



TECHNICAL REPORT

PROJECT RECOMMENDED PRACTICE COMPOSITE RISERS

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TECHNICAL REPORT

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Summary:

This project specific Recommended Practice RP has been developed in close co-operation with the industry. The following companies have been participants in the Joint Industry Project in addition to DNV:

ABB
Conoco
FMC Kongsberg Offshore
Kværner Oilfield Products
Norsk Hydro
Statoil
Timet

Subsequent to the termination of the Joint Industry Project, it has been agreed upon by the project partners that DNV shall transform this project RP into a DNV Recommended Practice, DNV RP-F202, which will be linked to the newly developed DNV Offshore Standard for Dynamic Risers DNV-OS-F201.

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A. General

A 100 Introduction

101 This Recommended Practice (RP) document gives criteria, requirements and guidance on structural design and analysis of riser systems made of composite materials exposed to static and dynamic loading for use in the offshore petroleum and natural gas industries.

102 The major benefits in using this RP comprise:

- provision of riser solutions with consistent safety level based on flexible limit state design principles;
- application of safety class methodology linking acceptance criteria to consequence of failure;
- provision of state-of-the-art limit state functions in a Load and Resistance Factor Design (LRFD) format with reliability-based calibration of partial safety factors;
- guidance and requirements for efficient global and local analyses and introduction of a consistent link between design checks (failure modes), load conditions and load effect assessment in the course of the global and local analyses;

- allowance for the use of innovative techniques and procedures, such as reliability-based design methods.

103 The basic design principles and functional requirements are in compliance with state-of-the-art industry practice.

A 200 Objectives

201 The main objectives of this RP are to:

- provide an international RP of safety for composite risers utilised for drilling, completion/ workover, production/injection, or transportation of hydrocarbons (import/export) in the petroleum and gas industries;
- serve as a technical reference document in contractual matters; and
- reflect the state-of-the-art and consensus on accepted industry practice and serve as a RP for riser design and analysis.

A 300 Scope and Application

301 This RP provides the design philosophy, loads and global analysis aspects valid for risers made of composite materials. The RP applies to all new built riser systems and may also be applied to modification, operation and upgrading of existing risers.

302 The risers covered in the RP can be jointed or continuous. Bonded rubber risers and risers with unbonded load bearing structures are not included. Applications are production, drilling and injection risers, as well as choke and kill lines.

303 Composites are fibre reinforced plastics. The fibres should have a higher modulus than the surrounding polymeric matrix material. The matrix may be thermoset or thermoplastic.

304 Composite risers have typically internal and external liners around the main pipe section. Any material may be chosen for the liners, as long as long term performance of the liners can be demonstrated. Standards related to chosen liner material shall be used to document liner performance. Additional requirements to liners and interfaces are given in *Section 6*.

305 Composite risers have typically metal end flanges. Any material may be chosen for the flanges, as long as long term performance of the liners can be demonstrated. Standards related to chosen flange material shall be used to document performance of the flanges. Additional requirements to end flanges are given in *Section 6 (composite metal interface)*.

306 The scope covers design, materials, fabrication, testing, operation, maintenance and re-assessment of riser systems. Aspects relating to documentation, verification and quality control are also addressed. The main purpose is to cover design and analysis of top tensioned and compliant composite riser systems operated from floaters and fixed platforms. The RP applies for permanent operation (e.g. production and export/import of hydrocarbons and injection of fluids), as well as for temporary

operation (e.g. drilling and completion/workover activities).

307 This RP is applicable to structural design of all pressure containing components that comprise the riser system.

Guidance note:

Most composite risers of today consist of metallic or polymeric liners within the composite pipes. The purpose of the liners is to prevent leakage of the riser, while the composite pipes are the load carrying part of the riser system. This RP covers risers with (and without) liners as well as riser connectors and other riser components such as tension joints and stress joints.

- end - of - Guidance - note -

308 There are, in principle, no limitations regarding floater type, water depth, riser application and configuration. However, for novel applications where experience is limited, special attention shall be given to identify possible new failure mechanisms, validity/adequacy of analysis methodology and new loads and load combinations.

Guidance note:

For application of this RP to new riser types/concepts (e.g. novel hybrid systems, complex riser bundles etc) it shall be documented that the global load effects can be predicted with same precision as for conventional riser systems. This may typically involve validation of computational methodology by physical testing.

As an alternative an appropriate conservatism in design should be documented.

- end - of - Guidance - note -

309 Examples of typical floater and riser configurations are shown schematically in Figure 1-1. Examples of some typical components/important areas included in typical riser systems are illustrated in Figure 1-2.

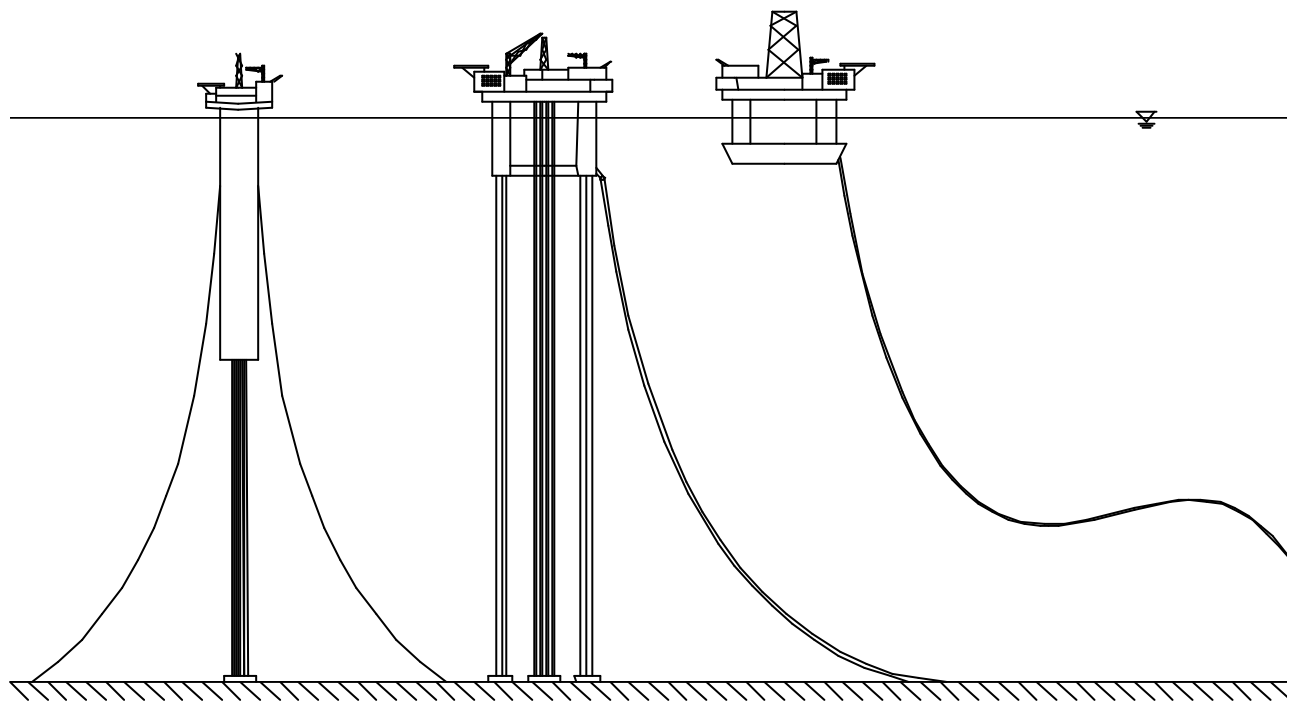
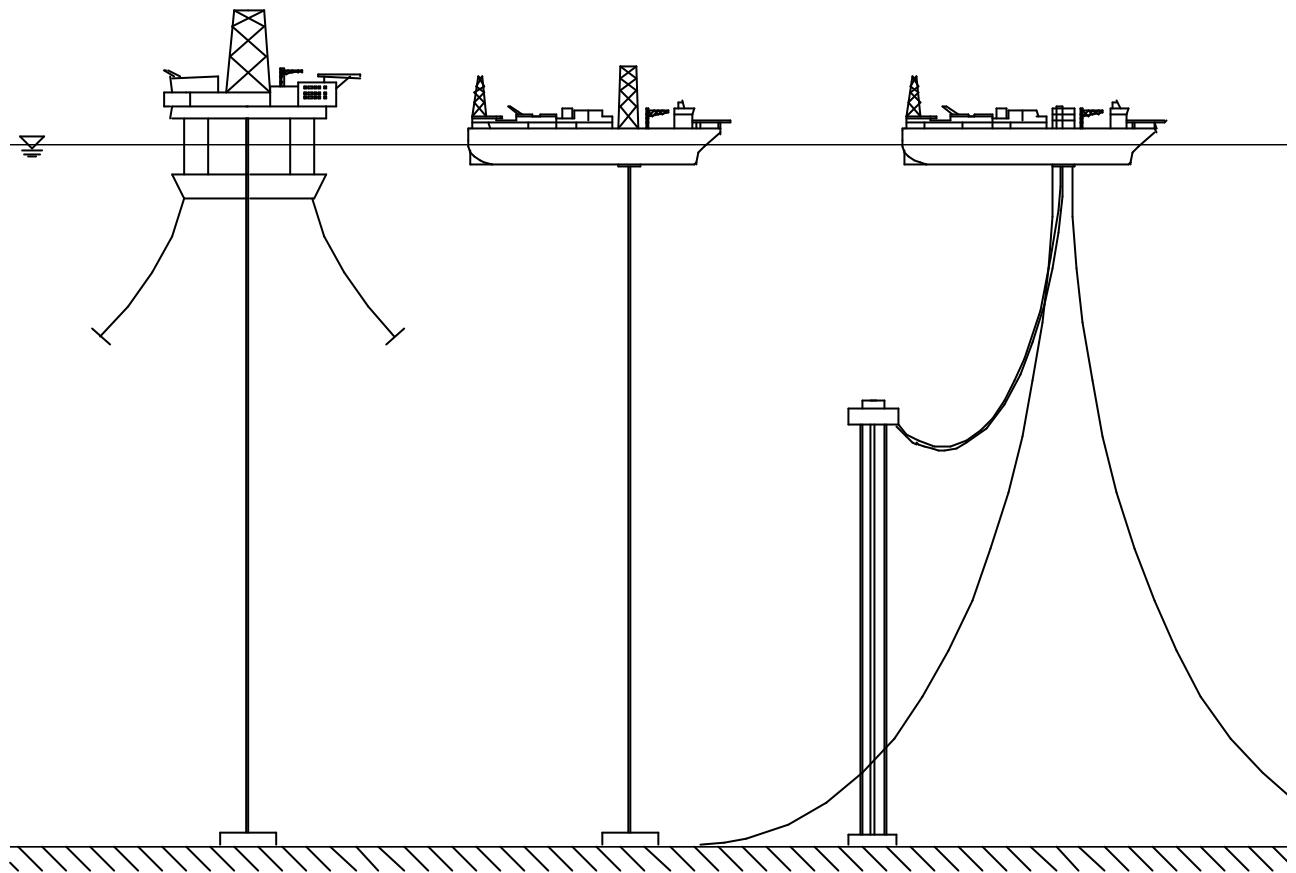


