



GUIDANCE NOTES ON

COMPOSITE REPAIRS OF STEEL STRUCTURES AND PIPING

SEPTEMBER 2019

**American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862**

**© 2019 American Bureau of Shipping. All rights reserved.
1701 City Plaza Drive
Spring, TX 77389 USA**

Foreword

Offshore structures such as Offshore Production Installations (FPSOs, FSOs, etc.) normally remain at their operation site for long periods of time. They have no regular drydocking intervals as ships do, and thus periodic inspections often discover local corrosion such as pitting and/or widely distributed general corrosion. Some substantial corrosion may call for renewal or reinforcement in order to meet structural strength requirements.

Repair by use of steel welding for degraded structural members is conventionally allowed by the current Classification Rules. However, when hot work welding is planned for repairs, it is necessary that the subject tank/location and adjacent tanks are in a gas free condition for compliance with safety requirements. In such cases, it causes a significant impact on the continuous operation of the units and has safety implications. Thus, adhesively bonded composite repairs for both steel structures and piping are generally preferred for site-specific offshore structures, as the repairs can be done without hot work welding. The repair principles may also be applied to other vessel types where permitted.

With the increased use of composites in repairs for primary and secondary structures, these Guidance Notes are essential to provide guidelines on the bonded composite repairs of steel structures and piping, primarily for applications on the site-specific offshore structures.

These Guidance Notes become effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

Terms of Use

The information presented herein is intended solely to assist the reader in the methodologies and/or techniques discussed. These Guidance Notes do not and cannot replace the analysis and/or advice of a qualified professional. It is the responsibility of the reader to perform their own assessment and obtain professional advice. Information contained herein is considered to be pertinent at the time of publication but may be invalidated as a result of subsequent legislations, regulations, standards, methods, and/or more updated information and the reader assumes full responsibility for compliance. Where there is a conflict between this document and the applicable ABS Rules and Guides, the latter will govern. This publication may not be copied or redistributed in part or in whole without prior written consent from ABS.



GUIDANCE NOTES ON

COMPOSITE REPAIRS OF STEEL STRUCTURES AND PIPING

CONTENTS

CHAPTER 1	Composite Repairs of Steel Structures.....	1
Section 1	General	5
Section 2	Assessment for Repair.....	10
Section 3	Repair Design	16
Section 4	Materials and Qualification	26
Section 5	Repair Installation and Quality Assurance.....	32
Section 6	Inspection, Survey and Monitoring	38
Appendix 1	Sandwich Plate with a Continuous Elastomer Core	40
CHAPTER 2	Composite Repairs of Piping	53
Section 1	General	56
Section 2	Repair Design	59
Section 3	Repair System Qualification	62
Section 4	Repair Installation and Quality Assurance.....	66
Section 5	Inspection, Survey, Monitoring and Maintenance	71

This Page Intentionally Left Blank



CHAPTER 1 Composite Repairs of Steel Structures

CONTENTS

SECTION 1	General.....	5
1	Scope	5
2	Personnel Qualification	5
3	Risk Assessment	6
4	Documentation for Review	6
5	Term and Definitions	6
6	Abbreviations	8
FIGURE 1 Bonded Composite Repair for Corroded Substrate Structure.....		5
SECTION 2	Assessment for Repair	10
1	General	10
2	Examination Report	10
3	Repair Decision.....	11
4	Corrosion.....	13
4.1	General.....	13
4.2	Corrosion Limits	13
5	Fatigue Cracking Repairs	15
FIGURE 1 Decision-making Process on Bonded Composite Repair.....		11
SECTION 3	Repair Design	16
1	General	16
2	Repair Design Basis	16
2.1	Scope	16
2.2	Repair Design Life	16
2.3	Loads	16
2.4	Environment	17
2.5	Electrical Conductivity	17
2.6	Repair Considerations	17
2.7	Failure Modes of the Bonded Composite Repairs	18
3	Repair Design Recommendation.....	18
3.1	General.....	18
3.2	Repair Classes	19
3.3	Material Safety Factor	19
3.4	Structural Analysis.....	20

3.5	Strength Check	24
4	Design Report	25
FIGURE 1	Example for Determining Material Allowable from Nonlinear Stress-Strain Curve.....	20
FIGURE 2	Decision-making on Linear FEA of Composite Repair	22
FIGURE 3	Nonlinear FEA for Decision-making of Composite Repair.....	23
FIGURE 4	Example of FEA Mesh for a Beam with Bonded Patch Repair.....	23
SECTION 4	Materials and Qualification.....	26
1	General	26
2	Qualification Testing	26
3	Steel Structure and Steel Plate Patch	28
4	Adhesives or Core Elastomer	28
4.1	Bonding Strength.....	28
4.2	Adhesive Properties.....	28
5	Laminate	29
5.1	General.....	29
5.2	Resins.....	29
5.3	Fiber	29
5.4	Relevant Material Properties	30
6	Components.....	30
6.1	General.....	30
6.2	Design Qualification.....	30
7	Properties under Fire	31
7.1	General.....	31
7.2	Fire Reaction	31
7.3	Fire Resistance.....	31
7.4	Insulation	31
7.5	Properties after Fire	31
8	ABS Certification.....	31
FIGURE 1	Minimum Materials Test Program	27
SECTION 5	Repair Installation and Quality Assurance.....	32
1	General	32
2	Repair Specification	32
3	Surface Preparation	32
4	Adhesive Bonding	34
4.1	General.....	34
4.2	Control of Bonding Thickness.....	34
4.3	Control of Patch Pressure.....	34
4.4	Control of Alignment	34
4.5	Control of Cure Temperature and Cure Time	34
4.6	Pull-off Strength of the Repair	34

