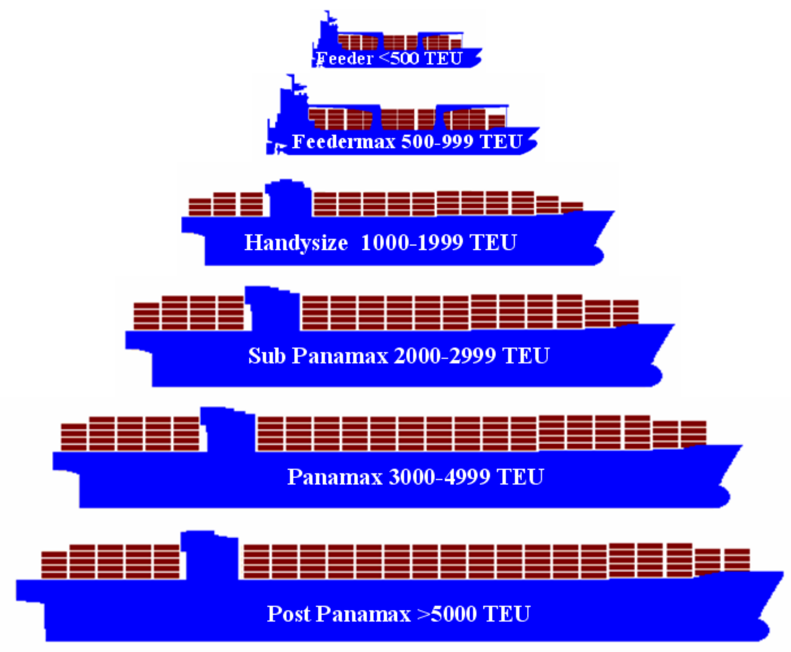
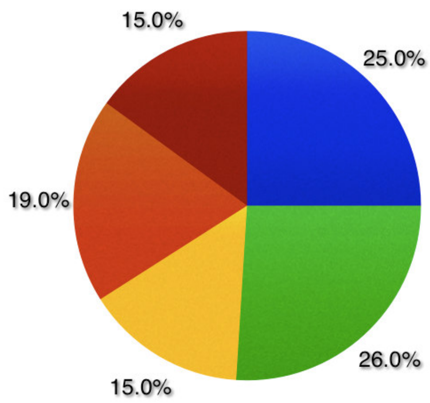


Figure C-28 Size categories of container carrier

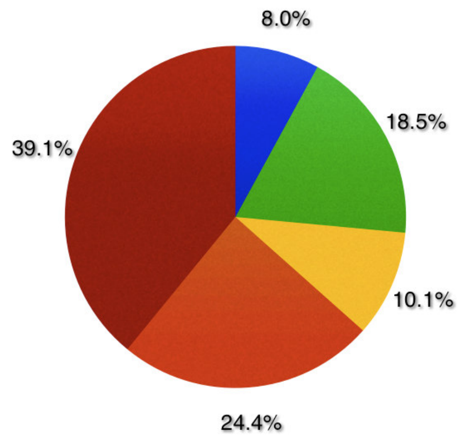
Size profile

The world fleet statistics do not identify a difference between Feeder and Feedermax-size vessels, and there are some differences in the size breakdown of the ABS fleet when compared to the world fleet. In Figure C-29, Feeder and Feedermax-size vessels have been combined into one category. Over one-half (51%) of the world fleet of container carriers consists of vessels smaller than 2000 TEU, while this accounts for slightly more than one-quarter (26.5%) of ABS vessels.

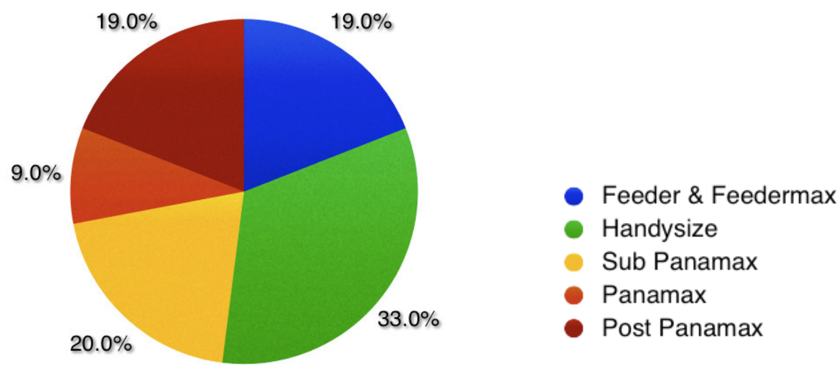
One-third of the analyzed ABS container carriers were Handysize and over one-half (52%) were smaller than 2000 TEU.



(a) World Fleet (4840 vessels)
(Clarkson Research Services Mar 2010)



(b) ABS Fleet (520 vessels)*
(ABS Record book Dec 2009)

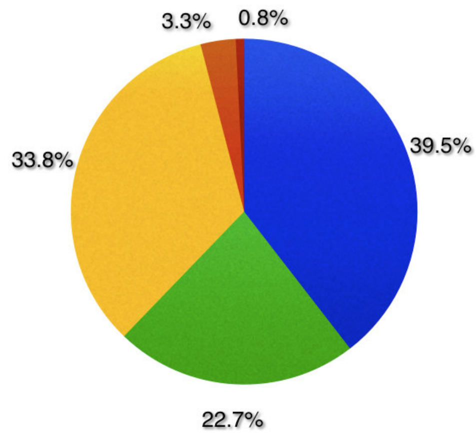


(c) Analyzed ABS Fleet

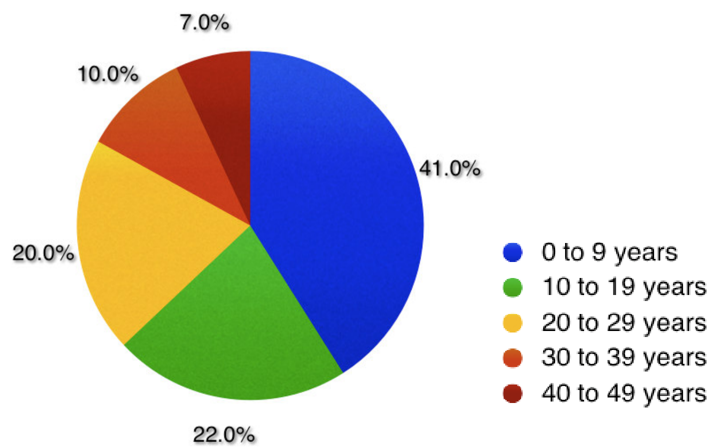
Figure C-29 Size profile of container carrier fleet

Age Profile

The analyzed ABS container carrier fleet has an average age of twenty years. 41% of the analyzed ABS container carriers are less than ten years old and 83% are less than thirty years old.



(a) ABS Fleet (520 vessels)*
(ABS Record book Dec 2009)



(b) Analyzed ABS Fleet

Figure C-30 Age profile of container carriers

7.5.3 Fractures reported in container carriers

Vessel age when fractures were reported

The distribution of reported fractures over the ship's life for each ship size category is given in the following table and figure. The majority of fractures (19.05%) were reported when the vessel was between 20 and 24 year of age.

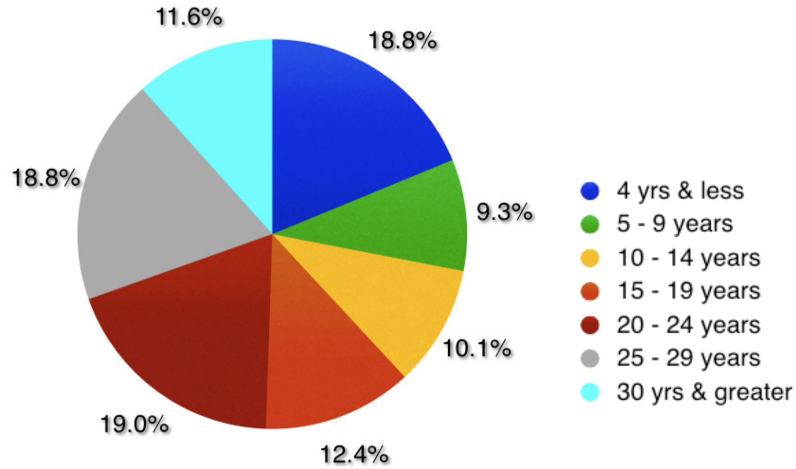


Figure C-31 Container carriers: Vessel age at time of report

Table C-11 Container carriers: vessel age at time of report

Age	Feeder	Feedermax	Handysize	Sub Panamax	Panamax	Post Panamax	Total
4 years & less	11.11%	26.83%	7.37%	2.58%	34.62%	75.00%	18.78%
5 – 9 years	0.00%	12.20%	10.53%	3.23%	7.69%	25.00%	9.26%
10 – 14 years	33.33%	2.44%	18.95%	7.74%	15.38%	0.00%	10.05%
15 – 19 years	55.56%	4.88%	23.16%	7.10%	26.92%	0.00%	12.43%
20 – 24 years	0.00%	14.63%	5.26%	38.71%	3.85%	0.00%	19.05%
25 – 29 years	0.00%	26.83%	11.58%	29.68%	11.54%	0.00%	18.78%
30 years & greater	0.00%	12.20%	23.16%	10.97%	0.00%	0.00%	11.64%

Fracture reports by compartment

Overall, 25.5% of the reported fractures have been recorded in the ballast tank, with the highest percentage of reports being recorded in Panamax vessels with over 40% of their fracture reports being identified as located in the ballast tank.

