SSC-332

GUIDE FOR SHIP STRUCTURAL INSPECTIONS

SHIP STRUCTURE COMMITTEE

1990

Member Agencies:

United States Coast Guard
Naval Sea Systems Command
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Military Sealift Command

Ship Structure Committee

An Interagency Advisory Committee
Dedicated to the Improvement of Marine Structures

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August 2, 1990

SSC-332
SR-1289

GUIDE FOR SHIP
STRUCTURAL INSPECTION

The importance of thorough inspections and appropriate inspection techniques cannot be overemphasized. In this era when older vessels are continuing in service longer and newer vessels are being designed with lighter scantlings and higher strength steels, it is particularly important that the effects of corrosion, fatigue and general service be adequately considered during initial construction and subsequent condition surveys. It is intended that this report provide guidance to those involved in the structural inspection of commercial and naval ships.

J. D. SIPES
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SSC-332		

4. Title and Subtitle	5. Report Date
Guide For Ship Structural Inspection	1985
	6. Performing Organization Code
7. Author(s) Nedret S. Basar & Victor W. Jovino	8. Performing Organization Report No. SR 1289
9. Performing Organization Name and Address M. Rosenblatt & Son, Inc. 350 Broadway New York, NY 10013	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTCG-23-C-20036
12. Sponsoring Agency Name and Address Ship Structure Committee c/o U.S. Coast Guard (G-M) 2100 Second Street, SW Washington, D.C. 20593	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code G-M

15. Supplementary Notes

16. Abstract

Based on surveys and interviews conducted in several commercial shipbuilding yards, a guide for ship structural inspections is developed for use by marine people involved in designing, building, accepting, and operating ships.

A balanced and sufficient amount of inspection activities is prescribed for all stages of a ship's life from the onset of design process through construction to the final operational years in service

17. Key Words			18. Distribution Statement
Crack	Fracture	Damage	Available from:
Inspection	Defect	Nondestructive	National Technical Information Service
Details	Distribution	Examination	Springfield, VA 22151 or
Structures	Failure	Welds	Marine Technical Information Facility National Maritime Research Center Kings Point, NY 10024-1699

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	46	

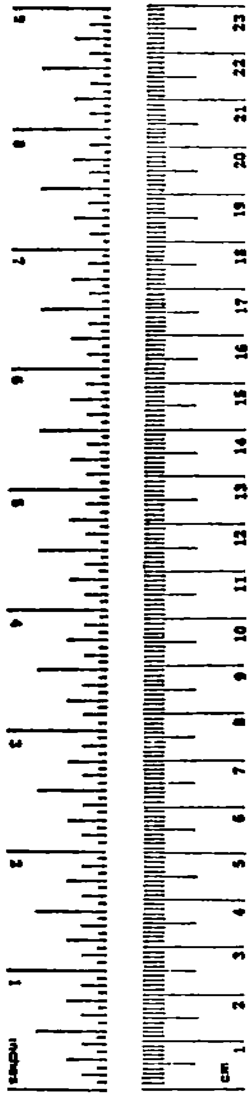
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

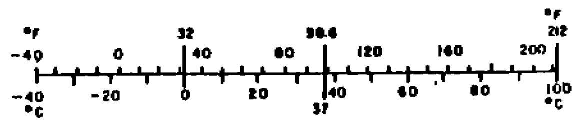
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

All shipyards conduct extensive inspections on newly constructed ships' structures during various stages of the building program with the purpose of assuring a structurally sound ship capable of withstanding the operational and environmental loads to be imposed on it during its service life.

The ideal materials, scantlings, and configuration of the structure are determined by the structural designer and depicted in the contract design drawings and specifications. However, the compliance of the constructed vessel with the ideal design depends on the following factors:

- The degree of attention paid during the detail design stage to inspection requirements,
- The degree of redundancy provided in the detail design,
- The care exercised in procuring and installing proper structural materials,
- The existence or lack of flaws in the materials actually installed,
- The effectiveness of inspection activities,
- The efficiency with which any structural deficiencies found through inspections are resolved and repaired.

During the course of a study for the Ship Structure Committee under contract to the U.S. Coast Guard (1)*, the authors had visited five commercial shipbuilding yards in the United States with the objective of surveying ship structural inspection practices and interviewing the personnel involved in inspections during construction.

Additionally, five existing ships were visited during limited availabilities in several shipyards with the purpose of attending periodical structural inspections being performed and interviewing the ABS surveyors and USCG inspectors involved in these activities.

The results obtained from these investigations were carefully analyzed, current inspection practices and weaknesses thereof noted, and areas of structural inspection activities in need of improvement identified.

It is recognized that these results are based on surveys made in only a limited number of shipyards and as such they do not reflect the practices of all U.S. commercial shipyards. However, it can reasonably be expected that any shipyard will have at least some of the deficiencies observed and will therefore benefit from a compilation wherein guidelines and procedures are contained to assist in formulating improved ship structural inspection practices.

Detailed findings from the surveys are presented in (1). The present "guide" is a slightly expanded and "stand-alone" version of Chapter 5 of that report.

*Numbers in parentheses denote similarly numbered references at the end of report.

The objective of developing a guide is further discussed in Section 2. In Section 3, a brief compilation on ship structural integrity and factors affecting it is presented.

The concept for and the contents of a guide for ship structural inspection are contained in Section 4.

Listings of references cited and definitions of terminology and abbreviations used in the text are included at the end of the guide.

2.0 OBJECTIVE

The construction process of any ship must be complemented with inspections and examinations to ensure compliance of the "as-built" vessel with its original design in regard to structures, materials, machinery, equipment, systems, and outfitting.

This "Guide" includes consideration of inspections for ship structures from the initiation of the design process to the end of the vessel's useful service life. Its objective is to provide, for use by all marine people involved in ship structural inspections, a thorough document recommending corrective action for typical deficiencies or deviations.

Through proper understanding and application of these procedures and methods by the structural inspectors:

- o minor and major deviations can be detected early in the construction process;
- o appropriate corrective measures can be accomplished so as not to allow an accumulation of defects;
- o costly rework which would have otherwise been required can be avoided;
- o an "as-built" structural history of the vessel can be prepared on the basis of which future in-service inspection results can be evaluated;
- o the structural integrity can be maintained by performing periodic in-service inspections and correcting any deficiencies found before they can progress to levels sufficient to cause failure of the parts or of the complete hull girder.

3.0 FACTORS AFFECTING SHIPS' STRUCTURAL INTEGRITY

The term "structural integrity" as used here is intended to convey the employment of structural design, material utilization, and fabrication technologies in the production of a ship.

The completeness and accuracy of the design procedures used in developing the ship's structure will obviously play a major role on the soundness of the end product. Utilization of materials of proper type and grade, and free of flaws, to satisfy the design requirements will also greatly affect structural integrity. Having as much, if not greater, influence on the final product's performance are the methods and techniques used in fabricating and inspecting the structure.

A majority of present day ship structural designs are developed on the basis of a combination of "safe-life" and "fail-safe" approaches. A "safe-life" design implies that the structure will not fail, at least in terms of failure due to crack initiation and growth, during its lifetime. A "fail-safe" design, on the other hand, assumes periodic inspections during the structure's lifetime, and implies the detection and repair or renewal of any parts of a structure that develop flaws.

The design process is an iterative one, and consists basically of the adoption of a geometry, analysis of the response of this geometry to the applied loads, evaluation of this response against an established norm, and recycling of the process until acceptable responses are obtained.

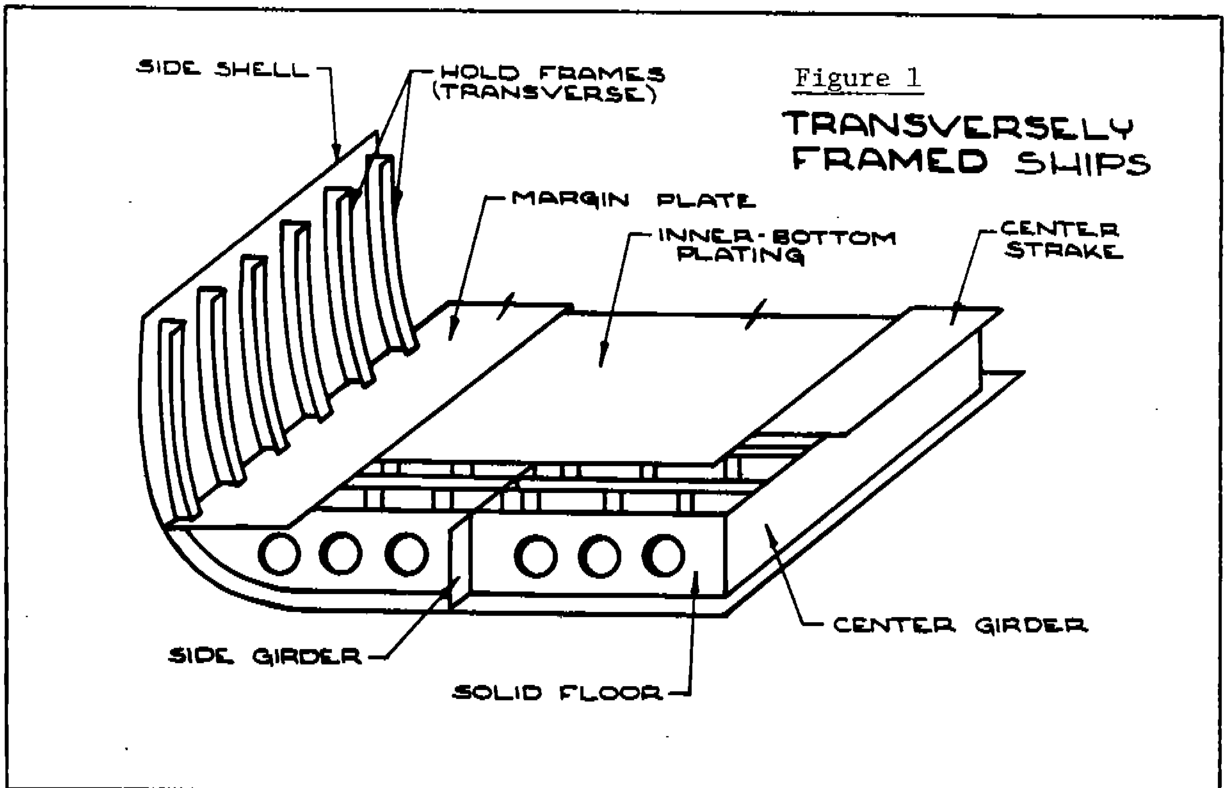
In investigating the longitudinal strength of the ship being designed, conventional or deterministic methods have mostly been employed to date. In recent years, however, probabilistic structural design approaches are being widely studied especially toward application for the design of the ship's longitudinal hull girder. A probabilistic structural design analyzes the uncertainties associated with ship hull strength and develops expressions for structural reliability.