Figure 1-1 Examples of typical riser configurations and floaters



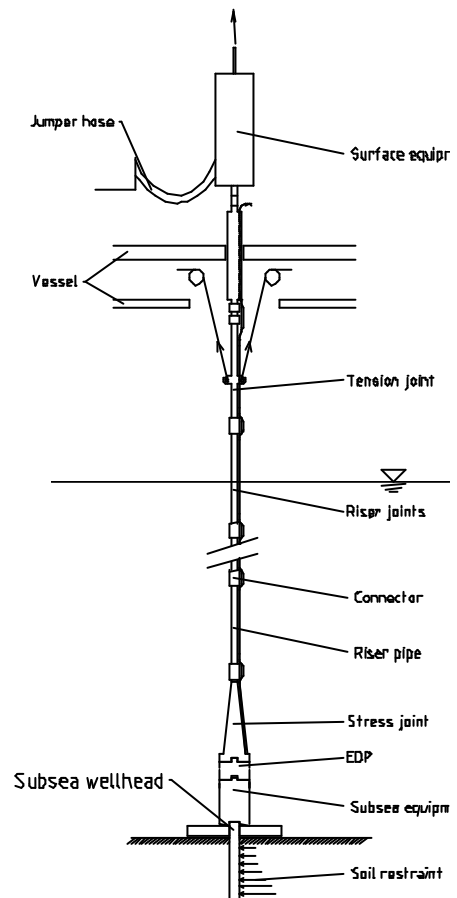
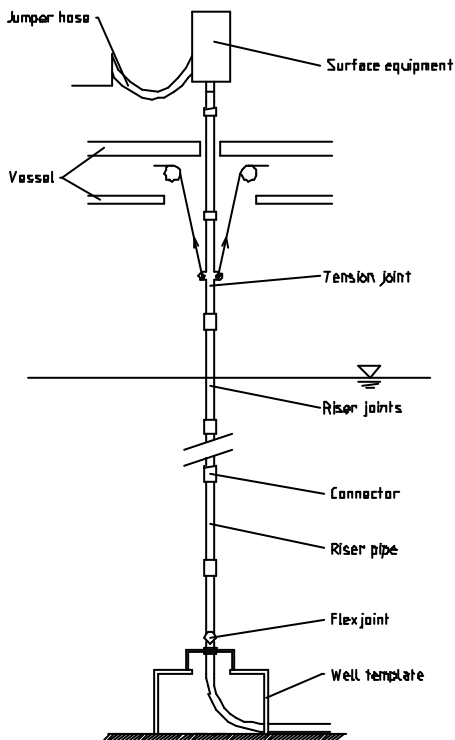
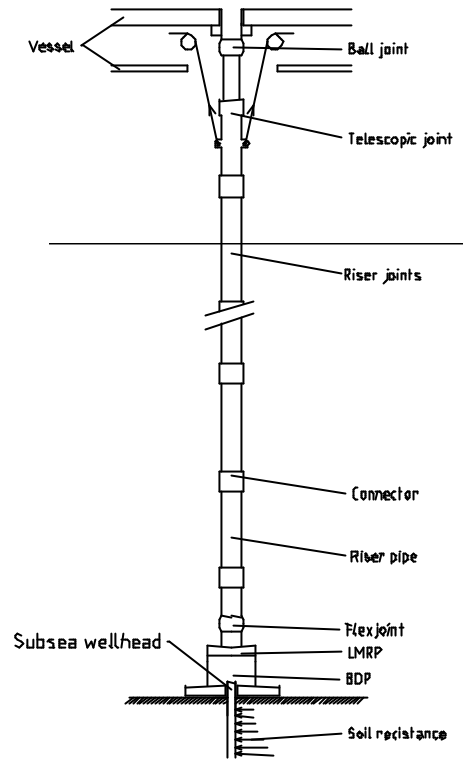
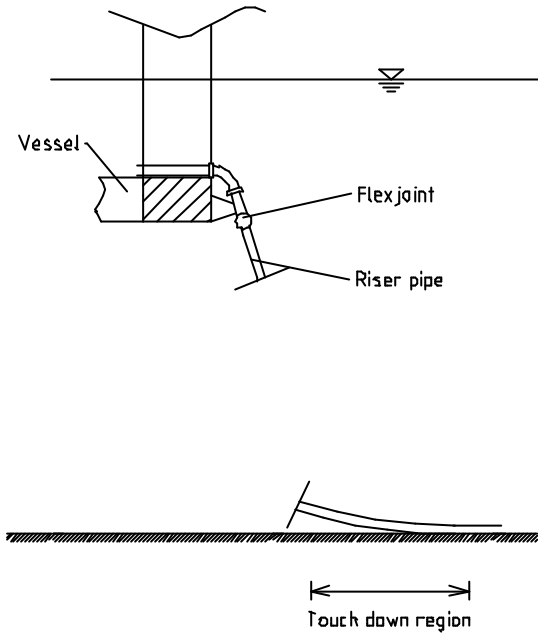


Figure 1-2 Examples of riser components

A 400 Other Codes

- 401** This RP should be used in combination with the standards for dynamic risers and submarine pipeline systems denoted DNV-OS-F201 and DNV-OS-F101 respectively. This RP shall not be used as a stand-alone document. The RP is also related to the offshore standard for composite components denoted DNV-OS-C501. The limit state design checks for this RP and DNV-OS-F201 and DNV-OS-F101 are similar, but due to differences in the governing failure modes and prevailing uncertainties some differences in safety factors exist.
- 402** In case of conflict between requirements of this RP and a reference document, the requirements of this RP shall prevail.
- 403** Where reference is made to codes other than DNV documents, the valid revision shall be taken as the revision that was current at the date of issue of this RP, unless otherwise noted, see B 700.
- 404** The framework within DNV Riser standards and RP's is illustrated in Figure 1.3.

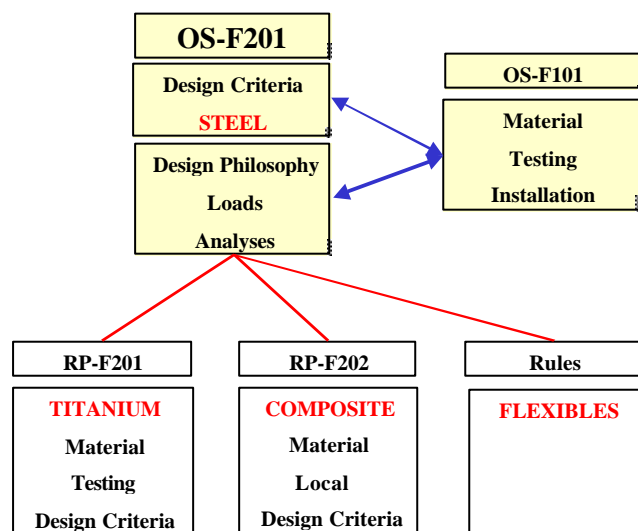


Figure 1-3 Framework for DNV Riser Standards and RP's

- 405** This RP provides specific aspects related to composite risers, including material description, local analysis and design criteria. General design philosophy, loads and global analysis aspects valid for all riser materials are covered by the Offshore Standard for Dynamic Risers DNV-OS-F201. The present RP document subscribes, for consistency, to the safety philosophy and analyses methodology set forward by this standard.

A 500 Structure of the RP

501 This RP is organised as follows:

Section 1 contains the objectives and scope of the RP. It further introduces essential concepts, definitions and abbreviations.

Section 2 contains additions to the fundamental design philosophy and design principles in DNV-OS-F201.

Section 3 in DNV-OS-F201 contains a classification of loads into pressure loads, functional loads and environmental loads. Important internal pressure definitions are given. This RP contains additional aspects that should be considered for composite risers. In particular the description of long term loads and environments.

Section 4 in DNV-OS-F201 contains the framework for global analysis methodology. This RP provides some additions to the combination of long term loads and concentrates mainly on the local analysis of composite risers.

Section 5 contains acceptance criteria for the riser pipe for ULS, SLS, ALS and FLS. This includes a definition of resistance and load effects and safety factors for explicit limit states. It provides links to DNV-OS-C501 for specific composite failure criteria.

Section 6 contains the fundamental functional requirements for connectors and liners. It also provides test requirements for these components.

Section 7 contains requirements for materials. They are identical to the requirements in DNV-OS-C501.