5	Patch Fabrication	35
5.1	General.....	35
5.2	Pre-fabricated Patch.....	35
5.3	On-site Lamination	35
6	Handling and Preparation of Materials	36
7	Repair Documentation (Technical File)	36
8	Installation Inspection	36
SECTION 6	Inspection, Monitoring and Survey.....	38
1	General	38
2	Nondestructive Inspection and Monitoring.....	38
2.1	Visual Inspection	38
2.2	Steel Substrate.....	39
2.3	Bond Layer	39
2.4	Laminate.....	39
3	Inspection Time.....	39
APPENDIX 1	Sandwich Plate with a Continuous Elastomer Core.....	40
1	General	40
2	Scope	40
3	Sandwich Plate Design	40
3.1	Documents for Review	40
3.2	Repair Design.....	41
3.3	Sandwich Plate Repair Extent.....	43
3.4	Faceplate Thicknesses and Core Thickness	46
3.5	Local Section Modulus	46
4	Sandwich Plate Installation Process	48
4.1	General.....	48
4.2	Materials.....	48
4.3	Personnel Qualification	48
4.4	Surface Preparation	49
4.5	Preparation of the Perimeter Bars and Steel Pads/Foundations ...	49
4.6	Placement of Spacers	50
4.7	Placement and Attachment of the Faceplate.....	50
4.8	Temporary Restraint System.....	50
4.9	Preparation of the Cavity for Injection	50
4.10	Injection of Elastomer	50
4.11	Hardness Check for Cured Elastomer Core	51
4.12	Removal of Restraint System and Sealing the Cavities	51
4.13	Nondestructive Testing and Repairs	51
4.14	Corrosion Protection of the Exposed Surface of Steel Plates.....	51
5	Inspection and Survey	51
TABLE 1	Recommended Sandwich Plate Components and Their Functions.....	43
TABLE 2	Typical Core Material Properties and Test Standards	43

TABLE 3	Modification Factor, ϕ , Changes with Temperature	44
TABLE 4	Recommended Minimum Thicknesses of Faceplate and Elastomer Core for Handling and Curing	46
FIGURE 1	Development Length of the Bonded Patch Repair	44
FIGURE 2	Reference Point for Calculation of Section Modulus and Hull Girder Stress for Local Scantling Assessment	47

CHAPTER 1 Composite Repairs of Steel Structures

SECTION 1 General

1 Scope

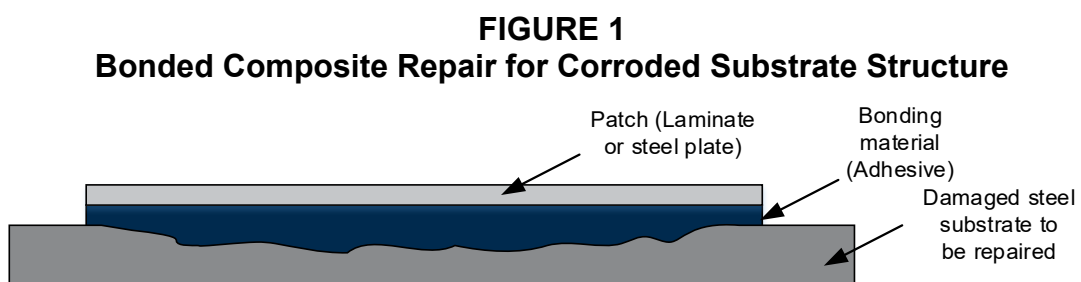
This Chapter is applicable to the use of composite repairs on site-specific offshore units such as FPSOs and FSOs. It provides guidelines on adhesively bonded composite repairs of the steel structures. It covers assessment, design, qualification, installation and inspection of a bonded repair.

This Chapter does not cover aluminum structures, even though this guidance may also be applicable to aluminum structure repairs.

These Guidance Notes provide an alternative to regular hot work renewal, where the hot work is considered risky to the offshore unit's operation. Instead of using hot welding, an existing degraded steel structure can be repaired to restore the integrity of the structure by utilizing patches of composite material, steel plates, or other structural materials that are bonded to the degraded steel structure.

1-1/Figure 1 illustrates the principle of a bonded patch repair. This repair technique can also be used for modification or upgrading of the existing structures by reinforcing structural elements to provide added strength.

Advantages of the bonded patch repair are that they are quick and simple with minimum preparation. Disadvantages are that the repaired section is thicker and heavier than the original, a very careful surface preparation is necessary for good adhesion and repair lifetime, and more frequent in-service monitoring and inspections may be required.



2 Personnel Qualification

Designers of bonded patch composite repairs and personnel engaged in the installation and inspection of the repairs should be qualified with a recognized certification or documented practical experience.

The laminator should receive relevant training to possess appropriate competence in the lamination process.

The entire repair process is manual. Thus, the quality of the bonded patch repair is directly dependent on the skill and experience of the personnel carrying out the repair. The repair procedure documentation should be provided to confirm that the personnel carrying out the repair and inspection are qualified for the job and the repair technology.

3 Risk Assessment

An assessment of the risks associated with the structural deterioration/cracking and repair method should be completed in line with relevant industry best practices. When applying a repair, the following items should be considered:

- i) The nature and location of the corrosion or cracking
- ii) Geometry of the structural element to be repaired
- iii) Design and operating conditions for the structural element and service environment (including impact, abrasion, fire, explosion, collision, and environmental conditions (temperature, exposure to chemicals))
- iv) Performance under worst conditions and major incident situations including impact, abrasion, fire, explosion, collision, and environmental loading
- v) Hazards associated with repair service
- vi) Repair installer skills, surface preparation quality and repair environment
- vii) Repair system materials selected
- viii) Repair life expected
- ix) In-service inspectability
- x) Failure modes

4 Documentation for Review

The documentation provided prior to installation of the repair should include:

- i) An examination report of the corrosion and/or fatigue cracking and providing information as specified in 1-2/2.
- ii) A design report covering the design basis, and the qualification results and design calculations. The design report should document all relevant information collected and all identified issues addressed in the design input, strength analysis, fabrication, and qualification of the bonded patch repair process. Details can be found in 1-3/4.
- iii) An installation report should be included with detailed installation and inspection specifications, including the installation procedures, QA/QC manual, installer qualification and inspector qualification. Details can be found in Chapter 1, Section 5.
- iv) In-service inspection and maintenance plan for maintaining the integrity of the repair should be provided. Information on the identification of the repair, location, repair lifetime, associated maturation year and survey intervals should be included in the In-Service Inspection Plan (ISIP) for offshore units.
Information contained in the In-Service Inspection Plan can be found in Chapter 1, Section 6.
- v) Risk Assessment Report (see 1-1/3), including risks of de-bonding and composites strength degradation due to environment, whenever applicable.