The deck area and cargo hold account for nearly 20% of findings each. Feeder-size vessels showed a high percentage of findings in the cargo hold, with 42.9% of reports, while post Panamax reported one-third of their report findings located in the cargo hold.

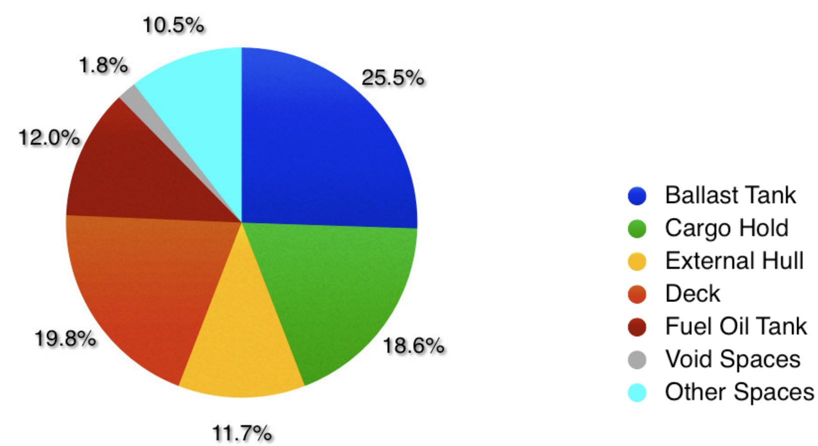


Figure C-32 Container carriers: Fracture report by compartment

Table C-12 Container carriers: Fracture report by compartment and vessel size

Compartment	Vessel Size						
	Feeder	Feedermax	Handysize	Sub-Panamax	Panamax	Post Panamax	Total
Ballast Tank	14.3%	25.7%	15.0%	29.8%	40.9%	25.0%	25.5%
Cargo Hold	42.9%	25.7%	20.0%	18.4%	22.7%	6.3%	18.6%
External Hull	14.3%	8.6%	12.5%	11.3%	18.2%	10.4%	11.7%
Deck	28.6%	14.3%	17.5%	20.6%	0.0%	33.3%	19.8%
Fuel Oil Tank	0.0%	5.7%	11.3%	14.2%	9.1%	14.6%	12.0%
Void Spaces	0.0%	2.9%	5.0%	0.0%	4.5%	0.0%	1.8%
Other Spaces	0.0%	17.1%	18.8%	5.7%	4.5%	10.4%	10.5%

Fracture reports by compartment and vessel size

With an increase in size of the container carriers, fractures were more likely to take place in the ballast tank, increasing from 14.3% of reports in Feeder-size oil carriers to 40.9% in Panamax, but drop to 25.0% in Post-Panamax.

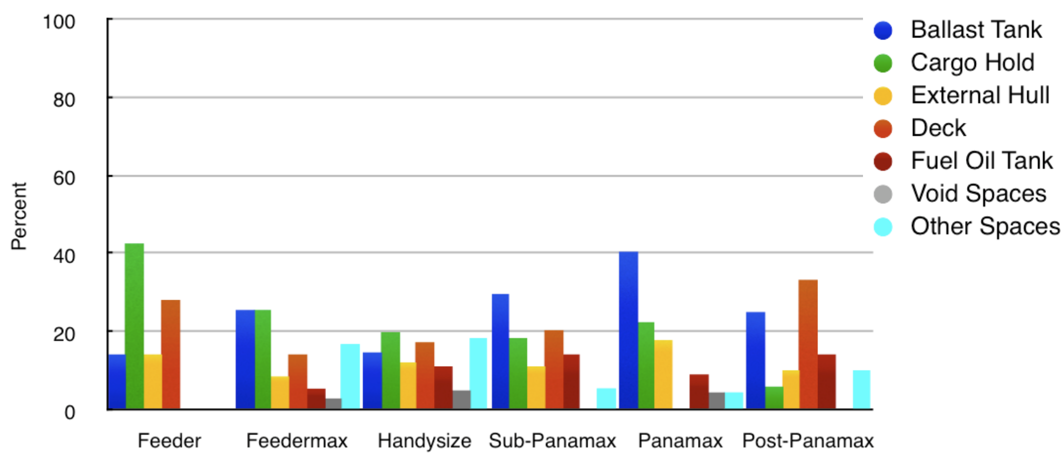


Figure C-33 Container carriers: Fracture report by compartment and vessel size

Fracture reports by structure type

Overall, 37.0% of the reported fractures have occurred in the deck, followed by 23.2% of reports in the sideshell, and 14.2% in the bottom shell. Together, these account for 74.4% of the reported fractures. The findings in the deck structure include fractures reported to hatch coaming.

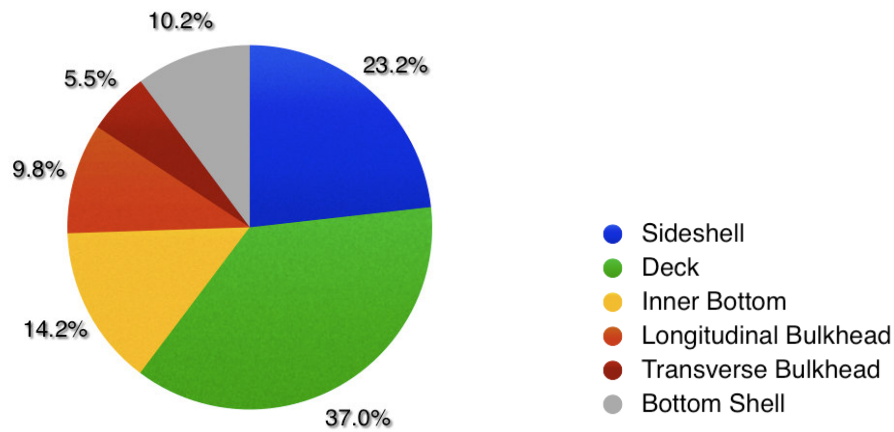


Figure C-34 Container carriers: Fracture report by structure type

Table C-13 Container carriers: Fracture report by structure type and vessel size

Structure Type	Vessel Size						
	Feeder	Feedermax	Handysize	Sub-Panamax	Panamax	Post Panamax	Total
Sideshell	14.3%	34.8%	26.6%	15.3%	50.0%	22.6%	23.2%
Deck	71.5%	56.5%	37.5%	36.0%	0.0%	38.8%	37.0%
Inner Bottom	14.3%	0.0%	12.5%	18.0%	27.8%	6.5%	14.2%
Longitudinal Bulkhead	0.0%	4.3%	9.4%	12.6%	11.1%	6.5%	9.8
Transverse Bulkhead	0.0%	4.3%	9.4%	1.8%	5.6%	12.9%	5.5%
Bottom Shell	0.0%	0.0%	4.7%	16.2%	5.6%	12.9%	10.2%

Fracture reports by structure type and vessel size

In Feeder-size vessels, over 71% of all fracture reports have been for the deck area, with 14% recorded for the sideshell and inner bottom. Panamax-size vessels had 50% of their fracture reports located in the sideshell and 27% within the inner bottom. Panamax-size vessels were the only vessels which did not report any fractures in the deck area.