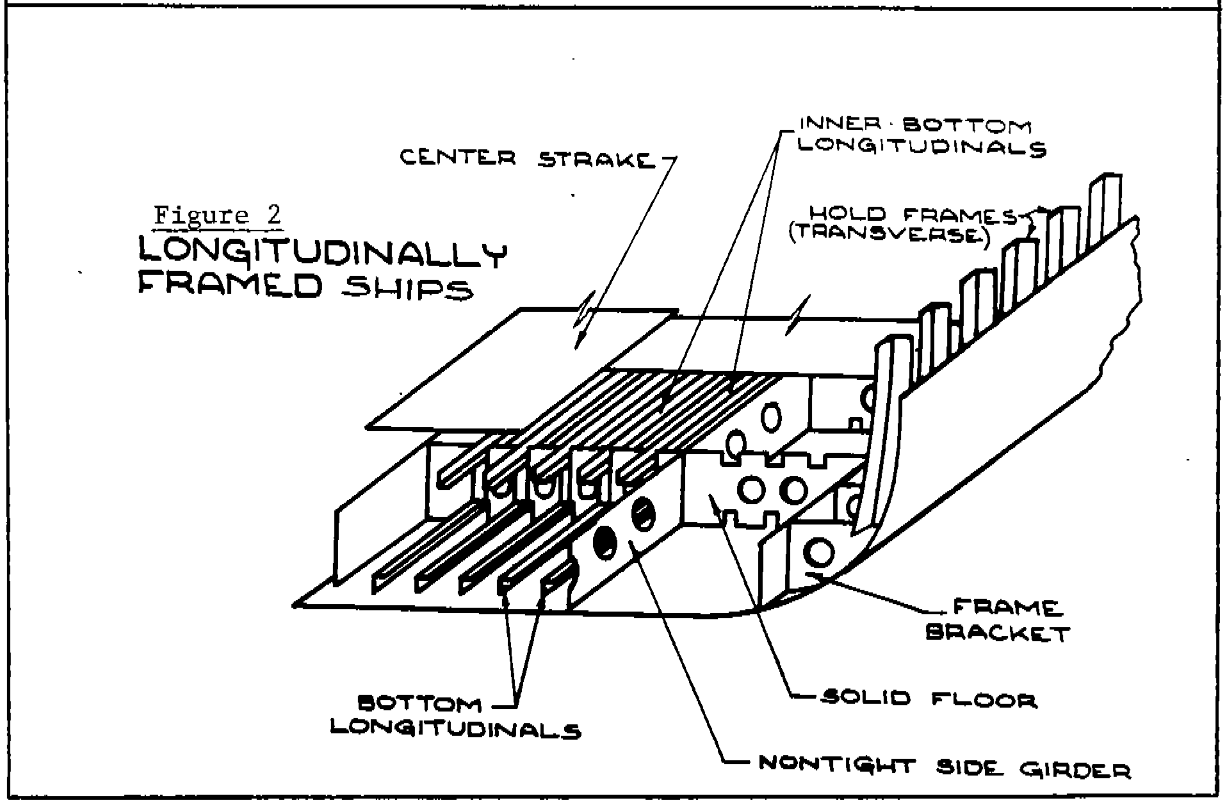
In order to better understand the philosophy behind the inspection requirements, an explanation of the functions of the ship structural components and potential failure modes is presented here.

3.1 <u>Hull Girder</u>

The main functions of a ship's hull girder are to act as a watertight envelope, to support local hydrostatic loads, and to resist the bending loads applied on the structure. These functions are provided by the structural elements that constitute the hull girder. Figures 1 and 2 show representative structural elements normally found in the bottom structure of transversely and longitudinally framed ships, respectively. The bottom structure, together with the side shell and the strength deck acts as a box girder (Figure 3) to provide the required strength for structural integrity.

The loads imposed on the structure create in-plane compression, tension and shear stresses which may cause excessive permanent deformations due to local yielding or buckling (from compressive and/or shear loads) and cracks due to





HULL CONSTRUCTION NOMENCLATURE

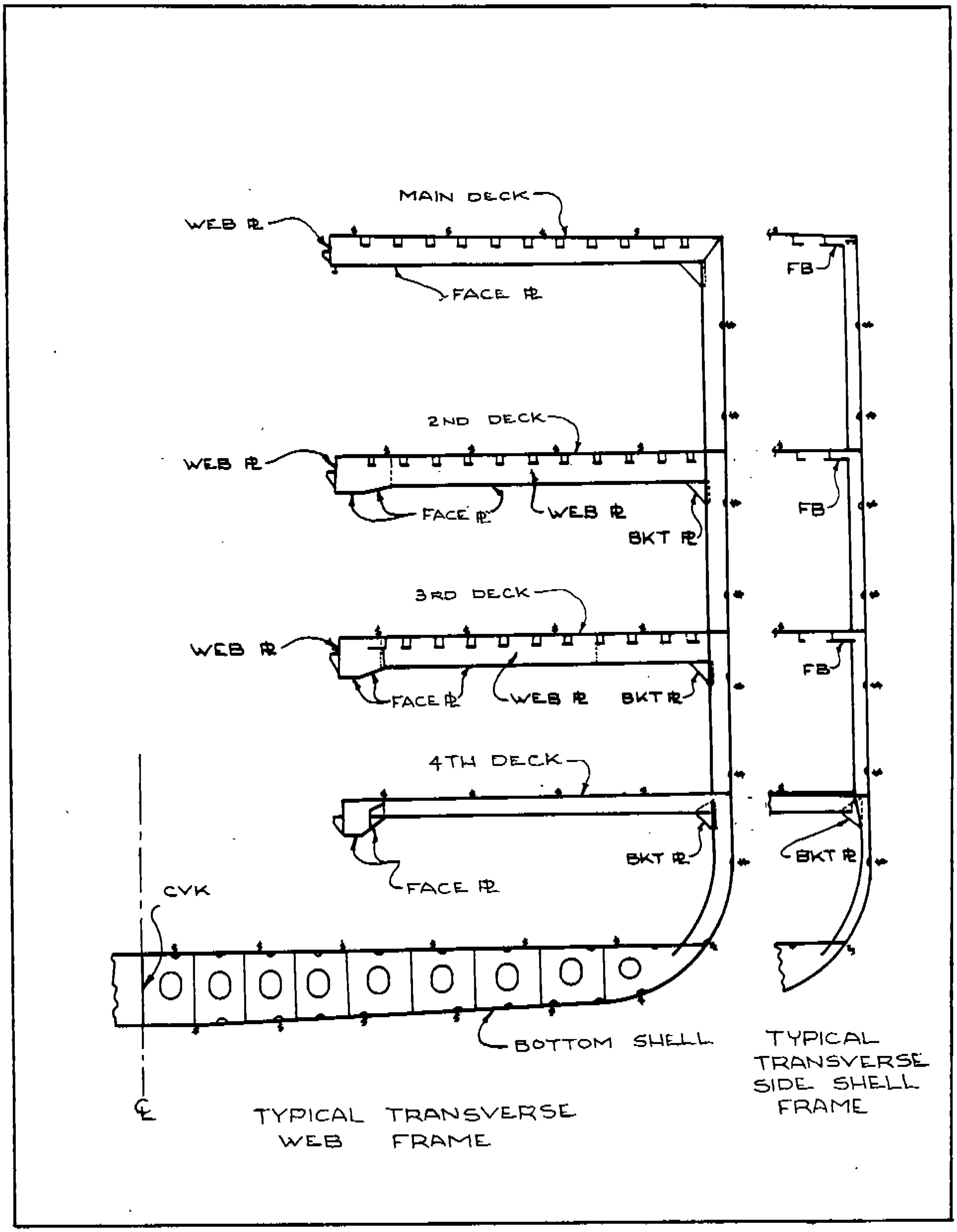


Figure 3: SAMPLE MIDSHIP SECTION

fatigue or local brittleness (usually from tensile loads).

In addition to the in-plane bending and shear loads, the hull girder must be capable of supporting local hydrostatic loads as well. In this case, the plating and stiffeners act together and are in turn supported by beams, girders and stanchions (for decks). Failure of these elements could occur in the form of tripping and web buckling for the stiffeners, beams and girders, and instability collapse of the stanchions.

Decks within the hull, which may or may not be strength decks, will also be subjected to local water, cargo, or equipment loads. In the case of non-strength decks, only the effects of the normal loads, unless they contribute to hull bending, need be considered. For strength decks, however, normal and in-plane loads will occur as mentioned above for the hull girder.

Bulkheads are one of the major components of the internal structure. Main transverse bulkheads may form tank boundaries, support decks, and provide support against racking loads. Longitudinal bulkheads also form tank boundaries and provide deck support; and if of sufficient length, they contribute to the longitudinal strength of the ship. Therefore, the loads in bulkheads may be very complex and the plating and stiffeners be subject to the same types of failure as other components of the hull girder. Other components of the hull girder are those associated with an inner bottom and are the floors and center or side girders. Potential failure modes discussed above apply to these components as well.

It is important to note that due to severe loadings, excessive wastage, poor structural design, improper use of materials, excessive fatigue cycling, etc., failure may occur at any structural component at some stress value that is much less than the theoretically allowable limit. Detection of such conditions by careful analysis and by sufficient inspection is consequently crucial for the prevention of failure.

3.2 Damage Versus Collapse

The types of failure anticipated for various structural components may lead to hull girder damage but not necessarily result in total collapse. A structure is damaged when its orginal form is changed sufficiently to be detrimental to future performance or usage, but there may be no immediate loss of function. Cracks, local yielding, or buckling are examples of this type of failure.

Collapse of the structure occurs when it is damaged beyond the point of being able to support the applied loads. Fatigue cracks may lengthen and cause gradual failure or, in the case of structural instability such as a terminal fracture, the failure may be sudden.

It is important therefore to detect (through inspection) and repair any damaged structural element to prevent collapse of the element or of the entire structural system.

3.3 Structural Details

Longitudinal hull girder design, using deterministic and/or probabilistic approaches, establishes the strength requirements and therefore the scantlings of primary structural elements. Equally important, from the standpoint of integrity of a ship's structure, however, is the design of structural details.

Structural details represent a considerable portion of the hull construction cost and are very often the source of cracks leading to hull girder damage.

The key to the design of sound structural details is to provide structural continuity, minimize stress concentration effects, and to specify welding procedures compatible with the materials. These measures will have the effect of minimizing crack initiation potential.

In an earlier Ship Structure Committee project (2), structural details common to many ships were surveyed to determine the effectiveness of various geometrical configurations that have been used for similiar shipboard conditions. Data from sound and failed details were gathered to provide feedback to the designer for analyzing the causes of failures. No conclusions were reached regarding any specific detail variations since many occurred only a few times, but some of these showed no signs of failure and may be considered as preferred details.