Section 8 contains requirements for documentation and verification of the riser system. They are identical to the requirements in DNV-OS-F201.

Section 9 contains basic requirements for operation and in-service operations in addition to DNV-OS-F201.

502 The close relationship between this RP and DNV-OS-F201 and DNV-OS-C501 is shown in Figure 1-4.

**Content of DNV-RP-202 Composite Risers
 and links to other DNV standards**

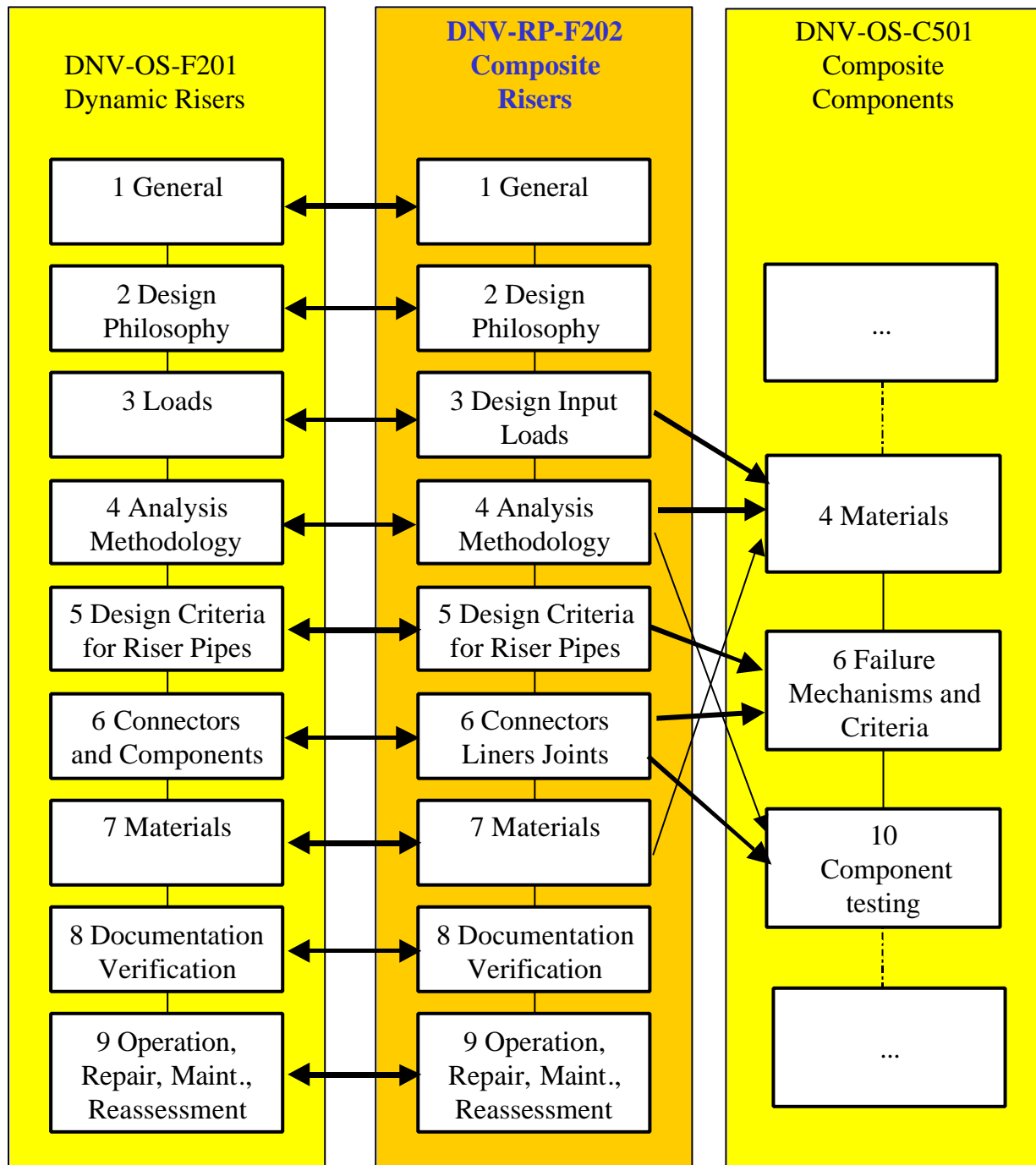


Figure 1.4 Relationship between this RP and DNV-OS-F201 and DNV-OS-C501.

B. Normative References

The latest revision of the following documents applies:

B 100 Offshore Service Specifications

DNV-OSS-301 *Certification and Verification of Pipelines*

B 200 Offshore Standards

DNV-OS-F101 *Submarine Pipeline Systems*

DNV-OS-F201 *Dynamic Risers*

DNV-OS-C105 *Structural Design of TLPs by the LRFD Method*

DNV-OS-C106 *Structural Design of Deep Draught Floating Units*

DNV-OS-C501 *Composite Components*

B 300 Recommended Practices

DNV RP B401 *Cathodic Protection Design*

DNV RP-C203 *Fatigue Strength*

DNV RP-F101 *Corroded Pipelines*

DNV RP-F104 *Mechanical Pipeline Couplings*

DNV RP-F105 *Free Spanning Pipelines*

DNV RP-F106 *Factory applied Pipeline Coatings for Corrosion Control*

DNV RP-F108 *Fracture Control for Reeling of Pipelines*

DNV RP-F201 *Titanium Risers*

DNV RP O501 *Erosive Wear in Piping Systems*

B 400 Rules

DNV Rules for Certification of Flexible Risers and Pipes

DNV Rules for Planning and Execution of Marine operations

DNV Rules for Classification of Fixed Offshore Installations

B 500 Certification notes and Classification notes

DNV CN 1.2 *Conformity Certification Services, Type Approval*

DNV CN 1.5 *Conformity Certification Services, Approval of Manufacturers, Metallic Materials*

DNV CN 7 *Ultrasonic Inspection of Weld Connections*

DNV CN 30.2 *Fatigue Strength Analysis for Mobile Offshore Units*

DNV CN 30.4 *Foundations*

DNV CN 30.5 *Environmental Conditions and Environmental Loads*

DNV CN 30.6 *Structural Reliability Analysis of Marine Structures*

B 600 Guidelines

DNV *Guidelines for Flexible Pipes*

B 700 Other references

- BS 7910 *Guide on methods for assessing the acceptability of flaws in fusion welded structures*
- API RP1111 *Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)*
- API RP2RD *Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)*
- EUROCODE 3 *Design of steel structures - Part 1.1: General rules and rules for building.*
- ISO/FDIS 2394 *General Principles on Reliability for Structures*
- ISO/CD 13628-7 *Petroleum and natural gas industries - Design and operation of subsea production systems - Part 7: Completion/workover riser systems*

Guidance note:

The latest revision of the DNV documents may be found in the publication list at the DNV website www.dnv.com.

- end - of - Guidance - note -

C. General Definitions (same as in DNV-OS-F201)

C 100 Verbal forms

- 101** “*Shall*”: Indicates requirements strictly to be followed in order to conform to this RP and from which no deviation is permitted.
- 102** “*Should*”: Indicates that among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required. Other possibilities may be applied subject to agreement.
- 103** “*May*”: Verbal form used to indicate a course of action permissible within the limits of the RP.
- 104** “*Agreement*”, “*by agreement*”: Unless otherwise indicated, this means agreed in writing between Manufacturer/ Contractor and Purchaser.

C 200 Definitions

- 201** The general definitions are identical to the ones in *DNV-OS-F201*.

D. General Abbreviations and Symbols (same as in DNV-OS-F201)

- 101** The general abbreviations and symbols are identical to the ones in *DNV-OS-F201*.

E. Definitions for Composite Risers

E 100 Definitions

- 101 *Angle-ply laminate*:** symmetric laminate, possessing equal plies with positive and negative angles.
- 102 *Anisotropy*:** material properties varying with the orientation or direction of the reference co-ordinate.
- 103 *Characteristic Load*:** reference value of a load to be used in the determination of the load effects. The Characteristic Load is normally based upon a defined *fractile* in the upper end of the distribution function load.
- 104 *Characteristic Resistance*:** the nominal value of the structural strength to be used in the determination of the design strength. The Characteristic Resistance is normally based upon a defined *fractile* in the lower end of the distribution function for resistance.
- 105 *Constituent*:** In general, an element of a larger grouping. In advanced composites, the principal constituents are the fibres and the matrix.
- 106 *Cross-ply laminate*:** special laminate that contains only 0 and 90 degree plies
- 107 *Delamination*:** separation or loss of bonds of plies (the 2-D layers) of material in a laminate.
- 108 *Environmental conditions*:** environmental exposure that may harm or degrade the material constituents.
- 109 *Environmental loads*:** loads due to the environment, such as waves, current, wind, ice, earthquakes.
- 110 *Fabric*:** planar, woven material constructed by interlacing yarns, fibres or filaments.
- 111 *Failure criterion*:** criterion to define or identify when failure has occurred, usually expressed as an inequality in the governing variables, e.g. load greater than resistance.
- 112 *Failure mechanism*:** A mechanism of failure is the underlying phenomenon at the material level that determines the mode of failure. Depending on its level of severity a mechanism of failure can lead to various failure. Failure mechanisms are specific to material type.
- 113 *Failure mode*:** State of inability to perform a normal function, or an event causing an undesirable or adverse condition, e.g. violation of functional requirement, loss of component or system function, or deterioration of functional capability to such an extent that the safety of the unit, personnel or environment is significantly reduced.
- 114 *Failure type*:** failure types are based on safety margin, intrinsic to a given failure mechanism. A distinction is made between catastrophic and progressive failures, and between failures with or without reserve capacity during failure.
- 115 *Fibre Reinforced Plastic (FRP)*:** a general term polymeric composite reinforced by fibres.