5 Term and Definitions

The following terms and definitions are used in this document:

Adhesion. The state in which two surfaces are held together by interfacial forces, which may be chemical and/or mechanical in nature.

Adhesive. A substance used to hold two surfaces together.

Barcol Hardness. A measure of surface hardness using a surface impresser. The Barcol hardness test characterizes the indentation hardness of materials through the depth of penetration of an indenter, loaded on a material surface and compared to the penetration in a reference material.

Bond Layer. The adhesive layer between the patch surface and the substrate surface. It may be primer layers, if any.

Composite. A material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The composite materials allowed for the bonded repair include, but are not limited to, glass, aramid, or carbon fiber reinforcement in a thermoset polymer (e.g., polyester, polyurethane, phenolic, vinyl ester, or epoxy) matrix.

Cure/Curing. Setting of a thermoset resin system, such as epoxy or polyester, by an irreversible chemical reaction.

Cure Schedule. Time-temperature dependence profile to achieve a desired hardness with a specified glass transition temperature, T_g .

Curing Time. Minimum time for a resin in an assembly or an adhesive to cure under heat or pressure, or both.

Debonding. Separation along the bond layer.

Delamination. Debonding between the repair laminate/patch/substrate and the bonding layer.

Filler. Materials used to repair surface imperfections.

Flash Rusting. Rusting that occurs uniformly on metal within minutes to a few hours after surface cleaning is complete. The speed with which flash rusting occurs may be indicative of salt contamination on the surface, high humidity, or both. Uniform flash rust is considered inert and a sign of general steel oxidation. If the flash rust evolves into a loose powdery layer, coating adhesion and performance may be compromised.

Galvanic Corrosion. Accelerated corrosion of a metal due to an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

General Corrosion. Relatively evenly distributed corrosion attacks on a steel surface.

Glass Transition Temperature (T_g). Temperature below which the polymer turns from a ductile material to a hard and brittle material. T_g of a material characterizes the range of temperatures over which this glass transition occurs.

Heat Distortion Temperature. Heat distortion temperature (HDT) is the temperature at which a polymer or plastic test bar deflects by a specified amount under a given load.

Laminate. Composite material used in a repair, which is an assembly of layers of fibrous composite materials joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion.

Localized Corrosion. Relatively concentrated or spot-wise corrosion attacks on surface (typically pitting, corrosion in way of welds, crevice corrosion, stress corrosion cracking, etc.). Localized corrosion can proceed rapidly and can be dangerous.

Patch. A piece of material used to reinforce the degraded substrate. It can be a steel plate or a composite laminate.

Pipework. Interconnected piping subject to the same design conditions.

Piping/Piping System. Assemblies of piping components used for fluid transportation.

Ply. Single wrap or layer of a repair lamination.

Post Cure. Additional cure at elevated temperature after a resin has hardened to achieve more complete curing.

Pot Life. The maximum elapsed time during which a coating can be effectively applied after all components of the coating have been thoroughly mixed.

Prepreg. Pre-impregnated with resin.

Prepreg Lay-up. A lay-up technique that uses a reinforcing fabric which has been pre-impregnated with a resin system. As a result, the prepreg is ready to lay into the mold without the addition of any more resin. For the laminate to cure, it is necessary to use a combination of pressure and heat.

Primer. A coating material applied as the first coat on an uncoated surface, specifically formulated to adhere to and protect the surface as well as to produce a suitable surface for subsequent coats.

Resin System. All of the components that make up cured resin in the matrix portion of a composite.

Shelf Life. The maximum length of time that packaged materials (e.g., coating materials) can be stored, at specified conditions, and still remain in usable condition.

Shore Hardness. Measure of surface hardness using a surface impresser or durometer (see also “Barcol Hardness”).

Substrate. Surface upon which a repair is carried out.

Technical Data Sheet. Information provided by the manufacturer containing detailed technical information relevant to the coating process and its application.

Thermoset Resin System. Resin system cured by polymerization.

6 Abbreviations

EPA	The Environmental Protection Agency (EPA) is an agency of the United States federal government
FEA	Finite Element Analysis
FOI	Floating Offshore Installations
FPI	Floating Production Installations
FRP	Fiber Reinforced Plastics
HDT	Heat Distortion Temperature
IDLH	Immediately Dangerous to Life or Health (IDLH), defined by the US National Institute for Occupational Safety and Health (NIOSH) as exposure to airborne contaminants that is “likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment”.
ISIP	In-Service Inspection Plan
IMO FTP Code	IMO Fire Test Procedures Code
MODU	Mobile Offshore Drilling Units
MSDS	Materials Safety Data Sheet
NACE CIP	Coating Inspection Program, NACE International
NDCV	Nominal Design Corrosion Values
NDI	Nondestructive Inspection
OSHA	The Occupational Safety and Health Administration of the United States Department of Labor
OSV	Offshore Support Vessels
QA	Quality Insurance
QC	Quality Control
RFL	Remaining Fatigue Life
RIFT	Resin Infusion under Flexible Tools
RTM	Resin Transfer Molding

SHE	Safety, Health & Environment
SSPC	The Society of Protective Coatings
SSPC-SP	Standard Practice, The Society for Protective Coatings
TDS	Technical Data Sheet
T_g	Glass Transition Temperature
USCG	United States Coast Guard
UV	Ultraviolet



CHAPTER 1 Composite Repairs of Steel Structures

SECTION 2 Assessment for Repair

1 General

This Section provides guidelines on assessing the criticality of corrosion and fatigue cracking to determine if the bonded composite repair is viable.

Criteria for wastage and renewal can be found in the *ABS Rules for Survey After Construction (Part 7)*. This document is not a substitute.

The inspection and assessment are the first steps in the repair process to determine the corrosion and fatigue cracking criticality, the repair extent, and the repair priority.