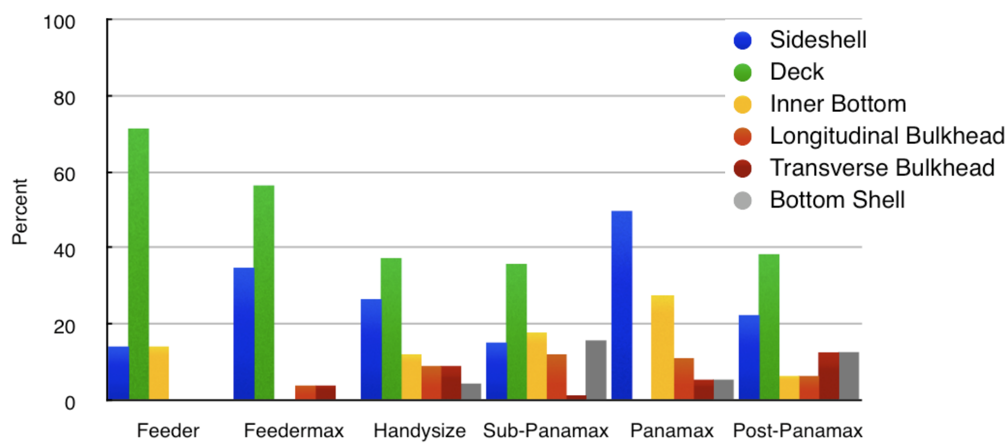


Figure C-35 Container carriers: Fracture report by structure type and vessel size

Reported fracture length

Fracture length was reported in less than 20% of ABS container carrier survey reports. This is due to the fact the Surveyor is not required to record the fracture length.

The majority of reported fractures were in the range of 2.1 to 6.0 inches in length (36.0%). 16.0% of reported fractures were 0.0-2.0 inches in length, and 48.0% of reported fractures were longer than 6.0 inches.

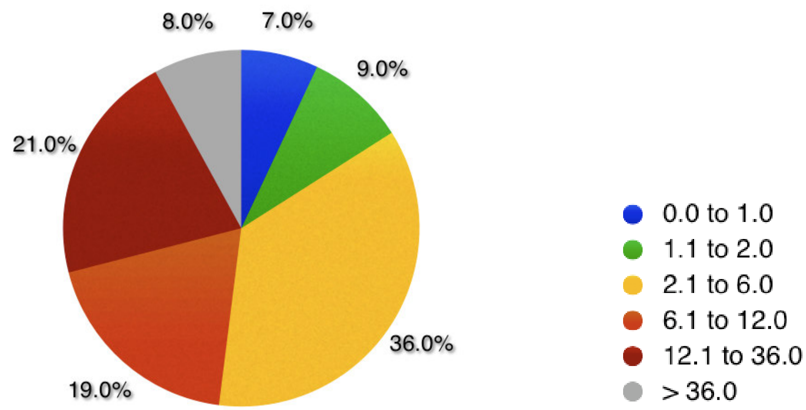


Figure C-36 Container carriers: Reported fracture length (inches)

Table C-14 Container carriers: Reported fracture length by vessel size

Fracture Length (inches)	Vessel Size						
	Feeder	Feedermax	Handysize	Sub-Panamax	Panamax	Post-Panamax	Total
0.0-1.0	16.7%	16.7%	0.0%	10.1%	0.0%	0.0%	7.0%
1.1-2.0	0.0%	5.6%	19.4%	7.2%	12.5%	4.0%	8.9%
2.1-6.0	50.0%	22.2%	19.4%	31.9%	37.5%	76.0%	36.3%
6.1-12.0	0.0%	22.2%	29.0%	20.3%	12.5%	8.0%	19.1%
12.1-36.0	0.0%	27.8%	25.8%	26.1%	12.5%	4.0%	21.0%
>36.0	33.3%	5.6%	6.5%	4.3%	25.0%	8.0%	7.6%

Reported fracture length by vessel size

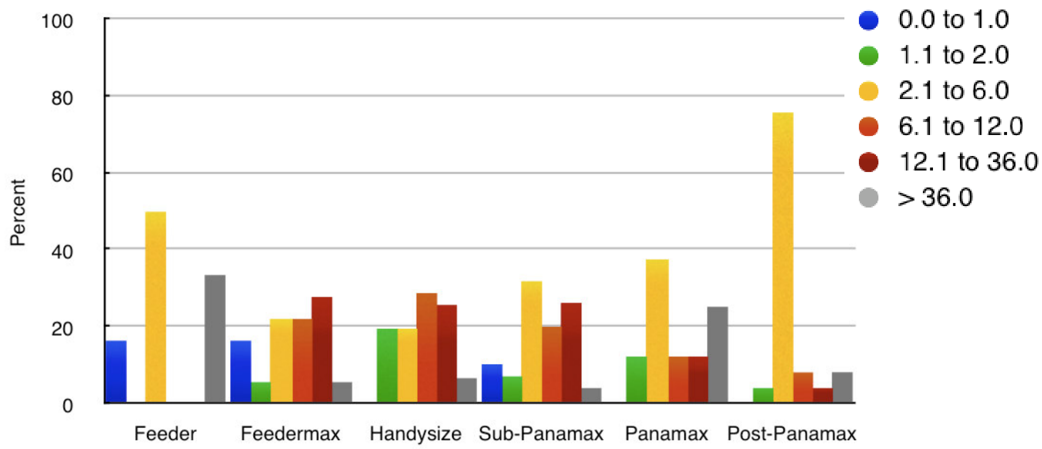


Figure C-37 Container carriers: Reported fracture length by size category

Fracture Repairs

Crop and renew is the most widely used repair method recommended 44% of the time for fractures in container carriers, followed by gouge and reweld with almost 24%. It is to be noted that repairs involving insert plates are included within crop and renew repairs.

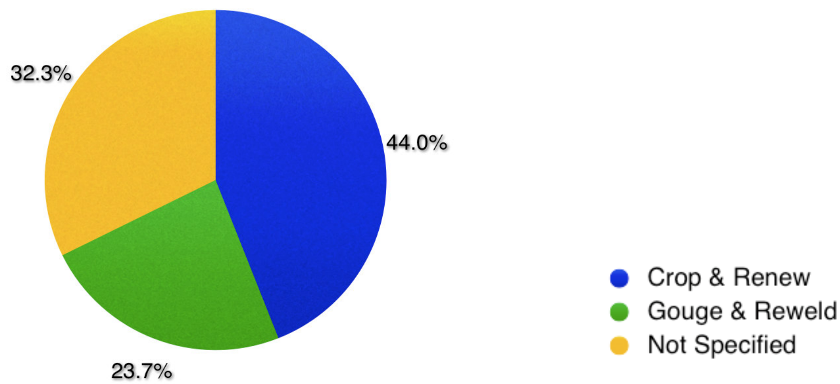


Figure C-38 Container carriers: Repair recommendations

Causes of reported fractures

Container carrier reports indicate that over 90% of fractures are related to structural failure. Less than 10% were damages caused by collision, grounding, or weather.

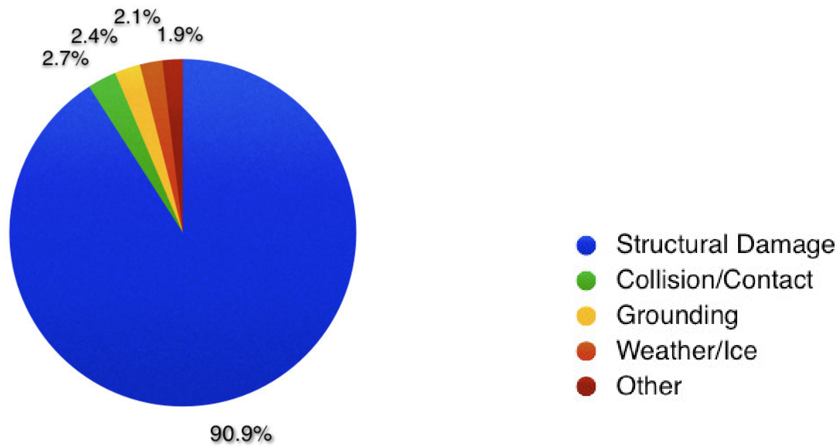


Figure C-39 Container carriers: Cause of reported fractures

Appendix D Repair Suggestion Examples Based on IACS Rec. No. 96, 84 and 76

Table D- 1 Fracture on inner bottom plating at connection of hopper plate to inner bottom (IACS Rec. No. 96, Section 5.3, Group 1, Example 1)

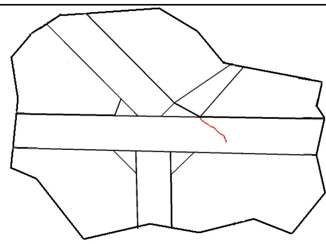
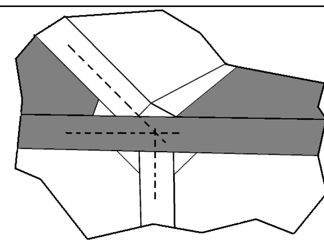
Detail of Damage	
	- Fracture caused by stress concentration, insufficient welding connection - Also may be caused by misalignment between hopper plate, inner bottom and girder.
Detail of Repair	
- Crop and renew plate - Ensure plate midlines intersect	