- 116 *Fibre*:** single filament, rolled or formed in one direction, and used as the principal constituent of woven or non-woven composite materials.
- 117 *Filament*:** The smallest unit of a fibrous material. The basic units formed during drawing and spinning, which are gathered into strands of fibre. It is a continuous discrete fibre with an effective diameter in the range of few micrometers depending on the source.
- 118 *Functional requirement*:** a functional requirement is defined as a requirement that the global structure has to fulfil.
- 119 *Glass Fibre Reinforced Plastic (GRP)*:** general term polymeric composite reinforced by glass fibres.
- 120 *Homogeneous*:** Descriptive term for a material of uniform composition throughout. A medium that has no internal physical boundaries.
- 121 *Inspection*:** activities, such as, measuring, examination, testing, gauging one or more characteristic of a product or a service, and comparing the results with specified requirements to determine conformity.
- 122 *Interface*:** boundary or transition zone between constituent materials, such as the fibre/matrix interface, or the boundary between plies of a laminate or layers of a sandwich structure. Bondary between different materials in a joint. An interface can also be the area where two components or parts touch each other.
- 123 *Lamina*:** same as ply.
- 124 *Laminae*:** Plural of lamina
- 125 *Laminate*:** Layers of a plies bonded together to form a single structure. Also the process to build a laminate.
- 126 *Laminate ply*:** same as ply.
- 127 *Layer*:** A single layer of reinforcement (see also definition for ply).
- 128 *Liner*:** The thin wall/pipe (usually made of metal) that is applied within the composite pipe of most composite risers. The purpose of the liner is to avoid leakage of the riser.
- 129 *Local analysis*:** Detailed analysis of parts of the riser system, e.g. critical cross-sections, connectors and joints. The local analysis should provide stresses and strains on the ply level.
- 130 *Matrix*:** the cured resin or polymer material in which the fibre system is imbedded in a ply or laminate.
- 131 *MCI*:** Metal Composite Interface
- 132 *Monolithic structure*:** laminate consisting uniquely of composites materials except core materials; also called single-skin structure.
- 133 *Off-axis*:** not coincident with the symmetry axis; also called off-angle.

- 134 *On-axis*:** coincident with the symmetry axis; also called on-angle.
- 135 *Orthotropic*:** having three mutually perpendicular planes of material symmetry.
- 136 *Ply*:** Basic building block of a laminate with orthotropic properties. Reinforcement surrounded by a matrix. Several layers of reinforcement may form a ply. Several plies form a laminate.
- 137 *Reinforcement*:** a strong material embedded into a matrix to improve its strength, stiffness and impact resistance.
- 138 *Roving*:** a number of strands, tows, or ends collected into a parallel bundle with little or no twist.
- 139 *Strand*:** Normally a untwisted bundle or assembly of continuous filaments used as a unit, including slivers, tows, ends, yarn and so forth, Sometimes a single filament is called a strand.
- 140 *Stacking sequence*:** A description of the orientation of plies in a laminate.

Guidance note:

The term stacking sequence is also often used to describe the order riser joints are mounted to make up an entire riser. It should be clear from the context which definition is valid.

End of guidance note

- 141 *Warp*:** The direction along which yarn is orientated longitudinally in a fabric and perpendicularly to the fill yarn.
- 142 *Weft*:** The transversal threads of fibres in a woven fabric running perpendicular to the warp.

F. Abbreviations and Symbols for Composite Risers

F 100 Symbols and Abbreviations

Variables	
1,2,3	: ply, laminate, or core local co-ordinate system , 1 being the main direction
a	: half crack length
a_i	: scalar
$A_{i,j}$: matrix A components
[A]	: extensional stiffness matrix
b	: width
b'	: horizontal distance between faces NA for boxed beam
C	: swelling agent concentration coefficient
COV	: coefficient of variation, i.e., standard deviation over mean
d	: vertical distance between faces neutral axis (NA)
D	: flexural rigidity
D_0	: flexural rigidity of faces about the NA of the entire sandwich structure
e	: core width
{e}	: expansional strain field
E	: modulus of elasticity
e_i	: general expansional strain
f	: correction factor – scalar
G	: shear modulus
G	: strain energy release rate
h	: height of boxed beam
H	: anisotropy factor
I	: 2 nd moment of area
k	: scalar
K	: stress intensity factor
l	: length
m	: surface mass
M	: moment
N	: in-plane load
$Q_{i,j}$: matrix Q components
[Q]	: stiffness matrix
R	: resistance
S	: shear stiffness, local or global structure response
SCF	: stress concentration factor
$S_{i,j}$: matrix S components
[S]	: transformed compliance matrix
t	: thickness
T	: transverse load, temperature

U	: strain energy
u,v,w	: displacement in (x,y,z)
V	: volume fraction
x,y,z	: global co-ordinate system
Φ	: failure criteria function
Ψ	: ratio between quantiles in the marginal distributions and extreme-value distributions
α	: thermal expansion coefficient
α	: loading mode factor
Variables	
β	: thermal swelling coefficient, or boundary conditions factor
ϵ	: direct strain, i.e. ϵ_1 in the main direction
$\hat{\epsilon}$: strain to failure
{ ϵ }	: strain field
γ	: shear strain
γ_F	: partial load factors
γ_{FM}	: partial load and resistance factor
γ_M	: partial resistance factors
γ_{Rd}	: partial model factor, resistance component
γ_{Sd}	: partial model factors, load component
μ	: mean value
ν	: Poisson's ratio, i.e. major ν_{12} , minor ν_{21}
θ	: ply angle
ρ	: density
σ	: direct stress, i.e. σ_1 in the main direction, or standard deviation
\hat{S}	: strength, or stress to failure
{ σ }	: stress field
τ	: shear stress, i.e. τ_{12} (or σ_{12} sometimes)
ω	: angular velocity

Table 1-1: Definitions of symbols for variables

Subscripts	
b	: bending effects
ben	: bending
c	: compression
core	: core
corrected	: value corrected by using a correction factor
cr	: critical
d	: design
Delam	: delamination
E(n)	: time curve
face	: face
Fiber	: fiber
i	: effects due to in-plane size of sandwich beam
ip	: effects due to in-plane size of sandwich panel
k	: characteristic value
Matrix	: matrix
max	: maximum
meas	: measured value
min	: minimum
nom	: nominal
ply	: ply
ref	: mean of the measured values
Shear	: shear
sl	: shear-loaded
SLS	: serviceability limit state
t	: tension
tc	: core thickness effects
typ	: typical value
ULS	: ultimate limit state

Table 1-2: Definitions of subscripts

Superscripts	
-	: maximum direct or shear stress in the structure/component
^	: direct or shear stress of material at failure
*	: elastic or shear modulus of damaged face or core
nl	: non-linear
lin	: linear
0	: initial
1	: final
top	: top face
bottom	: bottom face

Table 1-3: Definitions of superscripts

Sub-superscripts	
lin	: linear limit

Table 1-4: Definitions of sub-superscripts

F 200 Ply and laminate co-ordinate systems

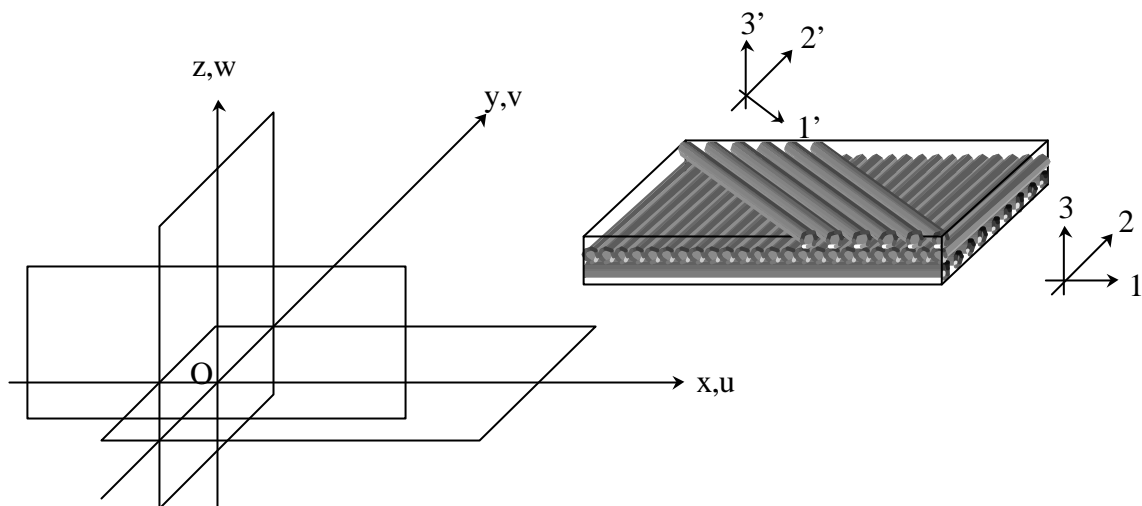
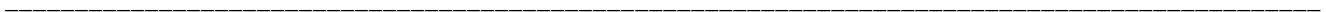


Figure 1-5: Local Co-ordinate System and Symmetry Planes in an Orthotropic Bi-directional Ply.



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A. General

A 100 Objective

- 101** The purpose of this section is to present the safety philosophy and corresponding limit state design format applied in this RP.
- 102** The design philosophy and design principles are basically the same as stated in the DNV offshore standard for dynamic risers DNV-OS-F201. This RP refers to this standard and addresses additional issues that are relevant for composite risers.

A 200 Application

- 201** This section applies to all risers that are to be built in accordance with this RP.