The composite repairs covered in this chapter are repairs for the structural deterioration from corrosion (see 1-2/4) and fatigue cracking (see 1-2/5). Mechanical damage to steel structures, as may be caused by grounding, explosion, contact/collision etc., is not covered.

2 Examination Report

Reporting examination of the corrosion and fatigue cracking and providing information about the extent of repairs that are proposed are important steps in making a repair decision.

If the unit's fitness to proceed is impaired or if there is a chance that the corrosion and fatigue cracking may progress to such an extent as to affect the structural fitness or watertight integrity of the unit at a later date, such corrosion and fatigue cracking should be repaired before the unit resumes operations, depending on the extent and severity of the structural deterioration, the intended service, and expected sea state.

The report should include the following information:

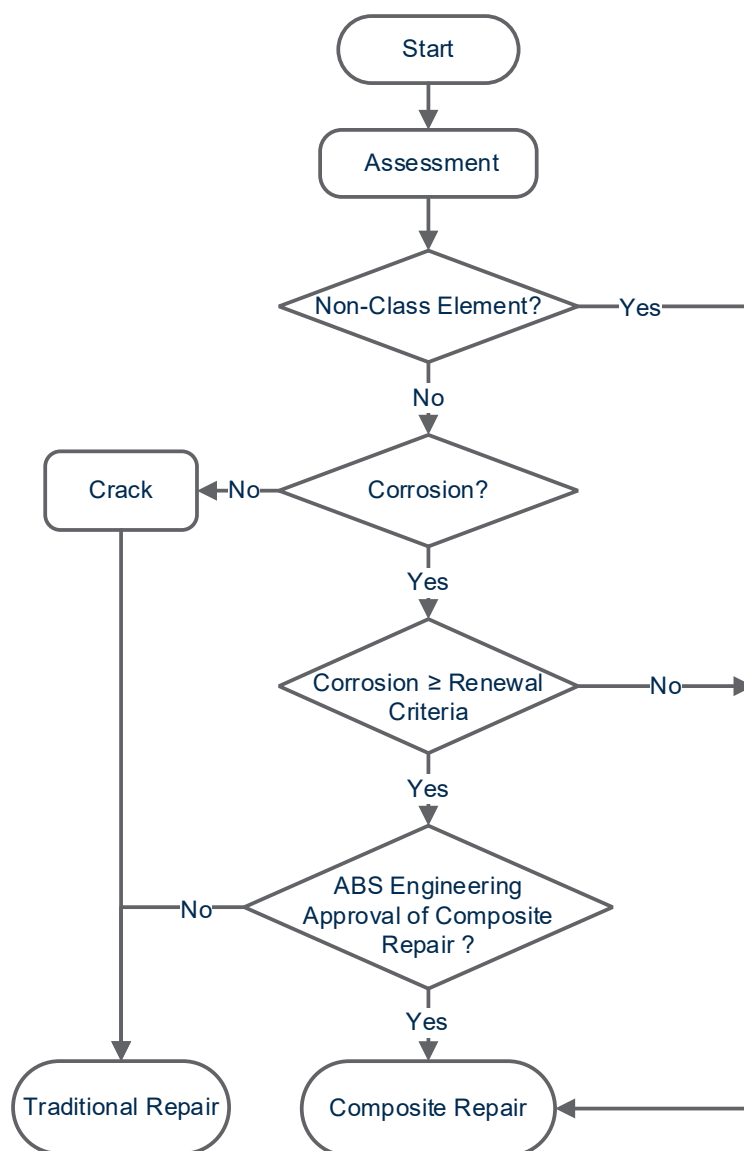
- i) Unit name and ABS class number
- ii) Date of the most recent inspection, which should have been completed within 15 months of the application of the composite repair
- iii) Description of corrosion and fatigue cracking and list of supporting documents:
 - Location, sizes and extent of the structural deterioration with drawings and photographs/video
 - Thickness gauging data
 - Environmental information such as operating pressure, temperature, type of fluid/cargo
 - Possible cause of the structural deterioration
 - Description of accessibility to the structural deterioration for repairs and further inspection/monitoring
- vi) ABS report including the Outstanding Recommendation or Additional Requirement identifying the area requiring repairs

3 Repair Decision

When the deterioration from corrosion and fatigue cracking has been detected and documented, a criticality assessment should be made.

An assessment of the structural deterioration should be evaluated for the criticality to determine whether bonded composite repairs can be applied. The determination on the criticality is based on applicable class Rules. The decision-making process on using the bonded composite repair method is summarized in 1-2/Figure 1.

FIGURE 1
Decision-making Process on Bonded Composite Repair



The degraded element can be critical or non-critical:

- *Non-class elements* are not subject to significant loads, and the structural integrity of the original structure is not compromised by their structural deterioration. Typically, a non-class structural element is not critical and is one where its complete failure does not generate the risk of progressive collapse of the overall structure. Non-class element repairs do not need to be considered in the structural strength evaluation of the unit.
- *Non-critical class elements* are important elements which are required for ABS reviews but would not necessarily need the structural strength evaluation or FEA. However, failure of those “class items” would not lead to rapid loss of structural integrity or cause a reduction in the remaining fatigue life of the unit, such as miscellaneous decks that do not contribute to longitudinal strength.
- *Critical class elements* are subject to significant loads, and failure of these structural elements would result in the rapid loss of structural integrity and produce an event of unacceptable consequence, as defined in 5A-1-4/7.5 of the *ABS Rules for Building and Classing Floating Production Installations (FPI Rules)*. The structural integrity of the degraded element can be restored by transferring loading from the substrate to the patch primarily by shear stresses in the bond layer. The capacity of critical class structural element repairs can be assessed based on small-scale testing or component testing, provided a documented method is used.