Table D- 2 Fracture in way of connection of longitudinal to transverse bulkhead (IACS Rec. No. 96, Section 5.3, Group 2 Example 1)

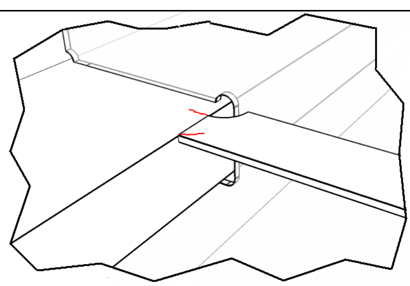
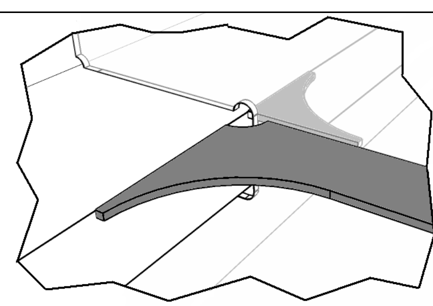
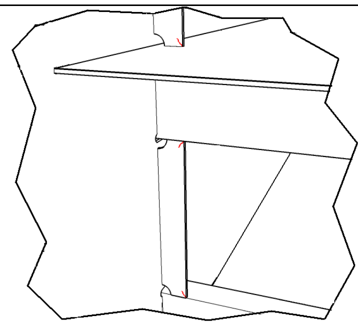
Detail of Damage	
	- Fracture caused by dynamic loading in water line vicinity
Detail of Repair	
- Soften toe bracket - Insert additional backing bracket - Crop and renew damaged longitudinal	

Table D- 3 Fracture in way of stiffeners at connection of inner bottom and bottom shell to transverse bulkhead and floors (IACS Rec. No. 96, Section 5.3, Group 3, Example 3)

<table>
<tr><th colspan="2">Detail of Damage</th></tr>
<tr><td></td><td>- Fractures cause by misalignment between bulkhead stiffener and inner bottom longitudinal

- High stress concentration</td></tr>
<tr><th colspan="2">Detail of Repair</th></tr>
<tr><td>- If tank top plating is fractured, part crop and insert

- Ensure proper alignment between bulkhead stiffener and inner bottom longitudinal

- Use soft brackets

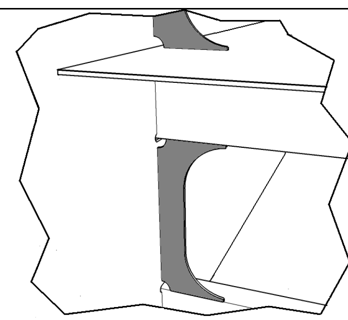
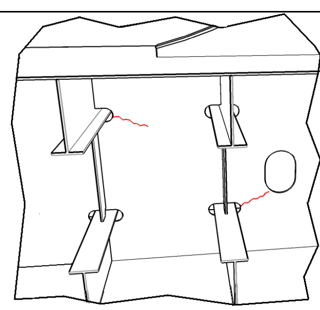
- Addition of soft backing bracket may be considered</td><td></td></tr>
</table>

Table D- 4 Fractures in cut-outs on floors (IACS Rec. No. 96, Section 5.3, Group 3, Example 6)

<table>
<tr><th colspan="2">Detail of Damage</th></tr>
<tr><td></td><td>- Fractures caused by high stress in the vicinity of the transverse web frame bracket toe

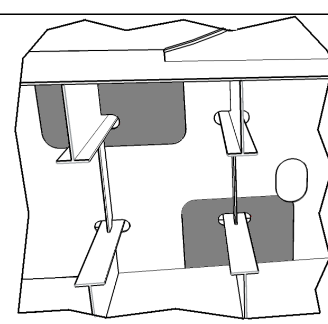
- Lack of material between manhole and cut-out for bottom longitudinal</td></tr>
<tr><th colspan="2">Detail of Repair</th></tr>
<tr><td>- Gouge and reweld fractures then fit with watertight collars</td><td></td></tr>
</table>

Table D- 5 Fractured deck plate around tug bit (IACS Rec. No. 96, Section 5.3, Group 6, Example 1)

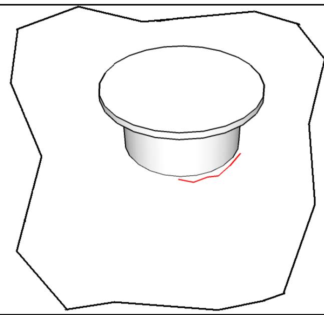
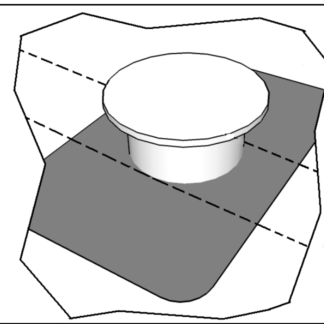
Detail of Damage	
	- Fracture caused by insufficient strength
Detail of Repair	
- Fractured deck plating should be cropped and part renewed - reinforcement by stiffeners should be considered	

Table D- 6 Fracture at main cargo hatch corner (IACS Rec. No. 76, Section 5.2, Part 1, Area 1, Example 1)

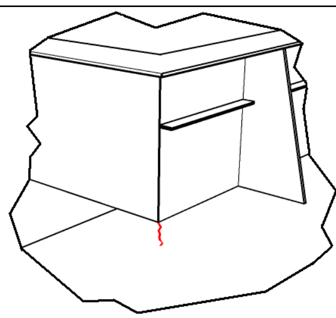
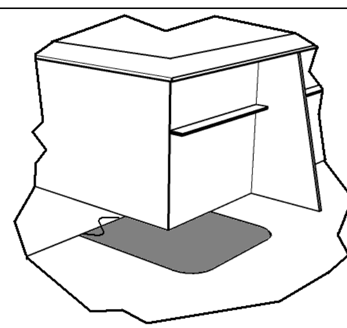
Detail of Damage	
	- Fracture caused by stress concentration at hatch corner
Detail of Repair	
- The corner plating in way of fracture to be cropped and renewed. Insert plate should be increased thickness, enhanced steel grade and/or improved geometry	

Table D- 7 Fractures in brackets at termination of frame (IACS Rec. No. 76, Section 5.2, Part 1, Area 3, Example 1-a)

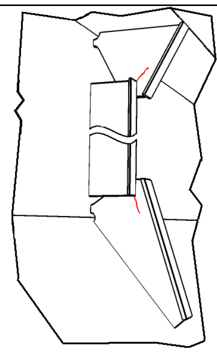
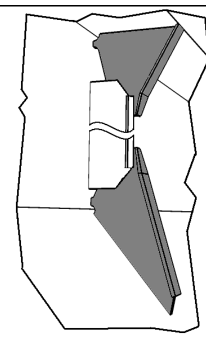
Detail of Damage	
	- Fractures caused by stress concentration
Detail of Repair	
- Small fractures can be veed-out, ground, examined for fractures, and rewelded -For larger fractures, crop and partly renew/renew frame brackets. If renewing, end of frames can be snipped to soften them (pictured). - Soft toes are to be incorporated at the bracket boundaries.	

Table D- 8 Fracture in side shell frame at bracket toe (IACS Rec. No. 76, Section 5.2, Part 1, Area 3, Example 2)

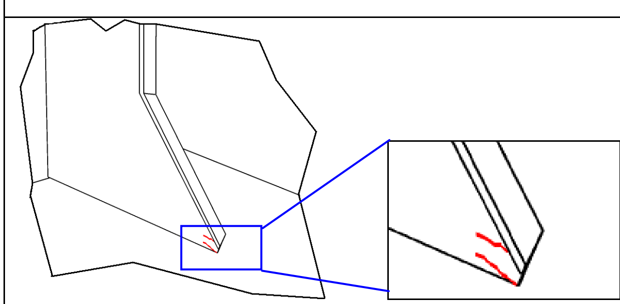
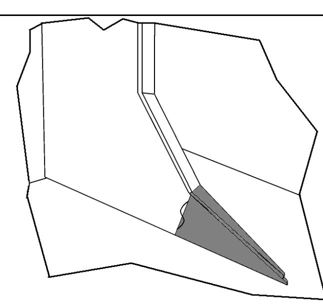
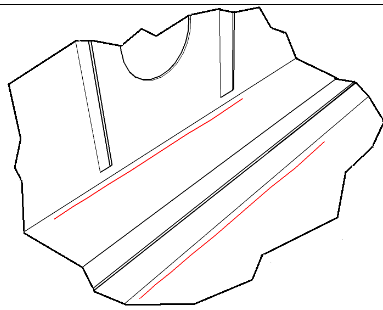
Detail of Damage	
	- Fracture caused by stress concentration
Detail of Repair	
- Repair should be cropped out and renewed - Toe end angle should be altered to allow a softer transition - Face plate should be chamfered at its extremity	