B. General Safety Philosophy

B 100 General

- 101** The general safety philosophy is described in the DNV Offshore Standard for Dynamic (Metallic) Risers DNV-OS-F201. It is also applicable for composite risers.
- 102** The following issues are addressed in DNV-OS-F201:
- Safety objective
 - Systematic Review
 - Fundamental requirements

- ❑ Operational considerations
- ❑ Design Principles
- ❑ Quality Assurance and Quality System

C. Design Format

C 100 General

101 The design objective is to keep the failure probability (i.e. probability of exceeding a limit state) below a certain value. All aspects described in the DNV Offshore Standard for Dynamic (Metallic) Risers DNV-OS-F201 are also applicable for composite risers.

102 The following issues are addressed in DNV-OS-F201:

- ❑ Safety class methodology
- ❑ Design by LRFD Method
- ❑ Reliability based Design
- ❑ Design by Testing

103 Additional requirements specific for composite risers are given below.

C 200 Failure Types

201 Composite materials can fail in different ways than metals. The safety factors given in this RP are linked to failure types that are modelled by the design criterion. **Failure types** are based on the degree of prewarning intrinsic to a given failure mechanism. A distinction is made between catastrophic and progressive failures, and between failures with or without reserve capacity during failure. The failure types for each failure mechanism described in this RP are specified for each design criterion. The specification is based on the definitions given below.

- Failure type *Ductile*, corresponds to ductile failure mechanisms with reserve strength capacity. In a wider sense, it corresponds to progressive non-linear failure mechanisms with reserve capacity during failure. The design criterion describes the onset of the failure process, e.g. it is based on the yield point and not the ultimate strength, even though it is used to describe total failure.
- Failure type *Brittle*, corresponds to brittle failure mechanisms. In a wider sense, it corresponds to non-stable failure mechanisms.

202 The different failure types should be used under the following conditions for materials that show a yield point:

The failure type ductile may be used if the design criterion is applied to the yield point and:

$$\sigma_{ult} > 1.2 \sigma_{yield} \text{ and } \epsilon_{ult} > 2 \epsilon_{yield}$$

where σ_{ult} is the ultimate strength at a strain ϵ_{ult}

and σ_{yield} is the yield strength at a strain ϵ_{yield}

The failure type ductile may be used if onset of damage is modelled, but extensive damage is needed to

cause failure, e.g. for the onset of matrix cracking, when failure is related to leakage and only a substantial number of cracks causes leakage.

In all other cases the failure type brittle shall be used.

C 300 Reliability Based Design

- 301** As an alternative to design according to the formats specified and used in this RP, a recognised Structural Reliability Analysis (SRA) design method may be used. All requirements given in DNV-OS-F201 shall be followed.
- 302** As far as possible, target reliability levels shall be calibrated against identical or similar riser designs that are known to have adequate safety based on this RP. If this is not feasible, the target safety level shall be as given in Table 2-1. The values are nominal values reflecting structural failure due to normal variability in load and resistance but excluding gross error.

Table 2-1: Target annual failure probabilities P_{FT} for ULS, FLS and ALS			
Failure type	Failure consequence		
	LOW SAFETY CLASS	NORMAL SAFETY CLASS	HIGH SAFETY CLASS
Ductile failure type (e.g as for steel)	$P_F=10^{-3}$	$P_F=10^{-4}$	$P_F=10^{-5}$
Brittle failure type (base case for composite)	$P_F=10^{-4}$	$P_F=10^{-5}$	$P_F=10^{-6}$

C 400 Design by Testing Combined with Analysis

- 401** Testing may be performed as described in DNV-OS-F201. Additional guidance and requirements are given in *Sections 4, 5 and 6*.

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A. Introduction

- 101** The offshore standard *DNV-OS-F201 Section 3* contains a classification of loads into pressure loads, functional loads and environmental loads. Important internal pressure definitions are given. All these are also relevant for composite risers.
- 102** This RP contains additional aspects that should be considered for composite risers. In particular the description of long term loads and environments.

B. Product specifications

B 100 General Function or main purpose of the riser

- 101** The general function or the main purpose of the riser and its main interactions with other components and the environment shall be specified in the product specifications.
- 102** The design life in service should be specified in the product specifications.

Guidance note:

E.g. the riser will work as a production riser for a deep water field of 1500 m for 25 years.

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C. Division of the product or structure into components, parts and details

- 101** The following levels of division of the riser (product or structure) are used in this RP:
- Riser (structure / product)
 - Sub-structure / sub-product
 - Components
 - Parts
 - Details
- 102** The riser can be divided into sub-products or sub-structures, each of which may belong to different safety classes.
- 103** The riser can be divided into components corresponding to the same Safety Class but may be subject to different functional requirements.
- 104** Each component can be divided into parts and each part into details.

Guidance note:

Structure = riser

Sub-structure = The riser can be divided into to sub-structures corresponding to different safety classes, e.g. parts of the riser underneath the platform and parts far away from the platform.

Components = the riser could be constituted of an inner liner, an outer shell and the connectors (flanges). The liner's function is to keep the riser tight, whereas the shell's function is to carry the pressure loads. The two components have different functional requirements. The connector carries all loads and transfers the loads into the main body of the riser.

Parts and details = Different design approaches and design solutions may be used for the different parts and details.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 105** A structure or substructure is an independent part for which a safety class can be defined. Components, parts and details are part of a structure or substructure. Failure of any of these components, parts or details shall be seen in combination with each other.
- 106** The interfaces between parts, components or structures should be considered carefully. Interfaces shall be analysed as a part itself if they belong to a continuous structure. If the interfaces are physical interfaces, the requirements of *Section 6 D and F* shall be considered.

D. Phases

D 100 Phases

- 101** The design life of the riser shall be divided into phases, i.e. well-defined periods within the life span of the product.
- 102** All phases that could have an influence on the design of the riser shall be considered.
- 103** As a minimum the construction phase and the operation phase shall be considered. However, it may be convenient to split the design life into more detailed phases as shown below:

Manufacturing	Construction
Fabrication / Assembly	
Transport	
Handling	
Storage	
Installation	
Testing	
Commissioning	

Operation	Operation
Maintenance	
Repair	
Retrieval / recirculation	Post-operation.

- 104** Spooling should be considered as part of the construction phase if relevant for the riser solution.
- 105** A decommissioning phase may be specified in some cases.
- 106** The duration of each phase should be specified. Especially, the lifetime in service shall be specified.

E. Safety and Service Classes

E 100 Safety Classes

- 101** The riser can be divided into sub-structures, each of which may belong to different safety classes.
- 102** For each sub-product the Safety Classes, as described in *DNV OS F201 Section 2C*, shall be specified and documented.
- 103** The safety class of a riser or its sub-structures may change from one phase to another during the life of the riser.

E 200 Service classes

- 201** The riser can be divided into *sub-structures*, each of which may belong to different service classes.

Guidance note:

Service classes may be used to discriminate between parts of a riser system with different maintenance requirements. For example, some parts of a riser system, which are less accessible, could be designed for a lower maintenance frequency.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

F. Loads

F 100 General

- 101** Loads for composite risers are the same as specified in DNV offshore standard DNV-OS-F201 Dynamic Risers. Loads and deformations are categorised into four groups:

- pressure (P) loads

- functional (F) loads
- environmental (E) loads
- accidental (A) loads

102 All the load cases shall be described separately for each phase during the design life of the structure.

103 Long term loads need special considerations as described below.

F 200 The sustained load effect

201 The *sustained* load effect value should be used for the determination of time-dependent material properties as described in *DNV-OS-C501 Section 4*.

Guidance note:

In general, it would be very conservative to determine the time dependent degradation of material properties under long-term loads by using the characteristic load effect value (i.e. extreme load effect value). The sustained value is defined in this RP as a kind of average load effect value over the lifetime of the product.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

202 Sustained load values are defined over an observation period, which can correspond to the entire design life of the riser or to a part of that design life. This observation period should be divided into several time intervals. Time intervals should not be chosen shorter than 1 hour. The maximum length of a time interval depends on the load variations. Variations in magnitude of the load within a time interval shall not be larger than half the absolute load amplitude during the total observation period.

203 Load effects are divided, according to their variation with time, into:

- permanent load effects: effects which are likely to act or be sustained throughout the design life and for which variations in magnitude with time are negligible relative to their mean values; or load effects which are monotonically in- or decreasing until they attain some limiting values.
- variable load effects: effects which are unlikely to act throughout the specified design life or whose variations in magnitude with time are random rather than monotonic and not negligible relative to their mean values.

204 The sustained value of permanent load effects shall correspond to their characteristic value, the 99% quantile in the distribution of the annual extreme value.

205 The sustained value of variable load effects is defined as the mean value of the effects over the time interval. The sustained value S_s during the time interval t_s is determined such that the corresponding total duration above S_s is a portion $\mu = 0,5$ of the exposure period t_s . See *Figure 3-1*:

$$\sum_i t_i \leq m t_s$$

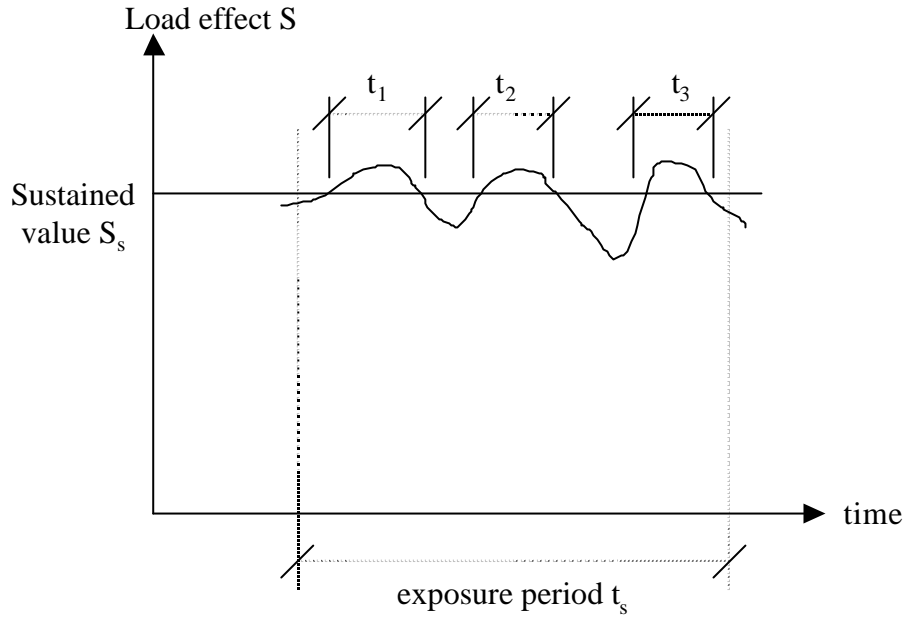


Figure 3-1: Sustained value of a variable load effect

206 The sustained value of the stress or strain fluctuations (load effect fluctuations) shall be specified within each observation period for each time intervals. Basically a table of the following form should be established.