The repair criticality can be evaluated based on the structural element criticality and the structural deterioration criticality:

- i) If the degraded element is a non-class element, it may be repaired using patch repair. Such element repair is considered non-critical.
- ii) If the degraded element is a class element but the extent of the degradation does not compromise the integrity of the element and will not develop to such within the next inspection interval, the repair is considered non-critical.
- iii) When material diminishment due to corrosion is within allowable limits (see 1-2/4), the repair is considered non-critical.
- iv) When the corrosion of a critical class element is more than allowable limits (see 1-2/4) (e.g., thickness diminution over an area large enough to affect the unit’s integrity), steel renewal may be required, and such repair is considered critical.

Any corrosion associated with wastage over the allowable limits or extensive areas of wastage over the allowable limits which would affect the unit’s structural, watertight, fire integrity and/or weathertight integrity should be promptly and thoroughly repaired. Areas to be considered include:

- Bottom structure and bottom plating
- Side structure and side plating
- Deck structure and deck plating
- Watertight or tank bulkheads

The bonded composite repair should not be allowed when the actual section modulus (before repair) is less than 90% of the global section modulus required for new construction or conversion/reassessment.

When a bonded composite repair is considered in lieu of steel structure replacement of an individual element, detailed global or local strength calculations using approved repair design and materials may be needed. For critical class element repairs, FEA is required. Special consideration of the minimum remaining thickness of the degraded critical class element for the bonded patch repair is needed. See details in 1-2/4.2.1 below. A bonded composite repair is not considered for critical class structural elements with complete thickness loss. However, localized pitted holes may be repaired by using a bonded composite, provided that the repair criticality is assessed.

- v) Cracks may often be considered critical. Laminate-based repairs may be considered inappropriate for critical fatigue cracks. For non-critical fatigue cracks, laminate-based repairs may be used to slow down fatigue crack propagation. However, the repair life is not predictable and constant monitoring may be needed to ensure the crack does not grow.

There are many situations wherein the corrosion is substantial and extensive, such as loss of thickness beyond corrosion margins and limits. In such cases, it may still be justifiable to allow the use of a bonded composite repair, provided the engineering assessment and calculations of the structure before and after repair are completed.

It is important that the repair does not accelerate the structural deterioration, this is done by using best practices for design, qualification, fabrication, inspection and maintenance of the repair. The effect on areas immediately adjacent to the element to be repaired should be considered in case of the repair failure. The repair should not create new issues such as attracting significant new loads or preventing future inspection.

The location of the composite repair should be also assessed regarding safety. It should not be considered in way of transit/escape routes without an adequate protection for people walking through it. Additionally, it should be verified that composite materials are adequate to maintain safety during a fire emergency (i.e., the composite repairs will not melt nor release any noxious component to the atmosphere under high temperatures).

4 Corrosion

4.1 General

This Subsection defines the forms of corrosion and the needs for steel replacement. As described in 1-2/3 for repair decision, when steel corrosion of an individual structural element does not exceed the allowable wastage, a bonded composite repair is allowed as such repair is considered as a non-critical repair. Otherwise, when the steel corrosion exceeds allowable wastage for class element, the bonded composite repair may be considered as a critical repair. The bonded composite repair of corroded elements should fully or partially restore the capacity and/or stiffness.

Corrosion can be divided into the following categories by corrosion forms:

- i) *General Corrosion.* Uniform corrosion with uniform loss of metal over an entire surface. The minimum thickness of hull structural elements may be applied in order to determine average diminution values. Typically, repairs include steel replacement to original scantlings or reinforcement upon special consideration.
- ii) *Pitting Corrosion.* A form of localized corrosion, which is an attack with localized holes or pits on the steel surface. The intensity of the pitting should first be estimated. Typically, pitting repairs include renewal of plates, building up pits by welding, or application of plastic filler compounds.
- iii) *Grooving Corrosion.* Another form of localized corrosion, which is local line material loss normally adjacent to welding joints. Special consideration of the corrosion repair may be needed.
- iv) *Edge Corrosion.* Local material wastage at the free edges of plates and stiffeners. Typically, depending on the severity of such corrosion, reinforcement may be added.

4.2 Corrosion Limits

4.2.1 General Corrosion – Extensive Areas of Corrosion

Extensive Area of Corrosion is corrosion of hard and/or loose scale, including pitting, over 70% or more of the plating surface in question, accompanied by evidence of thinning.

Where substantial corrosion is found, additional thickness measurements in accordance with 7-3-2/7 of the *ABS Rules for Survey After Construction (Part 7)* are taken to confirm the extent of substantial corrosion. Where extensive areas of wastage exceed allowable margins, renewals or repairs are typically required.

For example, for floating installations of the ship-type, column-stabilized-type, tension leg platforms and spar installations, as well as existing vessels converted to FPIs, the renewal scantlings are in accordance with 5A-1-3/3.11 of the *FPI Rules*. Care should be taken to distinguish between the reduced as-built scantlings and the ABS Rule-required scantlings. Renewal thickness should be based on ABS Rule-required scantlings.

Once the decision is made for acceptance of the bonded patch repairs in lieu of steel replacement, special consideration for the critical class structural element repair is needed so that the average remaining thickness of the degraded element should not be less than 30% of the as-built thickness (ABS Rule-required scantlings) or 6 mm (0.25 in.), whichever is greater. Use of composite repair for minimum scantlings less than 6 mm (0.25 in.) may be accepted on a case-by-case basis and subject to provision of adequate protection to the substrate steel to avoid any wastage during the remaining service life.

The longitudinal strength evaluation should be made in accordance with the longitudinal strength of the hull girder by using the as-gauged thickness of structural members measured. The decision should be made for renewal and reinforcement, as appropriate, during the surveys.

When calculating the hull girder section modulus, the degraded parts and its shadow areas should be deducted, similar to 3-2-1/Figure 6 of the *ABS Rules for Building and Classing Marine Vessels (Marine Vessel Rules)*.

The individual wastage allowances are typically acceptable, provided the global section modulus (SM) is not less than 90% of the as-built SM at the time of new construction or conversion/reassessment. The bonded composite repair of such corroded individual elements can be critical or non-critical depending on corrosion wastage of class elements and should not to be considered in the calculation of the global section modulus of the unit.

4.2.2 Localized Corrosion – Pitting

Pitting Corrosion is a localized corrosion with local material reductions greater than the general corrosion in the surrounding area. Pitting intensity is defined in 7-A-4/Figure 5 of the *ABS Rules for Survey After Construction (Part 7)*.