Table D- 9 Fracture in bottom plating alongside girder and/or bottom longitudinal (IACS Rec. No. 76, Section 5.2, Part 1, Area 5, Example 9)

Detail of Damage



- Fractures caused by vibrations

Detail of Repair

- Fractured bottom should be cropped and renewed
- Natural frequency of panel should be changed, e.g. reinforce with additional stiffeners and brackets

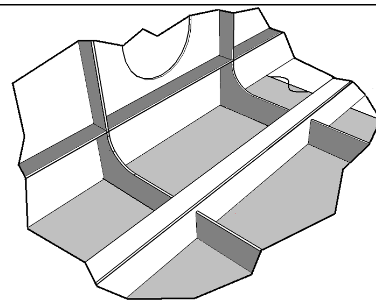
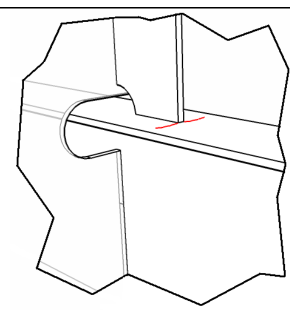


Table D- 10Fracture at connection of side shell longitudinal to transverse bulkhead (IACS Rec. No. 84, Section 5.2, Part 1, Area 2, Example 4-d)

Detail of Damage



- Fracture caused by stress concentration at connection of stiffener to longitudinal

Detail of Repair

- If fracture extends over one-third of the depth, then crop and partly renew. Otherwise, the fracture can be veed-out and welded.
- Introduction of soft toe brackets to reduce stress concentration

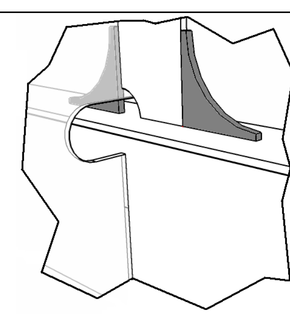
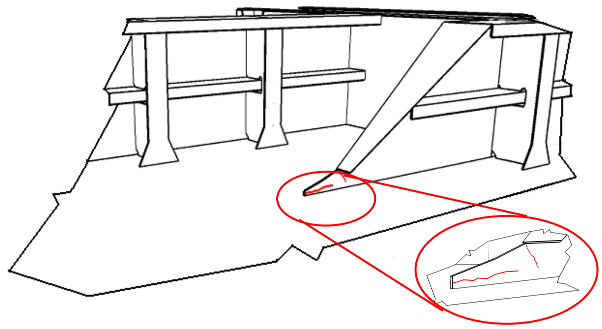
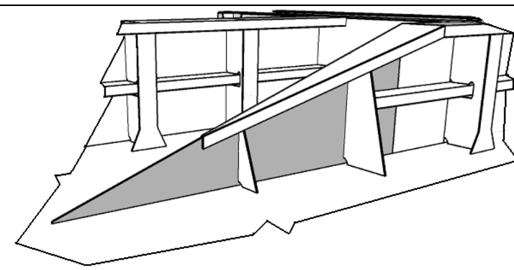


Table D- 11 Fracture at connection of hatch side coaming to deck (IACS Rec. No. 84, Section 5.2, Part 1, Area 4, Example 3)

Detail of Damage	
	Notes: - flange end force too high due to insufficient tapering - sheer force in web plate too high due to insufficient reduction of web height at end
Detail of Repair	
- Extend bracket as long as possible for a more gradual transition - Reduce web height at end of bracket - Reduce cross-sectional area of flange at end	

Appendix E Criticality Classes for Structural Failures

E.1 General

The consequences of structural failure can be measured by the impact on the safety of ship and personnel and/or environmental pollution.

Traditionally, the criticality scheme has been decided mostly based on consequences or likelihood of structural failures. A more recent trend is to put them in a risk assessment framework where both consequences and likelihood are taken into account.

E.2 Industry Guidance on Critical Areas for Inspection

Classification Societies define “critical areas” for guiding inspection of hull structures. These definitions are based on the experiences of structural failures, and are summarized herewith.

International Association of Classification Societies

Critical Structural Areas are “locations which have been identified from calculations to require monitoring or from the service history of the subject ship or from similar ships to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the ship.”

ABS

The *ABS Guide for SHCM* Program (ABS 2001) defines a *Critical Area* as “an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. The higher probability of failure can be a result of stress concentrations, high stress levels and high stress ranges due to loading patterns, structural discontinuities or a combination of these factors.” These Critical Areas include structural connections that should be carefully designed and constructed with a high degree of quality workmanship. Special attention should be paid to critical joints for alignment, details of welding, soft end toes, etc., as applicable.

DnV

The 2008 DNV Rules Areas in way of critical load transfer points and large stress concentrations where a failure will endanger the safety of the ship, such as:

- stress concentrations in rudder or intersection between rudder structure and hull,
- for twin hull vessels stress concentrations in way of connections between hull and wet deck,
- deck beams in open hatch container ships,

- strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration,

- other areas where the likelihood of occurrence of detrimental defects is considered to be especially high.

Class NK

The *NK Guidance for Condition Assessment Scheme* (NK 2004) specifies *Critical Areas* as “locations which have been identified from calculations to require monitoring or from the service history of the subject ship or from similar or sister ships to be sensitive to cracking, buckling or corrosion which would impair the structural integrity of the ship”.

Tanker Structure Cooperative Forum

The Tanker Structure Cooperative Forum, or TSCF, defines *Critical Areas* within the tank structure of double hulled tankers as “locations that, by reason of stress concentration, alignment/discontinuity and corrosion will have a higher probability of failure during the life of the ship than surrounding structures.”

E.3 Criticality Classes of Structural Components

IACS Common Structural Rules for Double Hull Oil Tankers, January 2006 “Background Document, Section 2 – Rule Principles” presents a schematic diagram of the “criticality class” for structural elements in the cargo region with respect to the consequences to Life, Environment and Property in the event of failure. This classification facilitated the selection of acceptance criteria and capacity models such that the more critical elements have stricter requirements and hence a lower probability of failure.

For the purposes of this report, the project team conducted a similar exercise for oil carriers, bulk carriers and container carriers with a modified approach to meet the requirements of the study. The criticality of all structural elements in the cargo region was evaluated with respect to consequences to People, Environment and Serviceability. The exercise for each vessel type involved the following steps:

- Defining the structural hierarchy

- Identifying the type of structural failure - loss of strength, loss of containment or both

- Identifying the possible consequences of structural failure for all the structural elements in the hierarchy

- Assigning a criticality class for these failure consequences with respect to people , environment and serviceability

- Obtaining the combined criticality class

E.3.1 Structural Hierarchy

The structural arrangements for oil carriers, bulk carriers and container carriers were reviewed and a structural hierarchy was established for each. The following levels in the structural hierarchy were identified:

Table E- 1 Structural hierarchy

Location of item in structural hierarchy	Structural component	Description
Global	This represents the top level in the hierarchy	
	Hull girder	
Major	This represents the 2nd level in the hierarchy Major components are bounded by bulkheads or the shell envelope	
	Major elements	This represents the major structural components 1 Deck 2 Bottom structure (combined bottom shell and inner bottom) 3 Side structure (combined side shell and inner side) 4 Longitudinal bulkhead (inner or centerline) 5 Transverse bulkhead 6 Topside tank 7 Hopper tank 9 Hatch coaming 10 Hatch cover
Primary	This represents the 3rd level in the hierarchy Girders are bounded by bulkheads or shell envelope Stiffened panels are bounded by girders/bulkheads	
	Girders	Collective term for primary support members including DB girders, bulkhead stringers, deck transverses, floors, etc.
	Stiffened panels	The plating and attached stiffeners/longitudinals of deck, bulkheads, etc.
Local	This represents the lowest level in the hierarchy Local components are usually bounded by girders and stiffener spacing	
	Stiffeners or longitudinals	This represents a single stiffener/plate combination comprising the stiffener profile and attached plate flange. Brackets are also included in this group.
	Plates	This is the plating between adjacent stiffeners/longitudinals or the web plate of girders.

For the purpose of this report, the detailed hierarchy of each ship structure was simplified and a universal hierarchy was created for each of the ship types.