It has been demonstrated that it is feasible to utilize finite element structural analysis techniques in the development of structural details. This technique is found to be an efficient and cost effective approach for determining the feasibility and integrity of structural details. By utilizing this technique, the high cost of repairs due to cracking or failure may be reduced (3). Not all structural details require a rigorous analysis, but those suspected of high stress concentrations and those which are repeated many times should be investigated.

4.0 UNIFIED CONCEPT FOR SHIP STRUCTURAL INSPECTIONS

4.1 General

A "unified" inspection concept is defined as that which covers all stages of a ship's operating life as well as its design and construction periods.

For each stage, the extent of and the procedures for inspections to be performed should be established. The purpose of inspections is to assess the capability of the structure to remain safe until the next inspection period and to accomplish any necessary corrective measures to maintain this capability.

The extent of structural inspections required will always be greatly affected by cost and time considerations. In actual practice, it will be impractical, if not impossible, to execute "perfect" inspections. However, even if the "perfect" level of inspection cannot be obtained, the surveyors/inspectors involved in ship structural inspections must try to conduct just the sufficient amount of inspection without going to unnecessary extremes.

4.2 Inspection Considerations During Design Stages

The design of a ship's structures is generally accomplished by means of a trial and error approach. The objective is to arrive at redundant, inspectable, and fail-safe structures. In order to assure these objectives, the designers must take the following inspection related criteria into consideration during the design stages:

- o inspectability of structural elements both during fabrication and during in-service inspections;
- o provision of redundant structures;
- o identification of critically stressed parts of structures;
- o determination of standard tolerances and acceptable levels for structural deviations on the basis of how they affect the structural performance.

4.2.1 Inspectability

During preparation of detailed structural drawings, special attention should be directed to providing easy access to all parts and especially critically stressed areas of structure for the purpose of inspections. Specific precautions that may be taken are:

- o adoption of greater spacing for members to facilitate access,
- o avoiding "blind" spots in the structural arrangements,
- o providing permanently installed access plates or holes for entering tightly arranged structures.

The general philosophy sometimes favored in shipyards that "if it can be built, it can be inspected" should be abandoned and the extra attention needed to provide inspectability should be given.

Precautions can also be taken and slight modifications or additions made to the structure during design stages to provide inspectability of those structural items that will be subjected to periodical in-service inspections. These may take the form of properly spacing stringers, bulkhead stiffeners, etc. or installing permanent rungs for use in climbing by inspectors to enable them to reach otherwise uninspectable areas. The need to install costly staging during in-service inspections may be avoided by this precaution.

The main objective is to make sure that the structural design facilitates in-service inspections rather than hampers them. Toward this goal, a thorough review of the detail structural design drawings must be undertaken prior to releasing them to the production department for fabrication.

4.2.2 Redundancy

Inspectability will also be aided by the provision of redundant structures. A redundant structure can be obtained by providing more than one member to serve the same function or to share the same load. By this measure, the probability of total failure due to the failure of a single element will be much reduced if not eliminated depending on the degree of redundancy provided. When more than one member exists to take up the same loading, then finding damage in one member will point out the need to carefully inspect other redundant members.

4.2.3 Critically Stressed Areas

The analyses and investigations performed during the structural design development will indicate that some areas or elements of a ship's hull girder will be subjected to higher stresses than others even though the "higher stresses" are still within allowable limits. Yet it will be found impractical and uneconomical to increase the scantlings of these elements further.

Such areas or elements are termed "critically stressed areas" and they should receive special attention during inspection activities. They should be identified on the inspection plans and specific inspection requirements given.

4.2.4 Inspection Plan

On the basis of analyses and investigations performed during design stages, an "Inspection Plan" should be prepared for the vessel to be constructed. The "plan" should provide accessibility instructions for parts to be inspected and identify the critically stressed areas as determined from stress analyses. In addition, it should contain a listing of all structural elements to be inspected and the type and extent of inspections for each. A typical summary checklist for primary strength members is given in Table 1. This list should be amplified to cover all primary, secondary, and detail structures as applicable to the specific ship to be constructed.

Also to be included in the inspection plan is a listing of or a reference to the applicable standard structural tolerances and acceptable levels of deviation from these standards.

Legend V - Visual Inspections M - Physical Measurements N - NDT Examinations * - To be done only when visual inspections show that it is necessary.	Proper Use of Materials	Dimensional Accuracy	Continuity	Alignment	Soundness of Welds	Distortion, Deformation	Unfairness	. . . etc.
Bottom Shell PL.	VN*		V		VMN		VM*	
Side Shell PL.	VN*		V		VMN		VM*	
Deck PL.	VN*		V		VMN			
Transv. Bulkhead PL.	VN*				VMN			
Long'l Bulkhead PL.	VN*		V		VMN			
Doublebottom PL.	VN*		V		VMN			
Long'l Frames	VN*	M	V	VM*	VMN	V		
Transv. Frames or Webs	VN*	M			VMN	V		
Long'l Girders	VN*	M	V	VM*	VMN	V		
Floors	VN*	M	V	VM*	VMN			
Pillars/Stanchions	VN*	M			VMN			
- - - etc.								

Table 1: INSPECTION CHECKLIST FOR PRIMARY STRUCTURES

Many compilations of such tolerance standards now exist and are in use in various shipbuilding countries. Based on the desires of the prospective shipowner and the requirements imposed by the design, the designer should decide on the acceptable tolerance levels and either adopt one of the existing compilations or modify it to suit his purposes for use in negotiations with the prospective shipyard prior to signing a construction contract. Guidance on standard tolerances and acceptable deviations can be obtained from references (4) through (9). Most of these publications also contain recommended repair and corrective action procedures for major deviations from acceptable levels. These recommendations may be used as a baseline in determining the specific corrective action procedures to be adopted for the specific ship to be constructed.

4.3 Inspection Activities During Construction

Inspection is a costly activity. By specifying inspections in excess of what is necessary to ensure structural integrity of the completed vessel, an extra heavy cost burden may be imposed on the shipyards, and therefore on the owners. On the other hand, by specifying and then conducting an insufficient amount of inspection, some deficiencies in the structures may remain undetected and may result in repair or renewal operations much costlier than the pre-planned inspections. Accordingly, the need to arrive at a reasonably balanced level of inspection among the parties concerned, i.e. the shipowner, shipyard, classification society, and the designer, is apparent.

The intent of this guide is not to set any stringent requirements for the structural inspections of any particular ship. The following suggestions for various inspection considerations, types/methods/frequencies of inspections, and procedures, are presented for the purpose of making available for review and use a broad set of guidelines to be used in the preparation of a specific inspection program for the construction of a particular ship.

4.3.1 Owner's Needs

The owner of a vessel may need and may wish to have conducted certain inspection activities and corrective measures which the shipyard may consider unnecessary or uncalled for from a structural strength viewpoint. A simple example is the desire of the owner of a high speed container ship to have all surface imperfections on the exterior hull plating (such as burrs, scars, spatter, etc) removed even though these do not affect the ship's structural integrity and may be considered "cosmetic" repair. However such removal is important for the shipowner since it will reduce the vessel's drag and hence its fuel consumption.

The owner may also have a preference for the type and extent of non-destructive examinations (NDE) to be employed in construction inspections.

All such needs expressed by the owner should be discussed by the parties involved and agreed procedures should be made a part of the construction inspection program.

4.3.2 Receipt Inspection of Materials

It is desireable to have all steel and aluminum structural materials inspected upon arrival at the shipyard's receiving area. However, this again becomes a matter of increasing costs. Therefore, the "receipt inspection" requirements to be in effect during the construction period should be established on the basis of a cost/benefit trade-off.

Specific defects to look for are:

- o deviations from nominal dimensions,
- o surface defects such as excessive pitting and flaking on plate and shape materials,
- o laminations on plates,
- o deviations from the specified type or grade.

In order to detect these defects, visual inspections must be made and must be complemented when necessary by measurements for dimensional accuracy and by ultrasonic examinations to detect laminations as necessary. Recommended tolerance standards and repair procedures for defects in excess of allowable levels are contained in references 4, 5, and 6. By reviewing these references, the minimum receipt inspection requirements should be established and included in the ship's construction inspection program.

4.3.3 In Process Inspections

In-process inspections should be performed by the production department supervisors as a "self-inspection" activity and by the quality assurance department inspectors for the purpose of assuring adequate control of quality during the ship construction process.

The specified procedures, methods, and organizational roles may vary depending on the shipyard where the construction will take place and on the type and size of the vessel to be constructed. In any case, however, the following particular inspection functions must be accomplished during particular stages of construction.

a. Visual Inspections

Visual inspections during subassembly, assembly, and erection stages should be directed to carefully examining the structure with specific attention to the following:

- o Completeness: To make sure that all of the major structural members on the subassembly/assembly/module/ship are in place as required by the detail design drawing.
- o Materials Used: To verify that only the correct materials as specified by the detail design drawings are used. Material identification color codes or markings can be used for this verification.
- o Accuracy: To pin-point apparent deviations from specified dimensions with the purpose of assuring that subassemblies and assemblies fit to-

gether. A pre-planned dimensional control program is necessary to accomplish this.

- o Joint Preparation: To ensure accuracy in fit-up, root openings, alignment of members, cleanliness, removal of slag, bevelling, etc.

- o Weld Layout: To determine that weld sizes are correct and that continuous and/or intermittent welds are being used in accordance with the detail design drawings.

- o Fairness: To observe any apparent unfairness in the completed unit with the purpose of requiring fairness measurements if necessary.

- o Structural Details: To verify compliance with detail design drawings of structural details such as clearance cutouts, collars, brackets, stiffener end connections, etc.

- o Supports/Braces: To verify that an adequate quantity and quality of supports, braces, and lifting pads are provided and properly located for use in moving and handling the unit without damaging it and/or disturbing its alignment.

- o General Workmanship: To see that the completed structural unit is free of discontinuities, undercuts, sharp ragged edges, nicks or other damage which may initiate or propogate cracks causing total failure of the structure; to verify that all temporary fabrication/erection attachments that are not required during later stages of construction are properly removed.

Specific guidelines for use in judging the acceptability of the structures on the basis of visual inspections are the detail structural drawings, construction specifications, and the inspection plan prepared during the design process. A lot still depends on the knowledge and experience of the inspector. Whenever the inspector is in doubt as to the acceptability of any part with regard to any inspection criterion, he should refer to the standard tolerances and acceptable deviations contained in references (4), (5), (7) or those that may be included in the ship's inspection plan, and if he considers it necessary to have physical measurements or NDE examinations made, he should request such.

b. Dimensional Accuracy

Dimensional control activities should cover all stages of construction from mold loft to launching.

- o Mold Loft: Loft sheets, roll molds, furnace molds, and battens should be inspected for dimensional conformance and for completeness of detail with the latest revised detail structural drawings. Steel tapes used in layouts and measurements should also be perodically inspected for accuracy.