Exposure time (duration)	Sustained value
t_s	S_s

Table 1-3: Sustained values

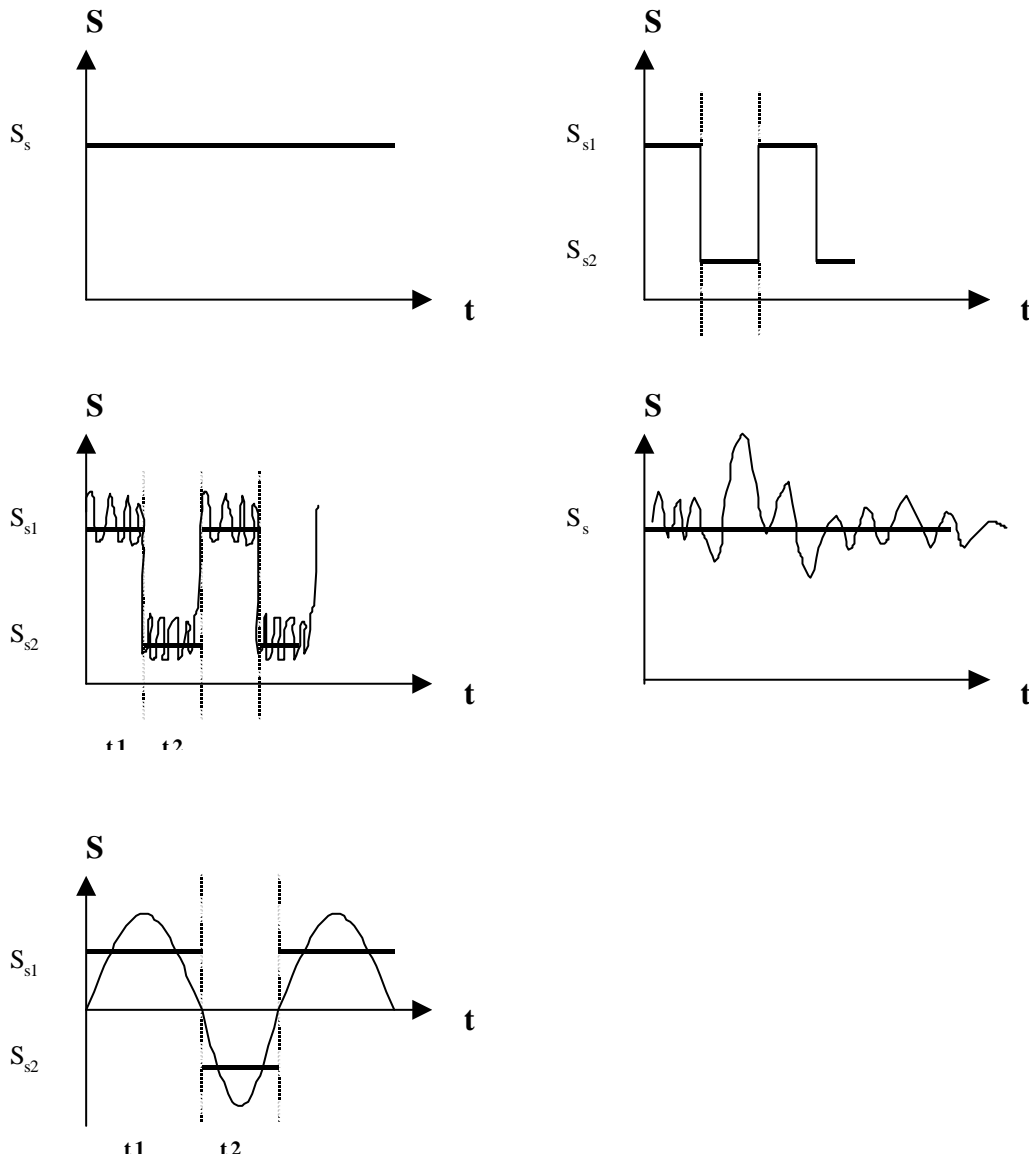
- 207** The sustained value of a load effect over an observation period may conservatively be chosen as the maximum value of that load effect during the observation period.
- 208** The sustained conditions should be considered for failure mechanisms or material property changes governed or influenced by long-term load effects.

Guidance note:

For example, the *sustained* load effect value shall be used for the calculation of creep and for stress rupture.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

Examples of division into time intervals and definition of the sustained values S_{si} for different load effect cases are shown on the figure below:



F 300 The fatigue load effects

- 301** All load effect fluctuations, e.g. stress or strain fluctuations, imposed during the entire design life, shall be

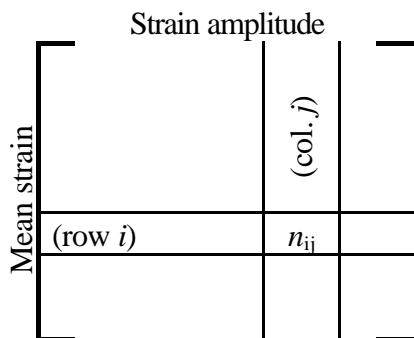
taken into account when determining the long-term distribution of stress or strain ranges. All phases shall be included and both low-cycle fatigue and high-cycle fatigue shall be considered.

- 302** Fatigue may be analysed for load effects in terms of either stress or strain. Strain is preferred for composite laminates.
- 303** The characteristic distribution of load effect amplitudes should be taken as the expected distribution of amplitudes determined from available data representative for all relevant loads. This is a long-term distribution with a total number of stress/strain cycles equal to the expected number of stress/strain cycles over a reference period such as the design life of the structure.
- 304** For fatigue analysis the mean and amplitude of the stress or strain fluctuations shall be specified. Basically a table of the following form should be established.

Number of cycles	Mean load	Amplitude
N	S	A

Table 3-2: Definition of fatigue loads

As an alternative to the representation in Table 2, the fatigue loads can be represented on matrix form with one row for each mean strain, one column for each strain amplitude, and number of cycles as the entry of each matrix element as shown in the Figure below.



Matrix representation of rain-flow counted strain amplitude distribution.

Guidance note:

- The history of mean and amplitude of stress should be established on discretised form by a rainflow analysis
- A minimum resolution of the discretisation of stresses has to be defined before the stress history is established
- Note that for the fatigue analysis the history of mean stress/strain and amplitude is needed. In a non-linear analysis, the mean may shift relative to the amplitude during the transfer from applied load to load response.
- If the time duration of some cycles is long or if the mean value is applied over a long time, these loads may have to be considered for sustained load cases (stress rupture) as well.
- Degradation is a non-linear, history-dependent process. If different load and environmental conditions can

cause different degradation histories, all relevant load combinations shall be considered.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 305** Based on the material properties, in particular the $S-N$ curve and the magnitude of its slope parameter, it shall be assessed whether the bulk of the fatigue damage will be caused by several thousand or more stress cycles from the characteristic stress distribution, or if it will be caused by only one or a very few extreme stress amplitudes from this distribution. In the former case, the natural variability in the individual stress amplitudes can be disregarded as its effect on the cumulative damage will average out, and the partial load factor can be set equal to 1.0. In the latter case, the natural variability in the few governing extreme stress amplitudes cannot be disregarded and needs to be accounted for by a partial load factor greater than 1.0. If no detailed analysis of the load factor can be made, the same factors as those given for static loads shall be used.

G. Environment

G 100 General

- 101** The term environment designates in this RP the surroundings that impose no direct load on the product.
- 102** The environment may impose indirect loads on the structure, e.g. thermal stresses or swelling due to moisture uptake. This should be considered as a load effect and should be calculated according to the relevant parts of *Section 4*. However, the environment is generally considered for its effect on the degradation of material strength or change of elastic properties.
- 103** The following aspects should be considered when evaluating the effect of the environment on local volume elements in a structure:
- Direct exposure
 - Possible exposure if protective system fails
 - Exposure after time
 - Exposure after diffusion through a protective layer
 - Exposure after accident
 - Exposure after degradation of a barrier material, or any material

Guidance note:

A list of the most common environments to be considered is given for guidance below.

NATURAL	Temperature internal and external
	Temperature variations
	Temperature gradients
	UV radiation (if above the water line)
	Moisture
	Sea water
	Animals (e.g. shark bites)
FUNCTIONAL	Transported or contained fluids and chemicals
	Temperature internal and external
	Pressure internal and external
	Oil spill
	Cleaning materials
	Paint solvents
	Accidental chemicals
	Fire
	Process gas leaks
	Service induced shocks
	Accidental high pressure steam

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 104** The time history of all quantities that characterise environmental conditions (e.g. temperature, humidity) should be documented for each phase during the design life of the structure.
- 105** The time history of all environments should be documented for the entire life of the product. Time histories and characteristic values should be established according to the same principles as described for loads in *Section 4B*.
- 106** Different environmental values are defined in this RP:
- the characteristic value
 - the sustained value

Guidance note:

The definition of the different load values is summarised in the table below. The detailed definition presented in the relevant chapters shall be used.