E.3.2 Types of Structural Failure

Structural failure was categorized into one of the following three groups:

1. Loss of containment : Means that the boundary is no longer water-tight, oil-tight or gas-tight implying that

- The contents of a tank (gas or liquid) can leak into another space or externally
- A tank or ballast space can be contaminated from the contents on the other side of the boundary
- Sea water can leak into the ship

2. Loss of strength: The structural component loses its strength as a load carrying element
3. Loss of strength and loss of containment: For elements higher up in the hierarchy, such as stiffened panels and major components, it is more likely that failure would result in both loss of strength and containment.

E.3.3 Consequences of Structural Failure

The following assumptions were made while evaluating the consequences of structural failure of component.

Failure of a structural component would compromise the effectiveness/structural capacity of the whole component being considered. For example, a crack in a stiffened panel would extend for the full breadth/length of the panel and include the plate and stiffeners of the panel.

Loss of strength of a structural component need not lead to a loss of containment. For example, a plate could buckle and lose its strength but still be water or oil-tight.

The function of the structural component was kept in mind when determining the criticality of the member. Structural components having adequate redundancy, thereby allowing redistribution of loads, were not considered to be as critical as members with minimal structural redundancy.

E.3.4 Criticality Class

The importance of each structural component may be identified by assigning a criticality class to the failure modes associated with it. Three categories of consequences were established in order to class the criticality of the structural component:

People (P): Potential for human injury and fatality

Environment (E): Potential for release/ leakage leading to environmental pollution

Serviceability (S): Potential for structural failure leading to structural damage and subsequent impairment of ship serviceability.

Each of the consequence categories (People, Environment and Serviceability) are affected differently by the structural failure mechanisms. Hence, for each structural component, the consequence of failure needs to be assessed for each of these categories. Criticality Class value was classified into one of the three categories –

High, Medium and Low as defined in Table E-2. Descriptions of the High, Medium and Low categories for People, Environment and Serviceability used in the assessment are presented in Table E-3.

Table E- 2 Definition of Criticality Class

Criticality Class	Description
High	For structural components where failure may imply high potential for fatality or human injury, significant environmental pollution or ship going out of service
Medium	When failure may imply medium potential for human injury, medium environmental pollution or impairment of ship serviceability
Low	When failure may imply low potential for human injury, minor environmental or impairment of ship serviceability

Table E- 3 Typical descriptions of the Criticality Class

Consequences	Criticality Class		
	Low	Medium	High
People (P)	Injuries: Few Fatalities: None	Injuries: Many Fatalities: None	Injuries: Many Fatalities: 1 or more
Environment (E)	No or Negligible release of pollutant	Minor release of pollutant	Major release of pollutant
Serviceability (S)	No impairment of service (No effect on normal operation)	May lead to limited impairment of service (Restricted operation)	May lead to ship going out of service

The descriptions in Table E-3 were used as reference to assign the criticality class during the exercise and are not to be taken as absolute guidance statements.

E.3.5 Combined Criticality Class

The assessment can be simplified by establishing a single combined criticality class for each structural component. The combined criticality class of the structural component is determined by the highest criticality class assigned to its consequence categories (P, E and S).

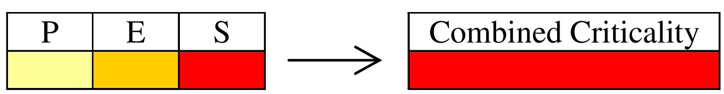


Figure E-1 Combined Criticality Class

This combined criticality of the structural component may be used to recommend appropriate and timely corrective action. Table E-4 lists typical recommendations based on the combined criticality class of the structural component.

Table E- 4 Recommendations of repairs based on the criticality class of a fracture

Combined Criticality	Recommendation of Repair
High	Initiate immediate corrective action
Medium	Evaluate necessity for corrective action when failure is found. Conduct temporary repair and monitor vessel's condition until permanent repair is carried out
Low	No immediate corrective action required. Needs to be monitored and re-examined at next scheduled inspection.

E.4 Summary

Criticality class charts have been developed for structural elements in a typical cargo block design for double hull oil carriers, bulk carriers and container carriers. These charts are vessel-specific but still consistent across the three vessel types based on the function of the structural element. The CAIP scheme of classifying structural failures and corresponding actions compares reasonably with the criticality class charts and its typical recommendations.

The structural elements with high combined criticality along with location in the hierarchy have been summarized in Table E-5.

Table E-5 Structural components with "High" criticality class of fractures

		Ship Types		
		Double Hull Tankers	**Single Skin Bulk Carriers**	**Container Carriers**
Structural hierarchy	**Global**	Hull Girder	Hull Girder	Hull Girder
	Major	Deck Side Structure Bottom Structure Longitudinal Bulkhead Transverse Bulkhead Fore/Aft End Transverse Bulkhead	Deck Topside Tank Side Structure Hopper Tank Bottom Structure Corrugated Transverse Bulkhead	Main Deck Side Structure Bottom and Bilge Structure Transverse Bulkhead
	Primary	Deck Panel Deck Girders Deck Transverse Inner Skin Panel Side Shell Panel Inner Bottom Panel Bottom Shell Panel Longitudinal Bulkhead Panel Transverse Bulkhead Panel	Deck Panel Hatch Coaming Hatch Cover Side Panel Hold Frame Bilge Shell Panel Inner Bottom Panel Bottom Shell Panel	Deck Panel Hatch Corner Hatch Coaming Hatch Coaming Corner Inner Bottom Panel Bottom and Bilge Panel
	Local			Deck Longitudinal Deck Plate Side and Top Coaming Plate

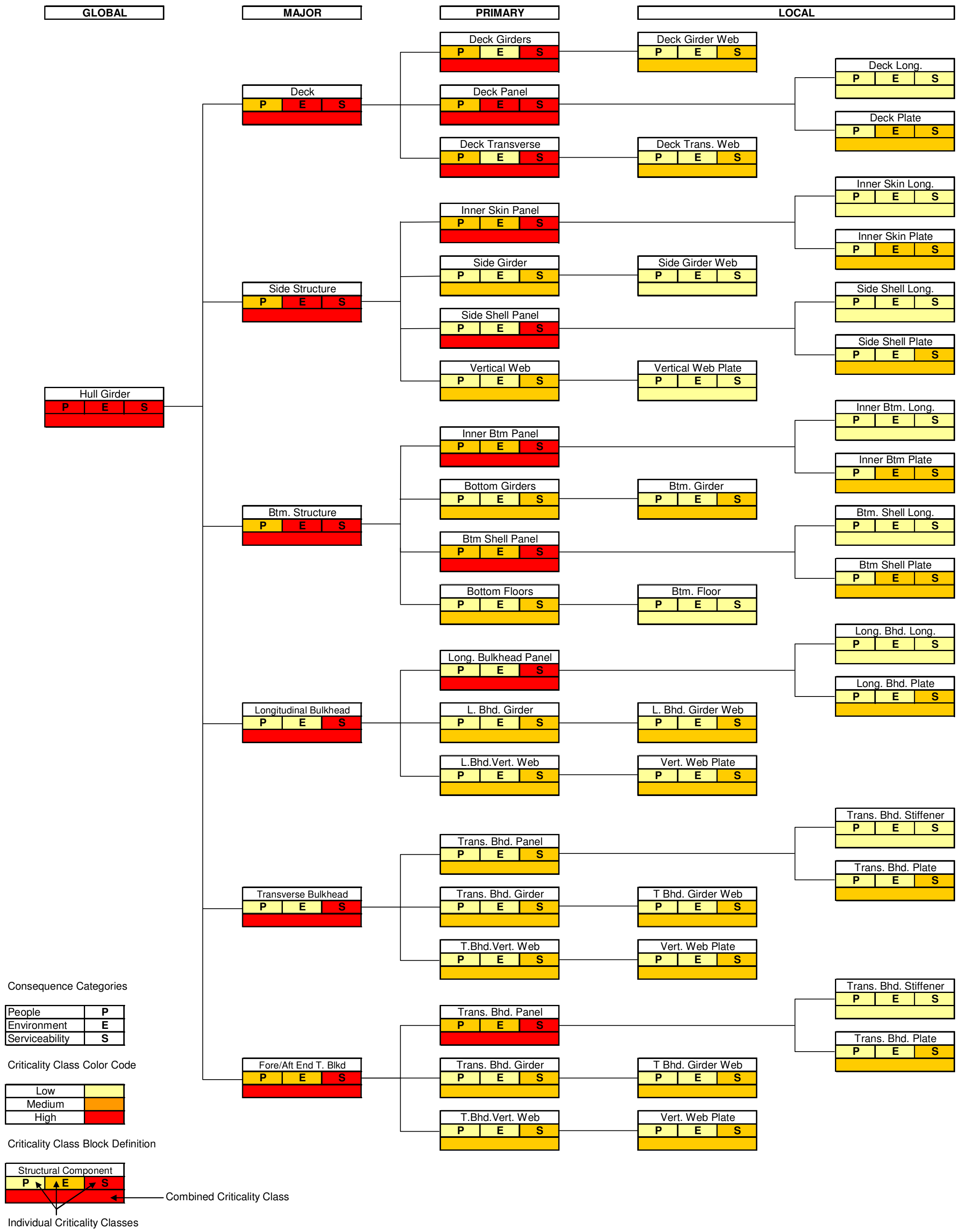


Figure E-2 Criticality class of structural elements in a typical cargo block design for double hull oil carrier