- o Plate Shop and Numerically Controlled Burning Area: In order to verify conformance with detail structural plans, the following should be inspected during plate preparation:

- orientation of plate with respect to the molded line

- centerline of the ship should be used as a master reference line and center punching of frames, buttocks, and waterlines should be inspected for dimensional accuracy;

- spacings and angularities of structural members

- it must be verified that a sufficient final cut allowance is provided;

- after the final cut, bevels and collars, final dimensions, alignment, and fairness should be inspected.

o <u>Subassembly/Assembly/Erection Areas</u>: During panel and subassembly fabrication, assembly/unit/module construction, and erection processes in platen areas, pre-outfitting areas, and in building basins or shipways, the following dimensional accuracy inspections should be accomplished:

  - orientation of plate with regard to the molded lines,

  - spacing and dimensions of frames, stiffeners, girders, headers, etc.,

  - alignment and fairness, conformance of welds with detail plans and specifications,

  - squareness and distortion,

  - ship's principal dimensions (length, beam, depth),

  - declivity and straightness of keel,

c. Alignment and Fairness

Excessive misalignment in structures may cause stress concentrations and may therefore lead to failure. Accordingly, alignment inspections must be made during all stages of construction and any excessive (i.e. beyond acceptable levels) deviations should be noted, recorded, and reported for research as to its root cause so that appropriate corrective measures can be determined.

Essentially, the alignment measurements for plate edges and structural shapes should be made, after welding, on the following:

o shell assemblies including transverse and longitudinal framing and floors,

o longitudinal and transverse bulkhead assemblies,

o strength decks.

Alignment inspections should also be made on secondary structures such as foundations, masts, rudders, tanks, trunks, etc.

The standard tolerances and acceptable levels for misalignment of various structural members are contained in references (4), (5), and (7).

The fairness of the plating and frames, beams, stiffeners, etc. should be checked and maintained within acceptable tolerances. Any unfairness found to be permissible should result in a generally fair curve across the plating panel or other structural members.

d. Weld Inspections and Non-Destructive Examinations

Weld inspections consist of visual surveys, physical measurements, and x-ray and/or ultrasonic examinations.

Weld inspections should be performed in the "as-welded" condition of the structure. The weld to be inspected must be clean and all slag must be removed. Simple tools such as a ruler, throat gauge, undercut gauge, or a fillet leg gauge shold be used in measurements to support visual examinations.

Visual examinations should be directed toward the detection of the following possible weld defects or deficiencies:

- o Errors in weld size per drawings
- o Lack of fusion (NDE when necessary)
- o Undercuts
- o Deviations from weld contour
- o Fissures, cracks, or crack-like indications (NDE)
- o Porosity (NDE)
- o Failure to wrap around fillet welds
- o Visible evidence of arc strikes
- o Sharp or ragged edges
- o Excessive slag

Non-destructive examinations should be performed as specified in the building specifications, as further detailed in the "design inspection plan", and as contained in the "construction inspection program" and its accompanying field sketches agreed to by the shipowners, shipyard, and classification society surveyors.

Tolerance standards and levels of acceptance for welding defects shown above are contained, as are all other structural standards, in (4), (5), and (7).

Methods, procedures, evaluation, and other requirements for NDE are given in (6), (10), (11) and (12) among others.

e. Final Structural Surveys and Tightness Tests

Final structural surveys should be accomplished prior to completion of any unit, module, or the complete erection on the shipway. For all in-process inspections, but specifically for the joint final structural surveys, the preparation of the structure for inspection is very important.

When the unit is called out for final structural survey, all structure should be visually inspected for completeness of all work including attachments, penetrations, and all permanent access fittings and closures.

Tanks, compartments, cofferdams, and void spaces should be tested for tightness to prevent the spreading of flooding, fire, and gases. Tightness checks can be accomplished by means of hose tests, air pressure tests, or hydrostatic tests. Tests should be carried out in accordance with a "compartment testing diagram" to be prepared by the Engineering Department.

4.3.4 Common Structural Deficiencies

Many shipyards already have "in-house" publications for use in identifying most frequently encountered structural deficiencies and recommended corrective measures. Publicly available documents also exist for this purpose; some of the references which contain common deficiencies, standard tolerances, and standard corrective measures are (4), (5), (7), (8), and (9).

Some commonly encountered structural deficiencies are illustrated in Figures 4 through 13 which should assist inspectors in identifying them during surveys:

- Misalignment, Figs. 4 and 5
- excessive gap between members, Fig. 6
- stiffener tilt, Fig. 7
- improper distance between adjacent welds, Figs. 8, 9, 10
- weld flaws,
- weld undercut
- distortion, Fig. 11, 12
- deformation of plate, Fig. 13
- cracks, dents, and other damage

4.3.5 Recording/Reporting/Evaluation Procedures

a. Documentation of Inspection Activities

Appropriate forms should be developed or adopted from similar forms used by others for requesting, recording, reporting for corrective action, analyzing, and processing structural inspections and NDE examinations. Forms developed and used by one shipyard may be different from others to reflect differences in the quality control organization.