Designation	Definition	To be used for
Characteristic value	Extreme value with return period of 100 years	Check of Ultimate Limit States
Sustained value	Average value over a long period	Long-term degradation of material properties
Fatigue value	Only for loads	
Accidental value	Same as characteristic value	

For example: when considering temperature as an environment, the following values can be defined:

- Sustained environmental value corresponding to the average temperature
- Extreme environmental value corresponding to the maximum temperature
- Accidental environmental value corresponding to a fire situation
- Fatigue environmental values corresponding temperature fluctuations imposing thermal stress fluctuations in the material

---e-n-d--- o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 107** The notion of fatigue value for the environment is not considered in this chapter. If the environment impose indirect fatigue loads on the structure, e.g. cyclic thermal stresses, these loads should be considered according to *Section 4B*.
- 108** Different types of loads and environment shall be combined. Depending on which load and environment values are combined, different load and environmental conditions are defined. These different load and environmental conditions define the different design cases to be considered. These design cases are described in *Section 4 B*.

G 200 Effects of the environment on the material properties

201 All possible changes of material properties due to the effect of the environment should be considered.

Guidance note:

The following interactions should be considered:

- Temperature: variation of the mechanical properties (stiffness, strength...)
- Exposure to water (salinity / corrosion, marine fouling...)
- Exposure to humidity
- Exposure to chemicals
- Exposure to UV
- Exposure to other radiation
- Erosion

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

202 The degradation of material properties caused by environmental conditions is described in *DNV-OS-C501 Section 4*.

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A. General

A 100 Objective

- 101 The purpose of this section is to provide an overview of the analysis methodology for composite risers.
- 102 Global analysis should be performed as described in the standard for dynamic risers DNV-OS-F201.
- 103 The global analysis should be used to obtain local loads, moments and pressures. These local effects are used as input to check the limit states locally. Two methods may be used, as described in *C*.
- 104 All phases identified in *Section 3D* shall be analysed.

B. Combination of load effects and environment

B 100 General

- 101 The fundamental approach to combine load effects is the same as described in *DNV-OS-F201 Dynamic risers*.
- 102 Combined loading in DNV-OS-F201 is described for acceptance criteria that can be used directly with respect to applied forces and moments. If such acceptance criteria can be found (see 500) the same methods as in DNV-OS-F201 can be used. Otherwise the procedures described in *B300* should be used.
- 103 If the local load effect is linearly proportional to the actual load, loads may be combined directly instead of combining load effects. Reference is also made to DNV-OS-F201 Appendix C on how to combine loads for nonlinear systems.

B 200 Fundamentals

- 201 The combination and severity of load effects and/or environmental conditions should be determined taking into account the probability of their simultaneous occurrence.

Guidance note:

For example, a severe wave climate producing a large wave load is usually accompanied by a severe vessel offset producing large axial loads or bending moments.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 202 Load effects and/or environmental conditions, which are mutually exclusive, should not enter together into a combination, e.g. ice load effects and wave load effects in a riser environment.
- 203 All directions of load effects are to be taken as equally probable, unless data clearly show that the probability of occurrence is different in different directions, or unless load effects in a particular direction is particularly critical.

204 Permanent load effects and permanent environmental conditions shall be taken into consideration in all combinations of load effects and environmental conditions. When combined with other load effects or environmental conditions, their characteristic values shall be included in the combination.

205 The following load effect and environmental conditions are defined in this RP:

- Load effects and environmental conditions for ultimate limit state
- Load effects and environmental conditions for time-dependent material properties
- Load effects and environmental conditions for fatigue analysis

206 The *Table 4-1* summarises the load and environmental conditions that should be considered for the determination of the time-dependent material properties and those that should be used for the design checks at various times during the life of the product.

		Loads		
		Characteristic value	Sustained value	Fatigue value
Environment	Characteristic value	ULS check Fully correlated only <i>See B302</i>	ULS check Not fully correlated <i>See 306</i>	
	Sustained value	ULS check Not fully correlated <i>See B306</i>	Material degradation <i>See B400</i>	Fatigue analysis <i>See B500</i>

Table 4-1: Combinations of load and environmental conditions to be considered for the determination of material degradation and for design checks.

B 300 Load effect and environmental conditions for ultimate limit state

301 At any time during the design life of the structure it should be documented that the structure can fulfil its functional requirements for:

- All characteristic load effect values combined with all sustained environmental values
- All sustained load effect values combined with all characteristic environmental values

302 When environment and load effect are *fully-correlated*, their *characteristic* values shall be combined.

303 The combination of characteristic load effects and environment should be determined such that the combined characteristic effect has a return-period of 100 years.

Guidance note:

A method to determine the 100-years combined effect of several load effects and environments is described in this chapter. It is based on the so-called Turkstra's rule.

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304 When several stochastic load effect and/or environmental conditions occur simultaneously, the extreme combined effects of the associated stochastic processes are required for design against the ultimate limit state. Each process is characterised by a characteristic value. The characteristic values are to be

factored and combined to produce a design effect. For this purpose, a (limited) number of possible load effect and/or environmental condition combinations are considered. The most unfavourable combination among these shall be found and will govern the design.

- 305** The most unfavourable relevant combinations shall be defined for every point in time during the design life.

Guidance note:

In most cases the most unfavourable relevant combinations are the same over the entire design life. However, in some cases conditions may change with time, which may in turn cause changes in the relevant combinations.

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- 306** The format of this RP for the combination of two or more independent random load effect processes is based on Turkstra's rule. The rule states that the maximum value of the sum of two independent processes occurs when one of the processes has its maximum value.

- 107** The design load effect corresponding to the combination of two independent load effect processes A and B should be determined as

$$S_d = g_{sd} \cdot \max \left\{ \begin{array}{l} g_F^A \cdot S_k^A + g_F^B \cdot S_k^B \cdot \Psi^B \\ g_F^A \cdot S_k^A \cdot \Psi^A + g_F^B \cdot S_k^B \end{array} \right. \quad (1)$$

Where:

- S_d Design load effect
- γ_{sd} Load effect model factor
- S_k^A Characteristic value of load effect A
- γ_F^A Partial load effect factor for load effect A
- Ψ^A Load effect combination factor for load effect A
- S_k^B Characteristic value of load effect B
- γ_F^B Partial load effect factor for load effect B
- Ψ^B Load effect combination factor for load effect B

308 The design load effect corresponding to the combination of a number of N independent load effect processes should be determined by the maximum of the following N combinations:

$$S_d = g_{S_d} \cdot \max_{j=1}^N \left[g_F^j \cdot S_k^j + \sum_{i \neq j} g_F^i \cdot S_k^i \cdot \Psi^i \right] \quad (2)$$

Where:

S_d Design load effect

γ_{S_d} Load effect model factor

S_k^i Characteristic value of load effect i

γ_F^i Partial load effect factor for load effect i

Ψ^i Combination factor for load effect i

- 309** The load effect combination factor $\Psi = 0.7$ should be used for independent load effect processes, unless a detailed probabilistic analysis can justify a different value. For permanent load effects and permanent environmental conditions $\Psi = 1.0$.
- 310** Some load effect processes are correlated such that the value of the one load effect process to some degree depends on the simultaneous value of the other load effect process. The combination rule for design load effects quoted in *clause 306* for independent load effect processes can be extended to be used also for correlated load effect processes. When applied to combination of correlated load effect processes, different (usually higher) values of the combination factors Ψ apply, depending on the degree of correlation.
- 311** The load effect combination factor $\Psi = 1,0$ shall be used for correlated loads, unless a detailed analysis can show that the load effects are correlated in a different way.

Guidance note:

For example:

- Water level (height) and pressure load effect are fully correlated processes

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B 400 Load effect and environmental conditions for time-dependent material properties

- 401** The sustained load effect values or the fatigue load effect values (when relevant) and the sustained environmental values should be used for the determination of time-dependent material properties as specified in *Section 3 F-200*.

B 500 Load effect and environmental conditions for fatigue analysis

- 501** The fatigue load effects should be combined with the sustained environmental values for the fatigue analysis as specified in *Section 3 F-300*.

B 600 Direct combination of loads and moments

- 601** The combination of load effects and environments as described above should be used to obtain the load effects, i.e., local stresses and strains.
- 602** If transfer functions and structural analysis are linear, loads or moments can be combined by the procedures given above instead of the load effects.

C. Analysis Procedure for Composite Risers

C 100 General

- 101** The global analysis of the riser system can be performed the same way as described in DNV-OS-F201. Detailed local analysis should be applied for connectors/joints and other critical parts of the riser system.
- 102** Risers made of composites possess a more complex behaviour due to the fact that the development of failure in composite materials usually involves a sequence of failure mechanisms (e.g. matrix cracking, delamination and fibre failure), each of which leads to local change of material properties.
- 103** Due to the large number of failure mechanisms and the fact that local effects are crucial for most failure modes related to composite structures, it is extremely difficult to establish analytical acceptance criteria on a global level for all failure modes. Therefore, local analysis should be extensively used in the evaluation of failures for composite risers. A method to obtain global acceptance criteria by numerical analysis is given in *C300*.
- 104** The development of local failure mechanisms, with corresponding local degradation of material properties, may result in decreased values for the global stiffness parameters. This may affect the overall global behaviour (e.g. displacements, bending moments and effective tension) of the riser system. Thus, the parameters that serve as boundary conditions for the local analysis may be modified.
- 105** In the following two analysis procedures for composite riser systems are recommended. The principal difference between the methods is the level on which the failure criteria (or limit states) are evaluated. Another obvious difference, which follows from the prior, is the order in which the global and local analysis is conducted. Other analysis procedures may be found in *DNV-OS-C502 Section 9*.