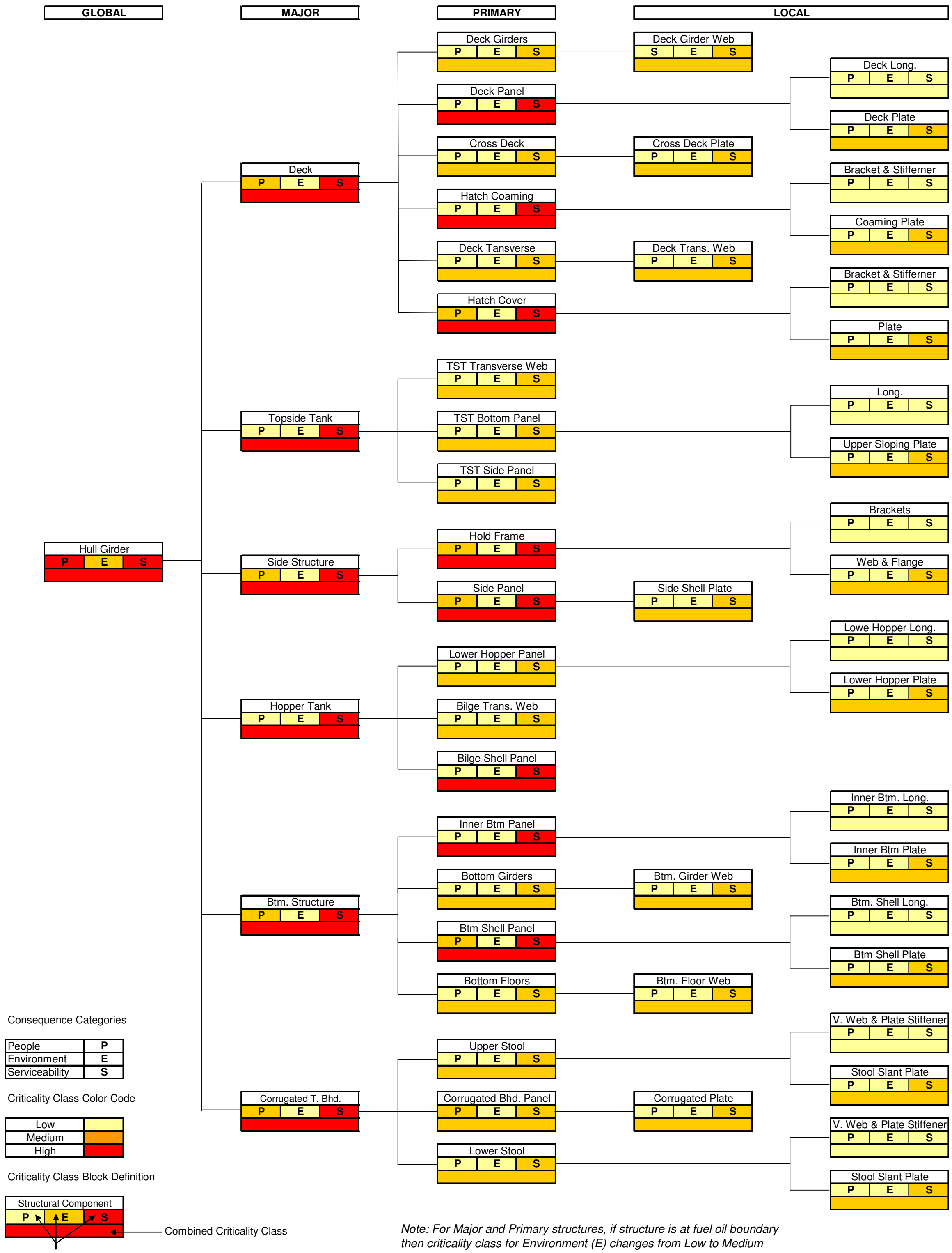


Figure E-3 Criticality class of structural elements in a typical cargo block design for bulk carrier

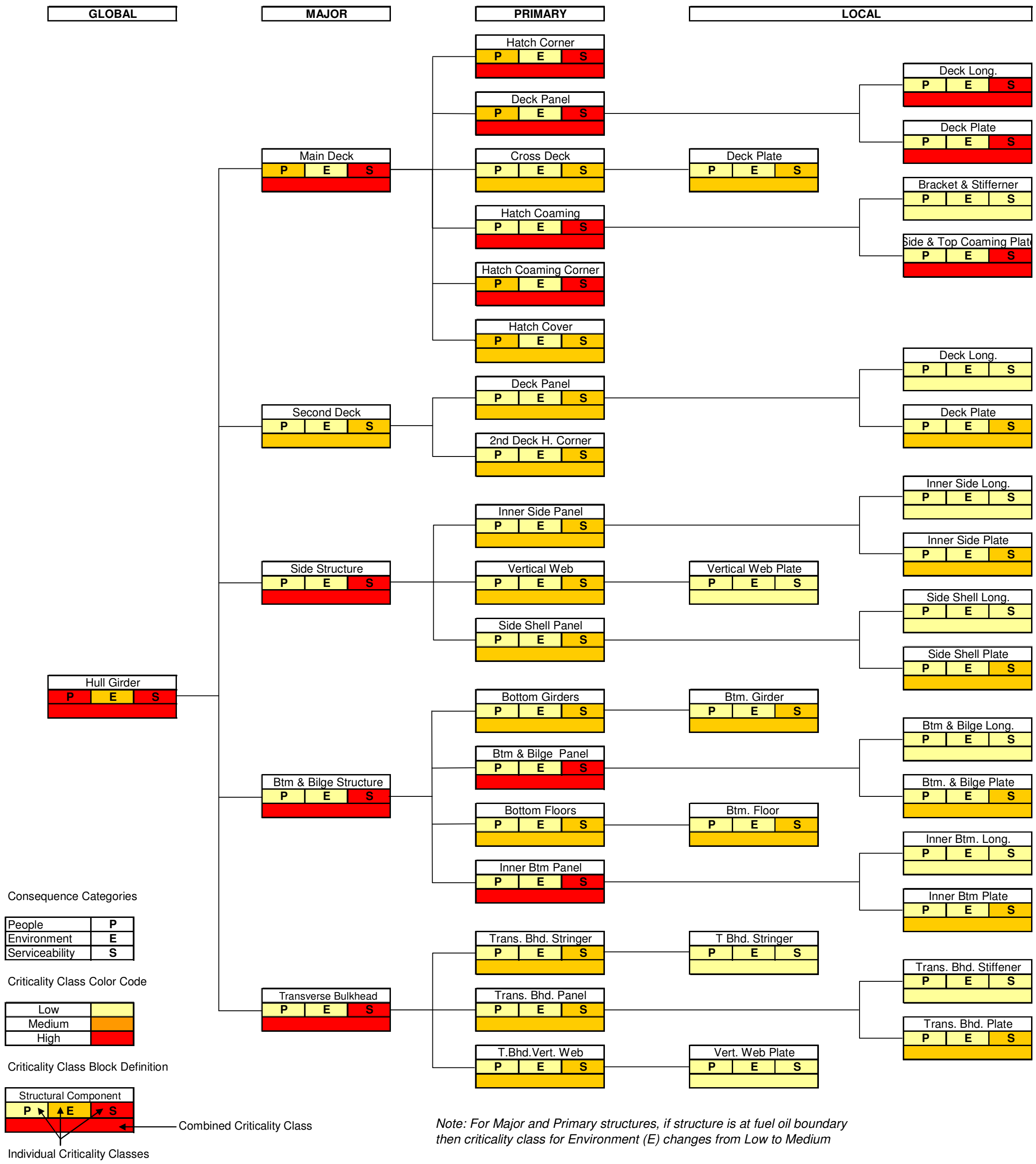


Figure E-4 Criticality class of structural elements in a typical cargo block design for container carrier

ABBREVIATIONS

ABS – American Bureau of Shipping

ACS – Authorized Classification Societies

ACP – Alternate Compliance Program

API – American Petroleum Institute

BS – British Standard

CAIP – Critical Areas Inspection Plan (USCG)