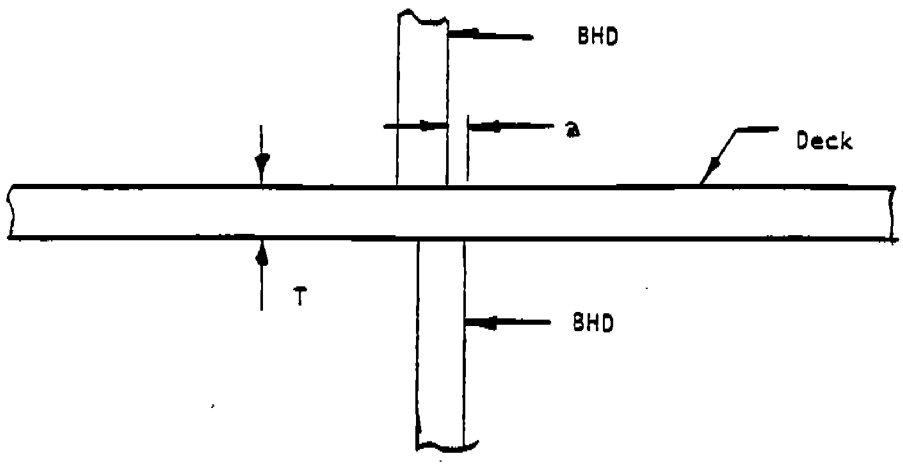


Figure 4: BULKHEAD MISALIGNMENT

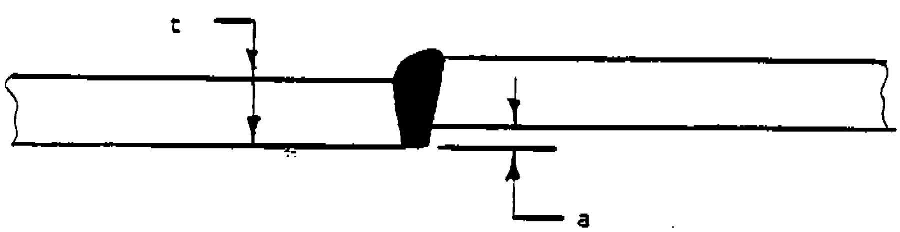


Figure 5: MISALIGNMENT OF BUTT CONNECTIONS

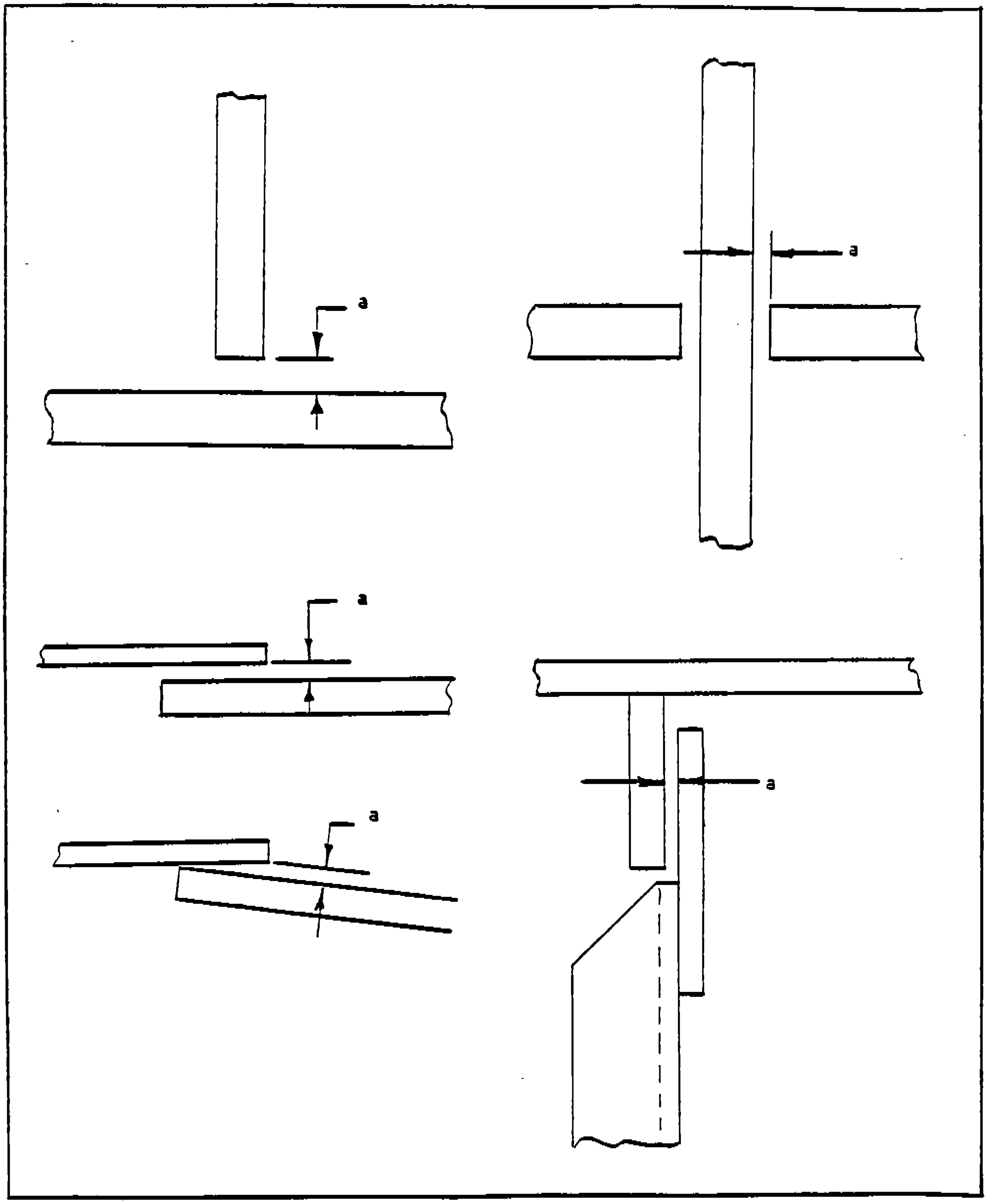


Figure 6: EXCESSIVE GAPS BETWEEN MEMBERS

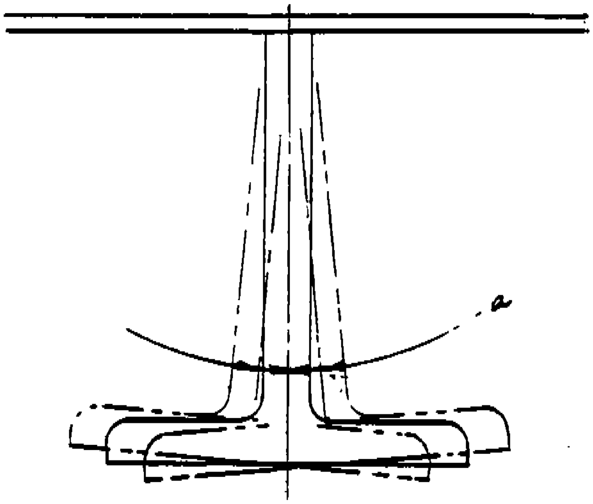


Figure 7: STIFFENER TILT

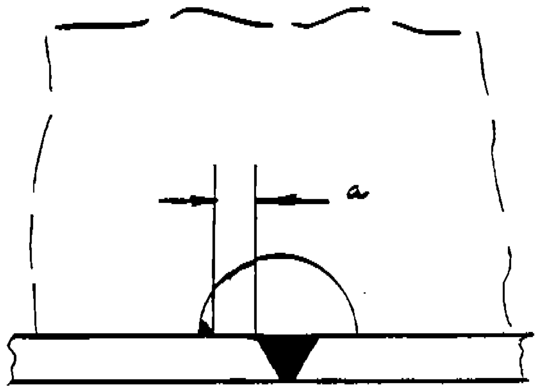


Figure 8: DISTANCE BETWEEN BUTT WELD AND SCALLOP

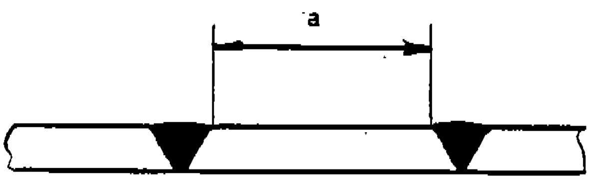


Figure 9: DISTANCE BETWEEN ADJACENT BUTT WELDS

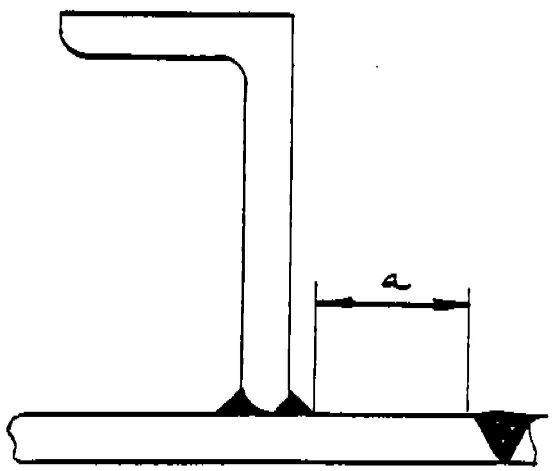


Figure 10: DISTANCE BETWEEN BUTT WELD AND FILLET WELD

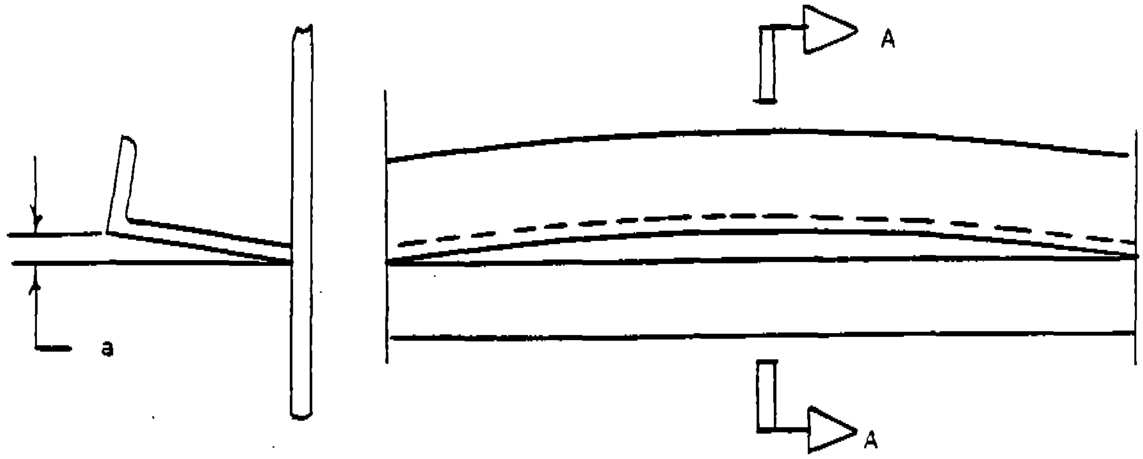


Figure 11: DISTORTION OF BEAMS, FRAMES, STIFFENERS

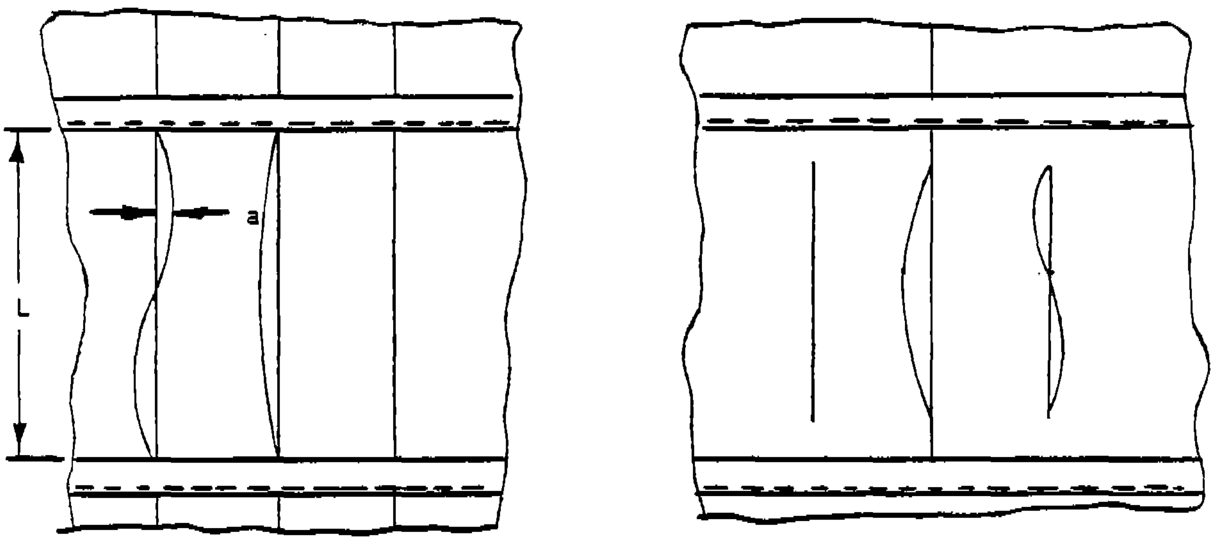


Figure 12: DISTORTION IN PANEL STIFFENERS

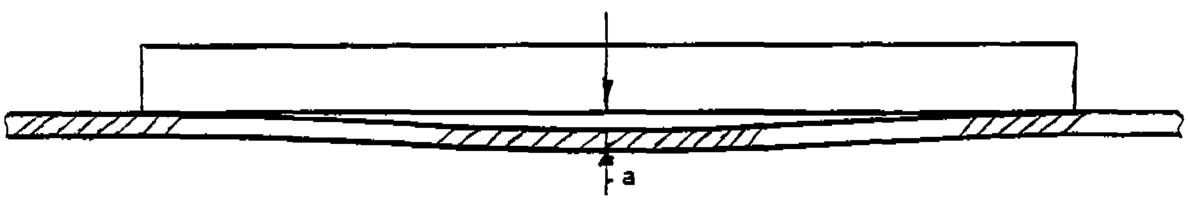


Figure 13: DEFORMATION OF PLATE

b. Dissemination of Inspection Results

Findings from inspection activities, as they relate to specific parts of the ship's structure, should be recorded on appropriate forms and maintained in the ship's inspection file. Applicable forms should be distributed to the proper departments in the yard, to owner's resident inspectors, and to ABS surveyors for review and execution or approval of the recommended corrective action.

Specifically important, from the standpoint of product liability, is the feedback of inspection results to the structural designer. By being aware of the deficiencies found and the corrective actions accomplished on the structure he has designed, the designer can analyze the causes and consequences of the deficiency, decide whether the corrective action was sufficient, and determine if the original design should be modified to prevent recurrence of similiar deficiencies in follow-on constructions.

Maintaining brief but clear records of all structural deficiencies and repairs will enable the shipyard to determine the "as-built" condition of the ship hull girder and the elements thereof.

It is also desirable to have all inspection results statistically analyzed, preferably by computerized techniques, for the purpose of measuring the level of efficiency obtained in structural workmanship.

4.3.6 Development of "Structure Condition Record"

A thorough review and analysis of all structural inspection reports and deficiency/corrective action records will enable the shipyard to prepare a structural "history" of the ship's construction and the condition of its structure as built. It will be possible to record:

- all structure that was inspected and found to be within acceptable tolerances;
- the actual "accepted" tolerances (or deviations from standard) for such structures;
- structures found to have deviations larger than allowable levels but jointly accepted by yard/owner/classification society inspectors as not requiring corrective action;
- the extent of actual deviations for such structures or structural elements; structures found to have unacceptable deviations and repaired using standard corrective action procedures;
- the "as corrected" remaining deviations, if any, on such structures;
- structures found to have unacceptably large deviations for which the original design had to be modified to avoid recurrences of deficiencies;
- the modified structural design for such members, parts;

- the "as modified" remaining deviations, if any, on such structures.

The information listed above should be compiled into a complete report which may be labelled "Structure Condition Record" for use as a reference basis throughout the ship's service life.

4.3.7 Preparation of "In-Service Inspection Program"

Towards the end of a ship's construction period, the "Design Inspection Plan", the "Construction Inspection Program", and the "Structure Condition Record" should all be reviewed again and a new updated document which may be labelled "In-Service Inspection Program" should be prepared for structural inspections to be performed during the vessel's operating life. This document should reconcile the three aforementioned documents and include the following:

- identification of critically stressed areas as determined in the "design inspection plan";

- any changes to critical stress areas due to built-in material deficiencies or accepted fabrication errors during the construction process;

- other significant areas for inspection not due to design allowance but due solely to material and/or fabrication errors during construction;

- an "inspection checklist" prepared on the basis of the above which identifies all structures to be subjected to in-service inspections;

The "inspection checklist" should include:

- inspection frequencies,

- methods and procedures for inspections,

- tools and equipment to be used,

- responsibilities for performance of inspections (i.e. whether to be conducted by the ship's crew while vessel is in service or by a shipyard crew while afloat or by the yard crew during drydocking, etc.).