Localized areas of excessive wastage, pitting or grooving may call for immediate repair according to the ABS survey requirements.

The following minimum renewal thickness due to pitting corrosion is recommended if no applicable ABS Rules are available, such as 5A-2-1/9.5 of the *FPI Rules* and 7-A1-4/35 of the *ABS Rules for Survey After Construction (Part 7)*, on pitting corrosion for particular types of structures:

- i) For plates with a pitting intensity less than 20%, the minimum remaining thickness in pitting should be at least 70% of the original as-built thickness (without voluntary addition) or 1 mm (0.04 in.) less than renewal thickness, whichever greater.
- ii) For plates with 70-100% pitting intensity (i.e., general corrosion), the average remaining thickness in the worst cross section through the pitting in a plate should not be less than minimum thickness for general corrosion in 1-2/4.2.1 above.
- iii) For plates with 20-70% pitting intensity, acceptance of the average remaining thickness in the pitted area may be decided based on linear interpolation between i) and ii) above.

The following equation may be used to estimate the average remaining thickness in pitted areas:

$$t_{ave} = t_{plate} \times (1 - Intensity) + t_{pit} \times Intensity$$

where

- | | | |
|------------------|---|--|
| t_{ave} | = | average remaining thickness for pitted areas |
| t_{plate} | = | average remaining thickness outside pitting |
| t_{pit} | = | average remaining thickness in pitting |
| <i>Intensity</i> | = | estimated pitting intensity. Pitting intensity is defined in 7-A-4/Figure 5 of the <i>ABS Rules for Survey After Construction (Part 7)</i> |

For widely scattered pitting where the remaining thickness in pitting is not less than the value calculated above, filler material such as epoxy resin or glass flake or bonded composite could be used for a non-critical repair. When the overall wastage is sufficient to warrant renewal of the affected plate, the pitting repair using plastic compound filler material should not be considered since it does not contribute to the strength. In such case, a bonded composite repair as a critical repair may be considered.

4.2.3 Localized Corrosion – Grooving

Grooving Corrosion is typically local material loss adjacent to weld joints along abutting stiffeners and at stiffener or plate butts or seams. An example of grooving corrosion is shown in 7-A-4/Figure 4 of the *ABS Rules for Survey After Construction (Part 7)*.

Commonly affected areas are:

- Side frames to shell plate
- Web frame connections to deck and stiffeners
- Webs of side and deck longitudinals
- External shell plates

For stiffeners and plates, the maximum groove breadth is 15% of the web height or 30 mm (1.18 in.), whichever is less. The allowable remaining thickness in the grooved area may be taken as 75% of as-built thickness or $t_{ren} - 0.5$ mm (0.02 in.), whichever less, but not less than 6 mm (0.25 in.).

When the areas are greater than 15% of the web height or 30 mm (1.18 in.), the renewal thickness due to general corrosion, t_{ren} , in 1-2/4.2.1 above, can be applied.

The accumulated length of transverse grooves in deck, bottom, longitudinal bulkhead or side plating within the cargo area is limited to 20% of the breadth respective height of the unit. For special unit with large deck openings, the accumulated length of transverse grooves in the passageway may be limited to 10% of the breadth. The allowable remaining thickness in the grooved area may be taken as 75% of as-built thickness or 6 mm (0.25 in.), whichever greater.

Where excessive grooving corrosion beyond the minimum thickness provided above is found, re-welding of grooves or appropriate bonded patch repair, as a critical repair, may be considered.

Where grooving corrosion is found within the minimum thickness provided above, a bonded patch repair as a non-critical repair may be used.

4.2.4 Localized Corrosion – Edge Corrosion

Edge Corrosion is defined as local corrosion at the free edges of plates, stiffeners, primary support members and around openings. An example of edge corrosion is shown in 7-A-4/Figure 3 of the *ABS Rules for Survey After Construction (Part 7)*.

The extent of corrosion on the free edge of the flange and the flat bar of deck longitudinals should be less than 25% of the flange's breadth or the flat bar height, and the remaining edge thickness should not be less than 70% of the as-built thickness or $t_{ren} - 1.0$ mm (0.04 in.), whichever is less. The average thickness of the breadth or the web height uses the minimum thickness due to general corrosion from 1-2/4.2.1.

Where excessive edge corrosion is found, renewal by inserts would normally be needed. However, alternative repairs with edge reinforcement, such as edge reinforcement from a bonded composite, may be considered.

Where edge corrosion is found above the minimum thickness for renewal, edge repair/reinforcement from a bonded composite is allowed.

5 Fatigue Cracking Repairs

While bonded composite repair is an established repair method for deterioration from corrosion, there are still few examples of fatigue crack repair. As indicated in 1-2/3v), composite repair of critical cracks should not be considered. However, applying the bonded composite repair to fatigue cracks could reduce crack growth considerably by

- Reducing the stresses to a level where the crack propagation is stopped,
- Reducing a rate to acceptable level with consideration of the intended lifetime of the repair, or
- Arresting the crack where the crack size is acceptable at some later time.

In such case, the configuration and placement of the patch relative to the crack and use of efficient crack monitoring systems are important.



CHAPTER 1 Composite Repairs of Steel Structures

SECTION 3 Repair Design

1 General

The design of a bonded patch repair using laminate or steel plate is different from steel welding repair. Bonded composite repair should have design and analyses for all components used in the repair, such as steel or composite laminate patches and adhesive.

To reduce the uncertainty of the repair life, the long-term performance of bonded composite repairs should be fully documented (see 1-3/3.2.4). The goal of such bonded composite repairs is to have a quick repair with or without drydocking. The owner/operator should make their own judgment on the necessity for quick qualification against the reliability of the repair and the risk of needing to upgrade or replace the repair in the future.

2 Repair Design Basis

2.1 Scope

The purpose of a bonded repair is to restore the function of the original structural component. The functional requirements include load capacity, stiffness, dimensional stability, fluid/cargo containment and tightness, and resistance to chemical/UV/temperature/heat insulation. The functional requirements also include, if applicable, wear resistance, electrical resistance, electrochemical properties, vibration and fire/explosion resistance.