CSR – Common Structural Rules (IACS)

CTOA – Crack Tip Opening Angle

CTOD – Crack Tip Opening Displacement

FM – Fracture Mechanics

IACS - International Association of Classification Societies

IACS UR – International Association of Classification Societies Unified Requirement

IACS REC - International Association of Classification Societies Recommendation

IIW – International Institute of Welding

IMO – International Maritime Organization

INTERTANKO – International Association of Independent Tanker Owners

MARPOL – International Convention for the Prevention of Pollution From Ships

MT – Magnetic Particle Testing

NDE/NDT – Non-Destructive Evaluation/ Testing

NVIC – Navigation and Vessel Inspection Circular (USCG)

PT – Liquid Penetration Testing

PTC – Project Technical Committee

RT – Radiographic Testing

SHCM – SafeHull Condition Monitoring (ABS)

SSC – Ship Structure Committee

TSCF – Tanker Structure Co-operative Forum

ULCC – Ultra Large Crude Carrier

USCG – United States Coast Guard

UT – Ultrasonic Testing

VLCC – Very Large Crude Carrier

VT – Visual Testing

USEFUL WEB LINKS

Classification societies

[1] American Bureau of Shipping (ABS), www.eagle.org
[2] Bureau Veritas (BV), www.bureauveritas.com
[3] China Classification Society (CCS), www.ccs.org.cn
[4] Det Norske Veritas (DNV), www.dnv.com
[5] Germanischer Lloyd (GL), www.gl-group.com
[6] International Association of Classification Societies Ltd. (IACS), www.iacs.org.uk
[7] Korean Register of Shipping (KR), www.krs.co.kr
[8] Lloyd's Register (LR), www.lr.org
[9] Nippon Kaiji Kyokai (ClassNK or NK), www.classnk.or.jp
[10] Registro Italiano Navale (RINA), www.rina.org
[11] Russian Maritime Register of Shipping (RS), www.rs-head.spb.ru

International and national regulatory bodies

[12] American Petroleum Institute (API), www.api.org
[13] European Maritime Safety Agency (EMSA), www.emsa.europa.eu
[14] Health and Safety Executive, www.hse.gov.uk
[15] International Maritime Organization (IMO), www.imo.org
[16] International Organization for Standardization (ISO), www.iso.org
[17] International Labour Organization (ILO), www.ilo.org
[18] Standard of Training, Certification & Watchkeeping (STCW), www.stcw.org
[19] Norwegian Petroleum Directorate (NPD) www.npd.no
[20] United States Coast Guard (USCG), www.uscg.mil

Incidents investigation

[21] Global Integrated Shipping Information System, http://gisis.imo.org
[22] Australian Transport Safety Bureau www.atsb.gov.au,
[23] Bureau d'enquêtes sur les événements de mer www.beamer-france.org
[24] Marine Accident Investigation Branch, www.maib.gov.uk
[25] Transportation Safety Board of Canada http://bst-tsb.gc.ca
[26] Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE), www.cedre.fr
[27] United States Coast Guard, www.uscg.mil/hq/g-m/moa/casua.htm
[28] U.S. National Transportation Safety Board, www.ntsb.gov
[29] Marine Accident Investigation and Shipping Security Policy Branch, www.mardep.gov.hk
[30] Danish Maritime Authority, www.sofartsstyrelsen.dk
[31] Accident Investigation Board Norway, www.aibn.no
[32] MARS - The Nautical Institute Marine Accident Reporting Scheme, http://www.nautinst.org
[33] USCG Casualty Reports, http://www.uscg.mil/hq/g-m/moa/casua.htm

[34] Hong Kong Marine Dept. Reports, http://www.mardep.gov.hk/en/publication/ereport.html
[35] Lloyd's MIU, www.lloydsmiu.com
[36] Marine incidents annual reports, www.msq.qld.gov.au

Shipowners and charterers associations

[37] International Association of Dry Cargo Shipowners (INTERCARGO), www.intercargo.org
[38] International Association of Independent Tanker Owners (INTERTANKO), www.intertanko.com
[39] International Chamber of Shipping (ICS), www.marisec.org
[40] International Tankers Owners Pollution Federation (ITOPF), www.itopf.com
[41] Oil Companies International Marine Forum (OCIMF), www.ocimf.com
[42] Chemical Distribution Institute (CDI), www.cdi.org.uk
[44] Baltic and International Maritime Council, BIMCO, www.bimco.com

Port State Control, Memoranda of Understanding

[45] Paris MoU, Europe and Canada, www.parismou.org
[46] Tokyo MoU Asia Pacific Region, www.tokyo-mou.org
[47] Carribean MoU, www.caribbeanmou.org
[48] Viña del Mar Agreement, Latin American Region, http://200.45.69.62/index_i.htm
[49] Indian Ocean Memorandum of Understanding, www.iomou.org
[50] Mediterranean Memorandum of Understanding, www.medmou.org
[51] Black Sea MoU, www.bsmou.net
[52] Arab States of the Gulf (Riyadh MoU)
[53] West and Central Africa (Abuja MoU), www.abuja-mou.org
[54] United States Coast Guard (USCG), http://homeport.uscg.mil

Protection & Indemnity Clubs

[55] UK P&I, www.ukpandi.com
[56] The London Steam-Ship Owners' Mutual Insurance Association Ltd., www.lsso.com
[57] American Steamship Owners Mutual Protection and Indemnity Association, Inc., www.american-club.com
[58] International Group of P&I, www.igpandi.org
[59] The American club, www.american-club.com
[60] The Shipowners' P&I Club, www.shipownersclub.com

PUBLICATIONS OF ABS, IACS, TSCF, USGC

United States Coast Guard

P1. United States Coast Guard (1968). Notes on Inspection and Repair of Steel Hulls. *Navigation and Vessel Inspection Circular No. 7-68*

P2. United States Coast Guard (1991). Critical Areas Inspection Plans. *Navigation and Vessel Inspection Circular No. 15-91.*

P3. United States Coast Guard (1991). Critical Areas Inspection Plans Enclosure (1) "Fracture Mechanics Methodology for Fracture Control in Oil Tankers". *Navigation and Vessel Inspection Circular No. 15-91 CH-1.*

P4. United States Coast Guard (1994). Inland Tank Barge Inspection and Repair Guidelines. http://www.shipstructure.org/project/1459/InlandRiverRepairGuide.pdf .

P5. United States Coast Guard (1996). Classing and Reporting Structural Failures, Modifications to Critical Areas Inspection Plan Requirements (CAPS) and Trans-Alaskan Pipeline Service (TAPS) Tankers Issues. *MOC Policy Letter No. 2-96.*

P6. United States Coast Guard (2001). Procedures for Hull Inspection and Repair on Vessels Build of Riveted Construction. *Navigation and Vessel Inspection Circular No. 7-01.*

P7. US Coast Guard (2006). The Alternate Compliance Program (ACP). *Navigation and Vessel Inspection Circular No. 2-95 CHANGE -2.*

P8. US Coast Guard (2000). Atlantic Area Best Practices: Rivet Inspection Guidance. *D8(m) Policy Letter 10-2000.*

International Association of Classification Societies

P9. American Bureau of Shipping, Det Norske Veritas, Lloyd's Register (2005). Common Structural Rules for Double Hull Oil Tankers.

P10. International Association of Classification Societies (2008). Shipbuilding and Repair Quality Standard. Recommendation no. 47.

P11. International Association of Classification Societies (1999). General Cargo Ships - Guidelines for Surveys, Assessment and Repair of Hull Structures. Recommendation no. 55.

P12. International Association of Classification Societies (2003). Surveyor's Glossary, Hull Terms and Hull Survey Terms. Recommendation no. 82.

P13. International Association of Classification Societies (2005). Approval of Consumables for Welding Normal and Higher Strength Hull Structural Steels. Recommendation no. 17.

P14. International Association of Classification Societies (2005). Container Ships - Guidelines for Surveys, Assessment and Repair of Hull Structures. Recommendation no. 84.

P15. International Association of Classification Societies (2006). Guidelines for Coatings Maintenance and Repairs for Ballast Tanks and Combined Cargo/Ballast Tanks on Oil Tankers. Recommendation no. 87.

P16. International Association of Classification Societies (2006). IACS Common Structural Rules for Double Hull Oil Tankers. January 2006, Background Document Section 2 – Rule Principles.

P17. International Association of Classification Societies (2007). Double Hull Tankers - Guidelines for Surveys, Assessment and Repair of Hull Structures. Recommendation no. 96.

P18. International Association of Classification Societies (2007). IACS Guidelines for Surveys, Assessment and Repair of Hull Structures-Bulk Carriers. Recommendation no. 76.

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