4.4 In-Service Inspections

4.4.1 General

The condition of the ship's structure should be kept under constant surveillance by continuous and periodical inspections throughout its operating life in accordance with the "In-Service Inspection Program" prepared during final stages of the construction period.

The continuous inspections, obviously, can only be provided by the ship's crew while the vessel is in operation. Some of the periodical inspections may be performed by the ship's crew as well, but some others would require preparations beyond crew capabilities.

4.4.2 Crew Inspections

In general, the ship's crew will have ample opportunity to inspect the structure while at sea. These inspections may reveal deterioration or damage to parts of structure which may be repaired by the crew or more detailed inspection and repair, possible in a shipyard, may be requested. In some cases, parts of the ship's structure may be uninspectable by crew while at sea since the structure may be inaccessible due to existence of fuel, water, cargo, insulation, etc. in the spaces to be inspected. In such cases too, the crew would request yard inspections.

Crew inspections, when possible, can accomplish the following:

- detect and repair minor damage and deterioration,
- obtain an early warning of major structural problems,
- keep corrosion control systems (if such are installed) under surveillance,
- identify areas for detailed surveys and prepare planning and budgets for shipyard availability,
- by doing all of the above, reduce overall survey and repair costs.

The "In-Service Inspection Program" prepared during the construction period will have identified those structural elements and details that the crew should perform continuous inspections for. It will have also flagged those structures which are considered significant due to design features or fabrication history (i.e. built-in material/fabrication/workmanship variations).

Some of the typical structural deficiencies that crew can detect are:

- Scale formation on plates and shapes
- Pitting
- Localized wastage
- Resultant loss of thickness
- Wastage of zinc anodes in tanks (if used)
- Condition of coatings
- Buckling in structural members
- Fractures, cracks
- Other obvious damage such as dents, etc.

In addition to main structural elements, inspections should also cover miscellaneous structures such as handrails, ladders, platforms, valve reach rods, etc.

Main structural members inspected by the crew, to the extent possible, should include deck plating, underdeck girders and longitudinals, side shell plating and framing, transverse and longitudinal bulkheads with their stiffeners, and stringer platforms, if any.

Figures 14 through 24 show some typical structural deficiencies (fractures, buckling, deterioration) that can be detected by crew inspections. These sketches are applicable to the design of a tanker; similar sketches should be developed for the specific ship to be inspected and included in the "In-Service Inspection Program".

4.4.3 Periodic Inspection by Classification Societies

The classification societies, e.g. the American Bureau of Shipping for vessels being built for U.S. owners in U.S. shipyards, conduct their own inspections by resident surveyors during the vessel's construction period. These inspections are made for the purpose of assuring the vessel's structural integrity and its compliance with ABS Rules from the standpoint of meeting minimum classification requirements. At the end of the construction period, resident ABS surveyors prepare and submit to the ABS Head Office a "New Construction Hull Report".

In order to keep the vessel in class during its service life and to ensure that it is in compliance with USCG regulations, ABS and the U.S. Coast Guard perform periodic inspections of structure, as well as of machinery and all equipment, in accordance with well established procedures and frequencies. These procedures and frequencies are described in detail in the ABS Rules (10) as applicable to vessels of varying types, and are regulated by a U.S. Coast Guard Navigation and Vessel Inspection Circular (13).

ABS makes available to its resident surveyors a "Survey Status" report of the vessel to be inspected prior to initiation of in-service inspections. This report will contain, if applicable, instructions for specific structures to be inspected on the basis of "circular letters" promulgated earlier by analyzing results from actual inspections.

4.4.4 Repair and Conversion Inspections

The procedures to be followed in performing structural inspections for and during major repairs and overhaul availabilities are, essentially, combinations of "construction" and "in-service" inspection procedures. The repairs to any structure due to damage or deterioration should follow the recommended repair procedures contained in the "In-Service Inspection Program". If however the damage is so extensive that it requires removal of the existing structure and renewal with new materials, then in the fabrication of new structures the "Construction Inspection Program" requirements should be observed.

When alterations are to be made to the existing structure as necessitated by a conversion design, the areas to be modified should be structurally inspected in accordance with "in-service" inspection requirements and the newly constructed parts or additional structures should be inspected in accordance with "new construction" requirements.

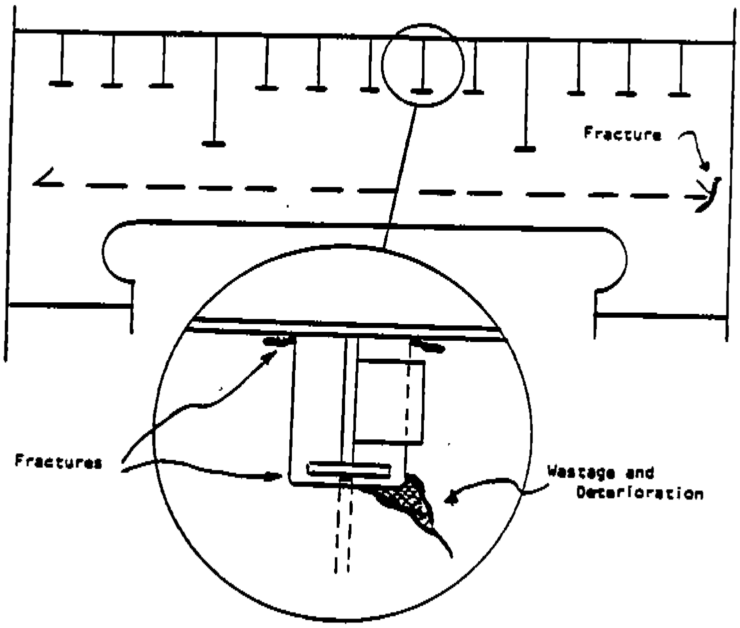


Figure 14: HORİZONTAL STRINGER IN WING TANKS

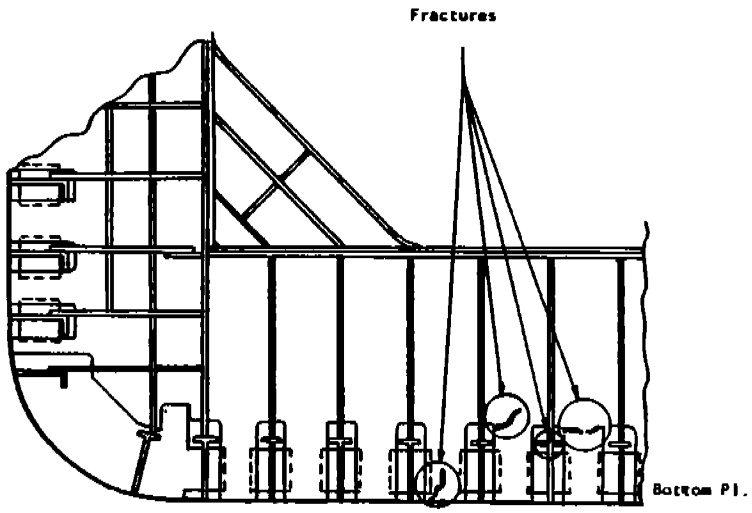
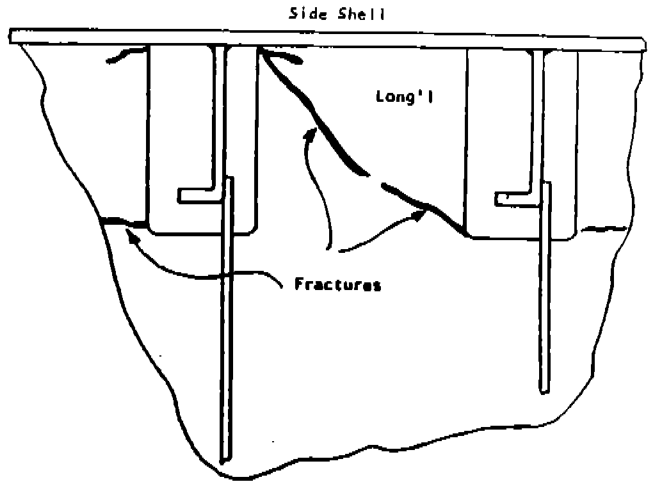


Figure 15: TRANSVERSE WEB FRAME AT BOTTOM

Figure 16: TRANSVERSE WEB FRAME AT SICE SHELL



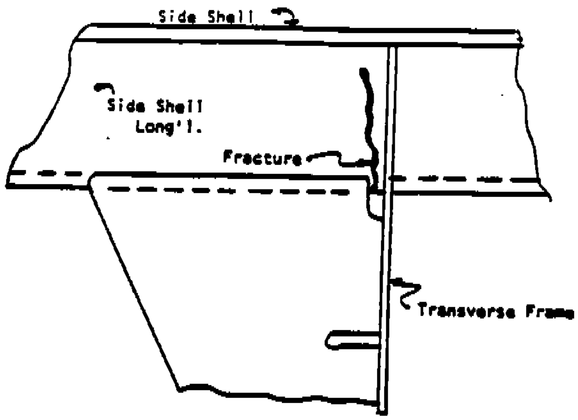
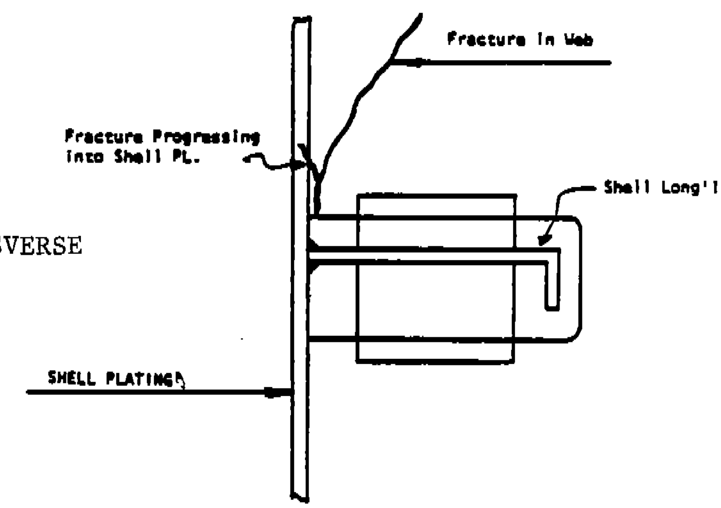