The repair design should consider all phases of the repair life, and the repair reliability should be established for each important phase during the installation and operation.

The design basis defines the documentation that is required as the basis for the design of a bonded repair.

2.2 Repair Design Life

The life of the bonded repair should be defined. The life of the bonded repair usually is at least the same as the remaining design life of the steel structure. A shorter life may be used for temporary repairs.

It is noted that there is no established accelerated test method that can reliably predict the lifetime of a bonded repair. The achievable repair life depends on the repair system installed and can be affected by the environment, opposite side corrosion/erosion mechanisms, and external mechanical influences. The corrosion/erosion rate of the opposite side of the repaired area should also be estimated during the repair design.

2.3 Loads

The design basis should specify loads in the design of the repair, such as

- Loads from equipment
- Loads from loading and unloading from ballast water and storage tanks
- Loads from fixed weights
- Weight of other parts of the structure
- Environmental loads (wind, wave, current, tidal, ice, snow, temperature variation, etc.).

The sequence of the loads should be identified. A simplified approach towards design for fatigue capacity may be adopted.

2.4 Environment

Composites are sensitive to chemical and thermal loads. Exposure to UV radiation, large temperature differences, elevated or very low temperatures, crude oil in a tank, sour gases, and marine environment also should be considered. Degradation of the composite materials may lead to accelerated degradation of a laminate patch and bonding. The design should consider and verify that the composite repair is suitable for the intended operating environment. The following should be particularly considered during the repair design:

- i) If the repaired surface is subjected to UV light, abrasion, wear and tear, and/or local impacts, the surfaces should be protected by a suitable coating or other protection system.
- ii) For bonded repairs exposed to weather, the extreme design temperatures should be determined from maximum and minimum temperatures for the repair. Possible temperature gradients over the length or thickness of the bonded repair should be identified. The lowest temperature should be used for evaluation of fracture toughness of the steel substrate.
- iii) The effects of exposure to water/oil should be considered in the material selection for the patch, adhesive, and primers if any. Generally, fresh water causes more degradation than saltwater on most composites.
- iv) For repairs designed to operate below the glass transition temperature (T_g) of the composite material and the adhesive, the maximum operating temperature should normally not exceed 20°C (36°F) below the glass transition temperature for any of the materials.
- v) Most composites are flammable and temperature sensitive. The fire performance of the complete composite structure system with fire protection should be evaluated.
- vi) For repairs in ice conditions, abrasion resistance to ice, ice impact and low temperature should be considered during the repair design.

2.5 Electrical Conductivity

Electrical conductivity requirements for the repair should be provided in the design. Nonconductive polymer materials may develop static electricity which can potentially cause a fire or explosion hazard. Specified conductivity requirements should be obtained with the repair solution. If no other specific requirements are given, the recommendations from ISO 14692-2 Section 6.6 should be applied to composite patch repairs.

Carbon fibers used in the patch may cause galvanic corrosion if the fibers contact the steel plates.

2.6 Repair Considerations

A suitable application procedure should be chosen. Chapter 1, Section 5 provides detailed recommendations on Repair Installation and Quality Assurance. Effectiveness of the repair should be verified after installation.

Applying a bonded repair may involve certain safety risks for the personnel performing the work. The repair installation should not involve a fire and chemical hazard.

Environmental conditions during installation are critical to the repair quality.

The following should be considered as a minimum:

- i) Accessibility to the surface to be repaired
- ii) The time and load condition allowed for repair application and curing
- iii) Surface cleaning, such as using steam, water jets, detergents, and abrasive blasting should be provided to meet the surface cleanliness requirements.
- iv) Ambient humidity and temperature should be considered during surface preparation, repair installation and curing.
- v) The chemical environment at the repair site should also be specified, including exposure to drilling muds, seawater, fresh water and hydrocarbons, gas, or gaseous phases of chemicals.
- vi) Ability of the repair to be examined for failures and verified to be sound after installation.

2.7 Failure Modes of the Bonded Composite Repairs

2.7.1 General

The relevant failure modes of bonded composite repairs may need to be considered in repair design (see 1-3/3). The primary modes are debonding and laminate patch failures.

2.7.2 Debonding

2.7.2(a) Bonding Layer Cracking. When a crack is repaired, an initial crack through the thickness of the bonding layer just above the crack to be repaired normally develops very quickly. This crack is arrested when it reaches the reinforced patch.

2.7.2(b) Bonding Layer Fatigue and Debonding Propagation. When the repaired component experiences a cyclic load, a debonding crack may initiate and propagate in the bond layer, thus partially separating the patch from the substrate.

2.7.2(c) Free Edge Cracking. A debonding crack may initiate and propagate from the free edges of the repair, thus partially separating the patch from the substrate.

2.7.2(d) Bonding Layer Fracture. If loading transmitted to the patch exceeds the capacity of the bonding layer, the bonding layer may fracture, resulting in repair failure.

2.7.2(e) Blistering. A fluid can build up on the interfaces between the bonding layer and the substrate/patch due to contamination on the interface and create pressure. When this pressure exceeds the bonding layer adhesion, blistering and then delamination can occur.

2.7.2(f) Creep Rupture. When a permanent load is applied, creep and subsequent creep rupture may cause partial or full separation of the patch from the substrate. This type of failure usually occurs when the service temperature approaches the adhesive's glass transition temperature, T_g .

2.7.2(g) Bonding Layer Property Changes Due to the Service Environments. Temperature and chemical environment changes may reduce the capacity of the bonding layer and lead to premature failure, such as bonding layer/laminate patch swelling, plasticization, or stress.

2.7.2(h) Substrate Corrosion. When the bonding layer is exposed to a corrosive environment, corrosion on the substrate behind the patch repair occurs and can cause premature failure of the bonding layer.

2.7.3 Laminate Patch Failure

If the strain or stress in the patch exceeds a certain critical level, cracks in the laminate patch matrix will start and propagate, which can cause failure of the repair.