Figure 17: SIDE SHELL LONGITUDINAL FRACTURE

Figure 18: COMBINED PROGRESSIVE SHELL PLATE AND TRANSVERSE WEB FRAME FRACTURE



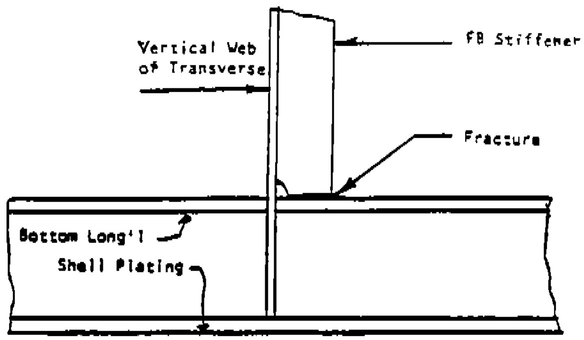


Figure 19: FRACTURE IN BOTTOM TRANSVERSE WEB

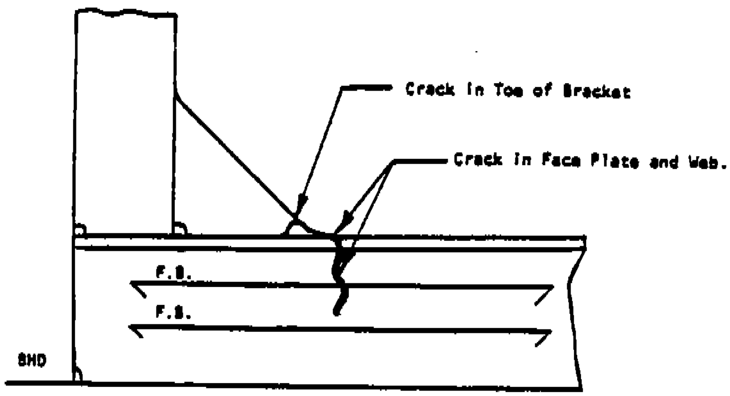


Figure 20: FRACTURE IN LONGITUDINAL INTERCOSTAL GIRDER

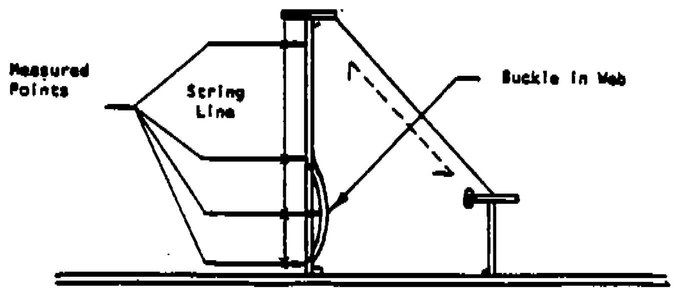


Figure 21: BUCKLING OF CENTERLINE GIRDER

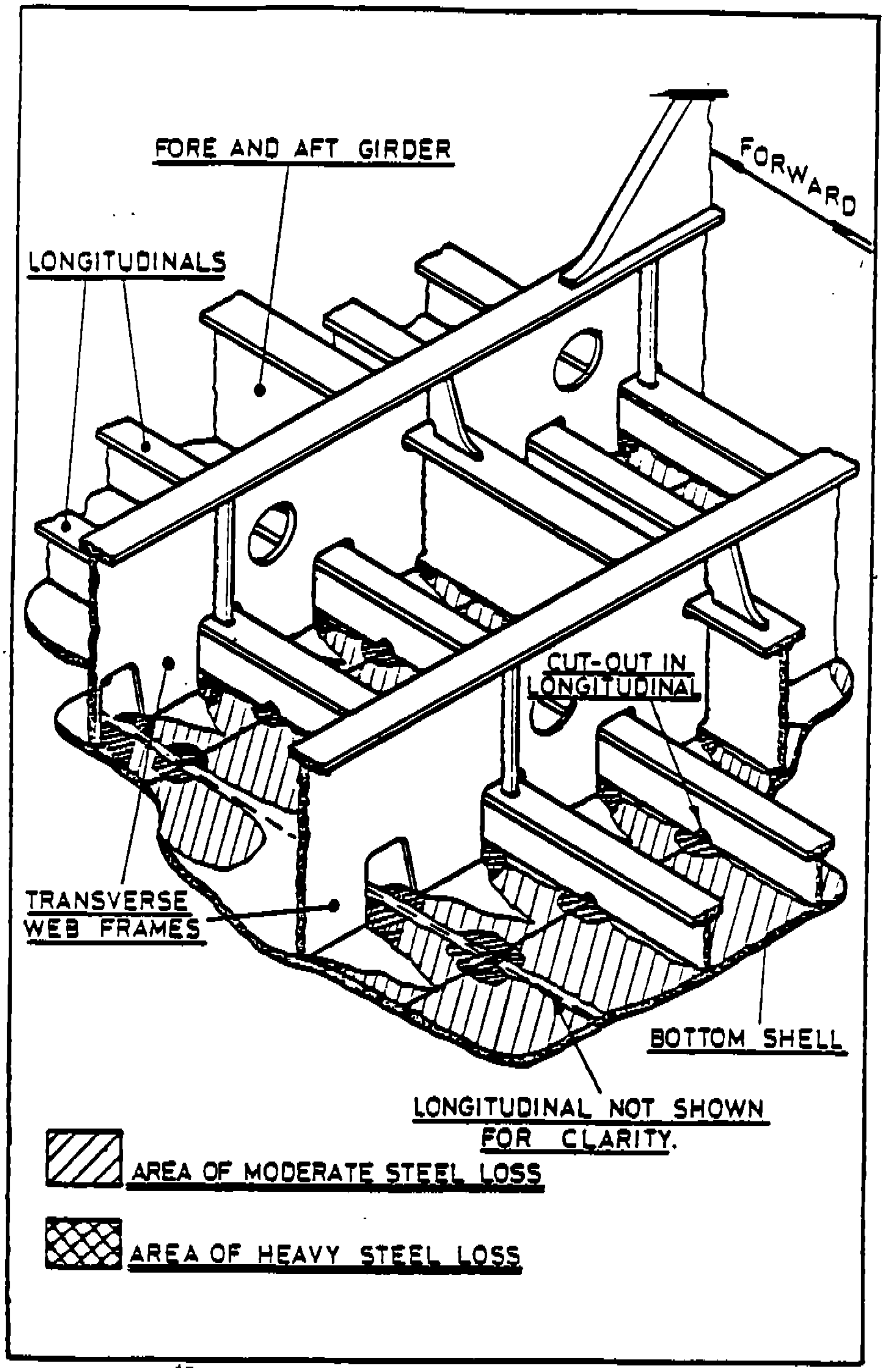


Figure 22: TYPICAL BOTTOM SHELL LOSS PATTERNS

(Reproduced by special permission from "Large Oil Tanker Structural Survey Experience" by Exxon Corporation Tanker Department, June 1982)

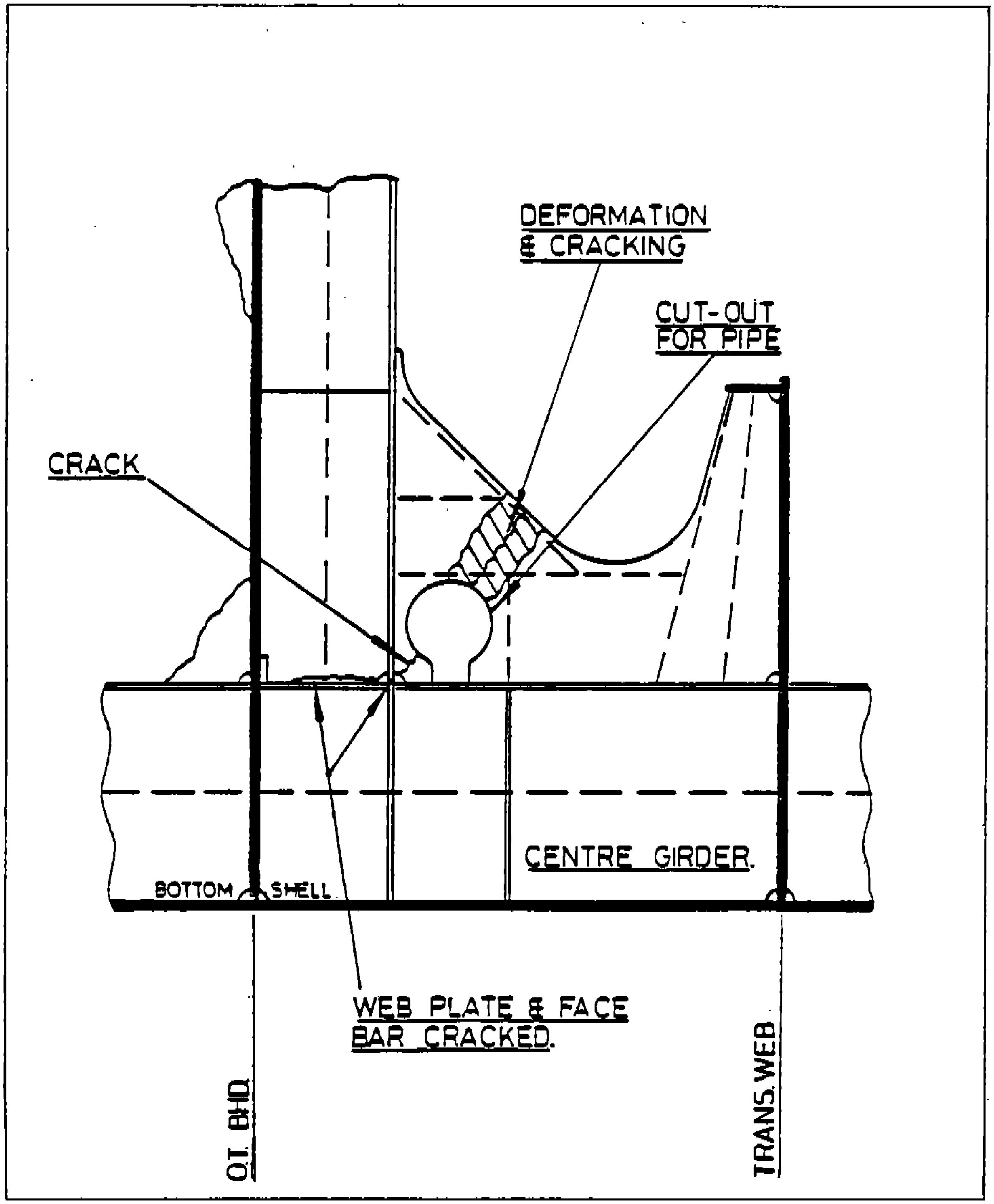


Figure 23: CENTER GIRDER CRACKING

(Reproduced by special permission from "Large Oil Tanker Structural Survey Experience" by Exxon Corporation Tanker Department, June 1982)

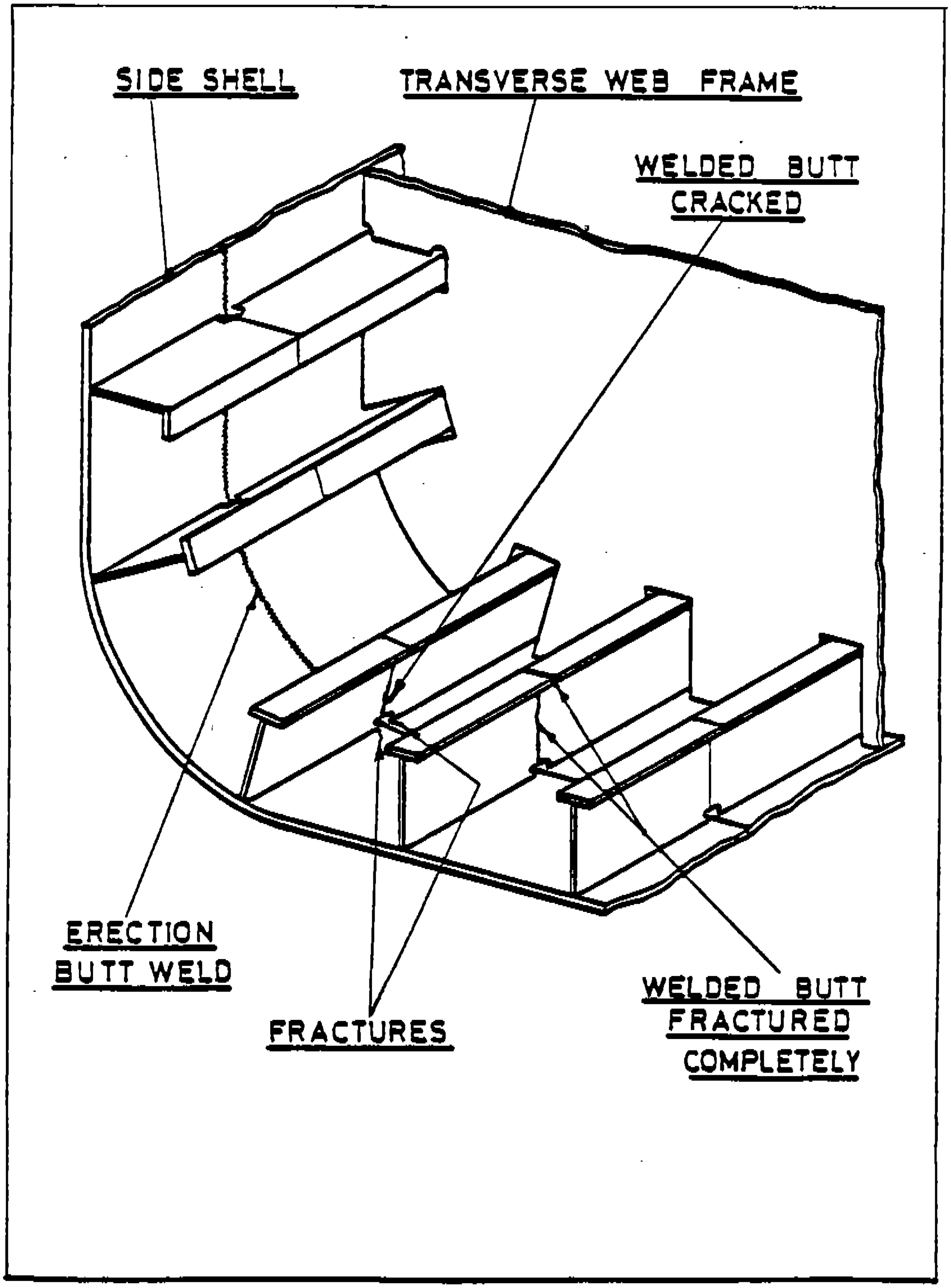


Figure 24: TYPICAL BOTTOM LONGITUDINAL CRACKING

In either case, i.e. both for major structural renewals due to damage or deterioration and for structural modifications and/or additions as required by the conversion design, special attention should be paid to the continuity and compatibility of structures and materials.

4.4.5 Maintaining and Updating the Structure Condition Record

The "Structure Condition Record" (SCR) prepared at the end of the construction period should be referred to prior to initiating periodic in-service inspection activities even if the specific requirements from it have already been incorporated into an "In-Service Inspection Program". SCR will have descriptive background information to enable structural inspectors to understand better the reasons for any special inspection requirements for any specific parts of the structure.

In order that the SCR preserve its usefulness and value to the inspectors, it must be maintained "current" by modifying the existing data or by adding new data, as applicable, from the results of any in-service inspections and/or any corrective measures taken on the basis thereof.

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ACKNOWLEDGEMENT

The authors wish to express gratitude to the members of the ad-hoc project advisory committee of the National Research Council for the support and guidance provided during the development of this guide.

SHIP STRUCTURAL INSPECTION

TERMINOLOGY AND ABBREVIATIONS

Acceptance/Rejection Criteria

Standard tolerances and allowable deviations from standards for structural deficiences observed.

ABS

American Bureau of Shipping

"As-Built" Condition

The actual configuration of the structure when completed.

Accuracy Control

All inspection operations performed in a shipyard with the objective of maintaining greatest possible accuracy at each stage of fabrication.

Alignment Checks

Scheduled and random checks on structure to ensure that any two pieces and the whole assembly or erection is correctly aligned prior to joining.

Annual Survey

Yearly inspections by the classification society for the purpose of renewing the classification certificate.

Bending Loads

Static and/or dynamic forces which act on structural elements and cause bending moments and stresses to develop through the cross-section of these elements.

Buckling

The deformation of structure due to axial compressive loads or stresses.

Brittleness

The behavior of a material whereby it fractures with relatively little or no elongation.

Construction Inspections

Structural inspections conducted on a new ship while under construction.

Continuous Survey

Spreading of all classification society surveys over a period of four years instead of once in four years.

Critical Nodes/Areas for Inspection

Analyses and calculations to determine the weak points or areas of high stress concentration in the structural configuration.

Corrective Measures

Methods of repair or reneval to be used in correcting structural deficiences beyond allowable limits.

Checkpoints for Inspection

A listing of all parts of structure that must be carefully inspected because they contribute to the overall longitudinal strength or they are critical stress areas.

Deficiency Report

A form filled out by structural inpectors to record, report, and recommend corrective action for deficiencies in excess of allowable deviations.

DnV

"Det Norske Veritas": Norwegian Classification Society.

Design Inspection Plan

A plan prepared during the detail design development stage to establish basic inspection requirements to be met during construction and service.

Final Acceptance Inspection

Joint inspections performed by shipyard, owners, classification society, and regulatory agency inspectors upon completion of block, assembly, unit, or erection for the purpose of acceptance.

Finite Element Analysis

The analysis of structures by mathematical idealization of the actual structure into discrete elements and solving the stiffness matrices for these elements for various applied loads, usually utilizing computer to perform the calculation.

Fit-up

Early fabrication processes in assembling panels, units, or blocks.

Fabrication Errors

Errors due to faulty fabrication practices such as poor welds, misalignment, etc.

Fabricability

Consideration during design stages of the ease with which a structure can be constructed.

Guarantee Period

A period during which all structure and materials of a delivered ship is guaranteed by the shipyard against errors - usually one year.

In-Plane Compression

Elastic deformation of a structural element such that compressive stresses are developed due to in-plane loads.

In-Plane Loads

Tensile, compressive and shear forces which act in a plane perpendicular to a structural elements' cross-section.

In-Process Inspections

Inspections performed on the structure by the yard's production and quality assurance personnel during various phases of the construction process.

Intermediate Survey

Classification society surveys conducted two years after vessel enters service and repeated two years after each subsequent special survey.

IHI

Japanese shipyard: "Ishikawajima Harima Heavy Industries"

"In-Service" Inspection

Inspections performed on the ship's structure by the crew, classification society and regulatory agency surveyors, and shipyards during its service life.

JSQS

"Japanese Shipbuilding Quality Standards."

JIS

"Japanese Industrial Standards"

Monitoring, Structural

Surveillance of an offshore platform's structure by means of an instrumented monitoring system.

MT and MPI

Non-destructive testing of metals by means of Magnetic Particle Inspection equipment.

New Construction Hull Report

A report filed by resident classification society surveyors upon completion of a newly constructed vessel to reflect the as-built condition and history of its hull structure.

NDE

Non-destructure examination of metals: equipment and/or techniques for.

Normal Loads

Those loads which act on a structure parallel to its cross-section.

Numerically Controlled Burning

The process of cutting steel using offset data as input to an automated flame cutting device.

Pre-Inspection

A term used in shipyards to denote all preparations and inspections performed on the structure prior to inviting classification society, regulatory agency, and owners surveyors to inspect the piece.

QA or QC

Organization and activities for controlling and assuring the quality and compliance with design drawings of all work being performed by the shipyard.

Racking Loads

The loads which induce lateral deformation or sidesway in a structural system.

Random Inspections

Inspections performed by structural inspectors and surveyors at random and in addition to the scheduled inspections.

Rework

Disassembling or dismantling of a unit, block, or assembly to correct a deficiency.

Redundancy

Provision of additional safety in structures by installing more than one member to share the same loads, by designing joints with longer fatigue lives, or by using increased factors of safety.

Receipt Inspection

Inspection of steel materials at the receiving point to ensure they are free of imperfections and they conform to specifications.

Shear

A load or stress which acts parallel to a plane as distinguished from tensile or compressive loads or stresses that act normal to a plane.

SUPSHIP

U.S. Navy "Supervisor of Shipbuilding".

SNAME

Society of Naval Architects and Marine Engineers.

SCR

"Structure Condition Record"

Special Periodical Survey

Classification Society surveys conducted once every four years for salt water service and five years for Great Lakes service.

Survey Status

A report published and distributed to classification society surveyors prior to initiation of periodical in-service inspections to reflect the background and current status of a specific ship.

SNAJ

Society of Naval Architects of Japan.

Splash Zone

The parts of side shell plating of a floating vessel that are constantly subject to the effects of wind and waves.

Safe-Life Design

A design based on the premise that the structure shall not fail, at least in terms of failure due to crack initiation or growth, during its lifetime.

Self-Inspection

Total inspection effort by the production department supervisors in a shipyard to assume that the ship being constructed is of good quality and in compliance with the detailed design drawings.

Stress Concentration

A high localized stress usually caused by an abrupt change in the geometry of the load path.

Technical Notes

Memoranda published by classification societies for in-house use pointing out to specific structural problems, determined on the basis of field experience, on a specific ship or a class of ships.

USCG

United States Coast Guard

UK

Great Britain

UTS

Non-destructive examination of metals by ultrasonic test equipment.

Welding Sequence

The correct sequence in which welding operations should be performed to avoid distortions and stress concentrations.

Wastage

The reduction in thickness and deterioration of metals due to corrosion effects.

Year of Grace Survey

Extension of the four (or five) year special survey period by one year upon determination of eligibility of the vessel by the classification society.

Yielding

The ability of structure to undergo permanent deformation without fracturing.

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SSC-320 A Study of Extreme Waves and Their Effects on Ship Structure by William H. Buckley, 1983

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None Ship Structure Committee Publications - A Special Bibliography, AD-A140339