3 Repair Design Recommendation

3.1 General

A bonded composite repair consists typically of a patch (composite laminate or steel plate) applied to a metal substrate with an adhesive bond layer, as shown in 1-1/Figure 1. The repair design covers all three components and their interfaces, with the following considerations:

- The reliability of the repair is assessed using design loads (see 1-3/2.3) and the capacity to resist these loads. The capacity may be affected by the environment (see 1-3/2.4).
- The relevant failure mechanisms (see 1-3/2.7) should be considered.
- The safety factors are described in 1-3/3.3 below.
- The characteristic material strength/properties (both characteristic short-term properties and characteristic long-term properties up to the design life) as described in Chapter 1, Section 4 are used for all calculations for composite laminates and adhesives.

Specific recommendations to the Repair Classes A, B and C are given in 1-3/3.2 below.

3.2 Repair Classes

3.2.1 General

There are three (3) repair classes defined by the repair qualification. The repair class is determined based on the structural deterioration criticality, failure mechanism (see 1-3/2.7) and the repair reliability. Class A is recommended for non-class element repairs. Class C is recommended for critical class element repairs for potential bond layer fatigue/creep/cracking debonding failures. For other failure mechanisms, either Class B or C is recommended for class element repairs.

3.2.2 Class A Repairs

Class A repairs are repairs where the integrity and efficiency of the repair are not qualified according to the recommendations provided in these Guidance Notes.

Class A repairs may be accepted for non-class element repairs without having acceptance specifications and having explicit structural analysis of the repair reliability as indicated in 1-3/3.4 below. However, certain design guidelines may be needed for such repairs with the following considerations:

- The repair patch should normally be balanced, and the patch edges should be extended and tapered to reduce potential stress raising.
- The repair extent should normally not be less than 50 times the patch thickness.
- Adhesives used for critical shear load transferring should not exceed the through thickness shear strength of the patch material.

3.2.3 Class B Repairs

Class B repairs are repairs where the qualification is based on small-scale test results or component testing. A larger safety factor and assumption of the debond size/development may be used in the static strength assessment without testing the long-term properties. The static bonding layer capacity and patch capacity should be checked. Initial and long-term efficiency of the repair may be documented.

The same considerations as Class A repairs may be used.

3.2.4 Class C Repairs

Class C repairs are repairs where sufficient documentation is provided to quantify with confidence the reliability of the repair for the intended service life of the structure.

Class C repairs may use the same static strength check as Class B repairs, but a reduced safety factor may be used. The long-term effects of cyclic and permanent loads are specifically considered. The failure modes (see 1-3/2.7) during the design life of the repair and at the end of the design life are estimated.

3.3 Material Safety Factor

The material factor, f_s , is provided as follows:

- i) For static bond layer capacity checks of Class B repairs, use 1.35 for short term assessment and 1.64 for long term assessment.
- ii) For static bond layer capacity checks of Class C repairs, use 1.35 for short term assessment and 1.00 for long term assessment.
- iii) For static laminate capacity checks, use 1.22 for short term assessment and 1.00 long term assessment. Laminate through thickness fracture safety factor could be 1.5.
- iv) The material fatigue safety factor is normally be taken as 15, which may be reduced if variable amplitude fatigue test results support so.
- v) For steel plate safety factor, refer to the relevant ABS Rules for the particular structural member to be repaired, loading and environment conditions.

The allowable stress for the laminate, σ , can be calculated from:

$$\sigma = \sigma_f / f_s$$

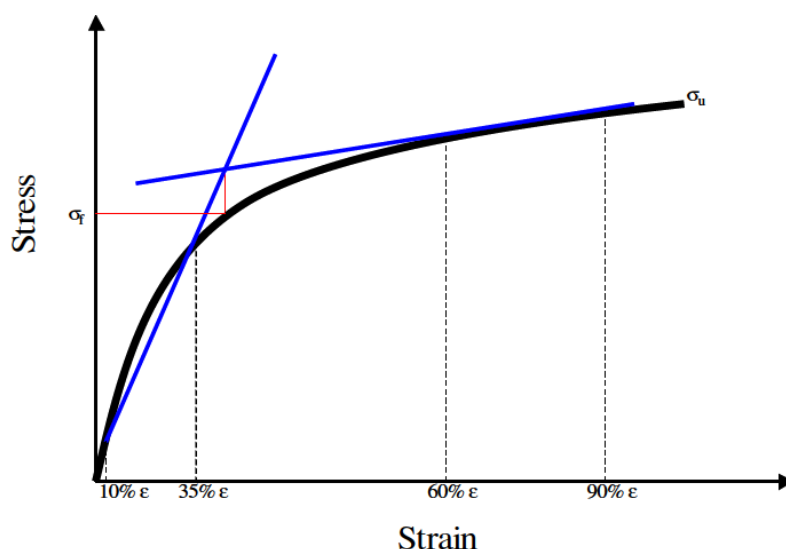
where

σ_f = material yielding stress, $0.3\sigma_u$ can be considered as an alternative.

σ_u = material ultimate stress

The material yielding stress and ultimate stress from the nonlinear stress-strain curve is schematically shown in 1-3/Figure 1.

FIGURE 1
Example for Determining Material Allowable from Nonlinear Stress-Strain Curve



3.4 Structural Analysis

3.4.1 General

Bonded composite repairs typically consist of three components: two face plates (patch plate and substrate steel plate), a core/adhesive, the two interfaces between the core/adhesive and two face plates. The following should be considered for structural analysis:

- Corroded steel plate is acting as one of the face plates.
- The patch face plate can be a composite laminate or new steel plate.
- When a laminate face plate is used, laminate can be pre-fabricated or on-site laminated (see 1-5/5).
- A core (bond layer) thickness (see 1-5/4) can be controlled when pre-fabricated laminate or a new steel plate is used.
- When on-site lamination is designed, the primer layer (thin) acts as the adhesive/core layer.
- Some repairs may use two or more layers of different adhesives.

Any other type of bonded patch repair should be considered to be a special composite repair which may need more rigorous analysis and possibly testing.