C 200 Global - Local Procedure

- 201** In order to evaluate the limit states one first performs global analysis of the entire riser system. The resulting global load effects (e.g. effective tension, bending moment and internal or external overpressure) serve as boundary conditions for the forthcoming local analysis.
- 202** Based on the load effects from the global analysis, local analysis, which leads to local load effects (stresses and strains), is now conducted.
- 203** The local load effects resulting from the local analysis are finally applied in the local acceptance criteria (or failure criteria) in order to detect possible failure mechanisms of the riser components.
- 204** If the local investigations are performed by progressive failure analysis (E300) it is possible to detect a sequence of (acceptable) failure mechanisms that may happen prior to the final (unacceptable) failure mechanism (often fibre failure). Let us assume that the local analysis predicts the presence of matrix cracking somewhere in the riser (and that matrix cracking is accepted), which in turn leads to reduced riser stiffness. This local reduction of stiffness may influence the overall behaviour of the riser system. Therefore, in certain cases it may be necessary to repeat the global analysis (with degraded material

properties where relevant). Then, the presence of additional failure mechanisms should be investigated through a new local analysis. This iterative procedure (between global analysis (with degraded material properties) and detailed local failure analysis) should be performed until no new failure mechanism is observed (acceptable design) or until a crucial failure mechanism is predicted (unacceptable design).

Guidance note:

The change of axial stiffness due to local degradation mechanisms is usually small and does not influence the global loads on the riser system. In such cases, the global (static and dynamic) analysis does not need to be repeated although the local analysis demonstrates that (acceptable) failure mechanisms occur.

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C 300 Global Procedure with Global Failure Criteria

- 301** As an alternative to the global – local procedure presented in *C200*, a procedure may be used that requires extensive local analysis to be conducted prior to the global failure analysis. The local analysis is used to establish global failure criteria that can be used in subsequent global analysis.
- 302** A riser system is a relatively simple structure on a global scale. Usually, the riser pipes contain a large number of identical pieces of composite pipes that are all connected with the same type of connectors or joints. In other applications continuous riser pipes, with constant properties along the pipe, may be used. In all these situations, the following procedure for evaluation of failure may be advantageous.
- 303** Prior to the global analysis of the riser system, global limit states (on the form $g_{\max} = 1$) are established by performing local failure analysis (of the pipes as well as the connectors/joints) for a large number of combinations of global load effects (bending moments, effective tension and internal or external overpressure). The global limit states are represented as surfaces in a space/coordinate system with bending moments, effective tension and internal/external overpressure along the axes. The surfaces are obtained by interpolating a collection of points (load cases) from the local analysis that satisfies $g_{\max} = 1$. Such global limit states may be established for several kinds of (local) failure mechanisms.
- 304** After these initial local investigations, the rest of the riser analysis may be performed on a global level.
- 305** If the initial local investigations are conducted by progressive failure analysis (E300) global limit states may be established for a wide range of (local) failure mechanisms. In this way, an iterative procedure may be adopted. In the first step (after having established the limit states) global analysis is performed with initial (non-degraded) stiffness properties. Let us assume that a limit state (corresponding to a non-crucial failure mechanism) is exceeded in certain global elements. Then the stiffness properties in those elements should be reduced (according to the observed local failure mechanism) and the global analysis should be repeated. This iteration should continue until no new limit state is exceeded (acceptable design) or until a crucial limit state is exceeded (unacceptable design).

Guidance note:

The change of axial stiffness due to local degradation mechanisms is usually small and does not influence the global loads on the riser system. In such cases, the global (static and dynamic) analysis does not need to be repeated although the local analysis demonstrates that (acceptable) failure mechanisms occur.

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Guidance note:

Example of a global failure criterion

The global failure criterion should be established for a small section of the riser that repeats itself along the length of the string. Typically such a section could be a riser joint of about 15m length consisting of a pipe section with two end fittings. A joint could also be modeled by establishing two separate global failure criteria, one for the pipe section and one for the joint. For a long continuous riser a global failure criterion would typically only be established for the pipe section. The two joints would be investigated individually.

Typically a section is analysed for the following loads:

- Pressure P
- Axial Load A
- Moment M
- Torsion T

The loads and a riser section are shown schematically in Figure 4-1.

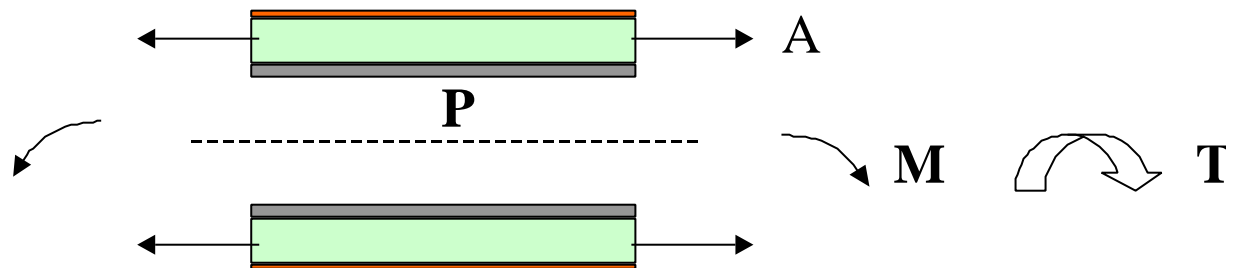


Figure 4-1: General loading conditions for a riser pipe

The axial load can be defined as effective axial load, i.e., the axial load without the axial end cap load caused by the pressure, or it can be defined as the absolute axial load. Which choice is made is a matter of convenience, but it is important to use a consistent approach. Torsion can often be neglected for metal risers. However, even small torsional loads may cause damage in a composite riser, depending on the particular layup and joint geometry.

The selected section of the riser should now be analyzed for all possible combinations of P, A, M and T.

For each combination a stress analysis of the section is carried out and all relevant failure criteria are checked at all places of the section. The relevant failure criteria are at least fibre failure and buckling, but other criteria

like matrix cracking may have to be considered. Which criteria should be considered is described in Section 5.

Once all combinations of P, A, M and T have been analyzed a four dimensional failure envelope can be defined for that section of the riser.

To make the example more specific, just a riser pipe section is described in the following part. The same type of arguments can also be used for joints or a combined pipe-joint analysis. The laminate of the pipe has a 0/90 orientation with the same number of fibres running in the hoop direction as in the axial direction.

A typical failure envelope for such a laminate is shown in Figure 4-2.

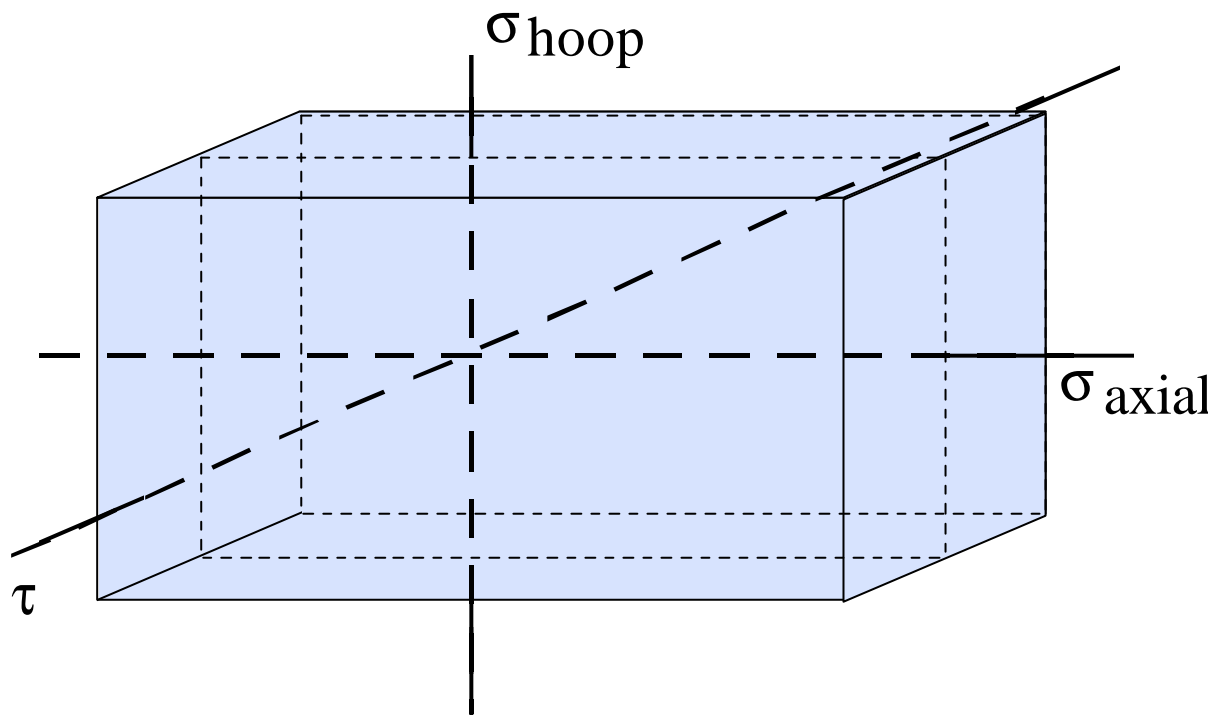


Figure 4-2: Simple schematic of a failure envelope of a 0/90 laminate.

If the pipe is put under internal pressure, the fibres in the hoop direction see twice as much stress as the fibres in the axial direction (since we have the same number of fibres running in both directions). The burst pressure will be related to the maximum stress the fibres can take in the hoop direction, provided the laminate is thin and we have the same stress in the hoop fibres through the thickness (a condition that is often NOT fulfilled for composite risers). The calculation gives point P1 in the global failure envelope on the pressure axis. This is shown in Figure 4-3 for a two dimensional P vs. A failure criterion.

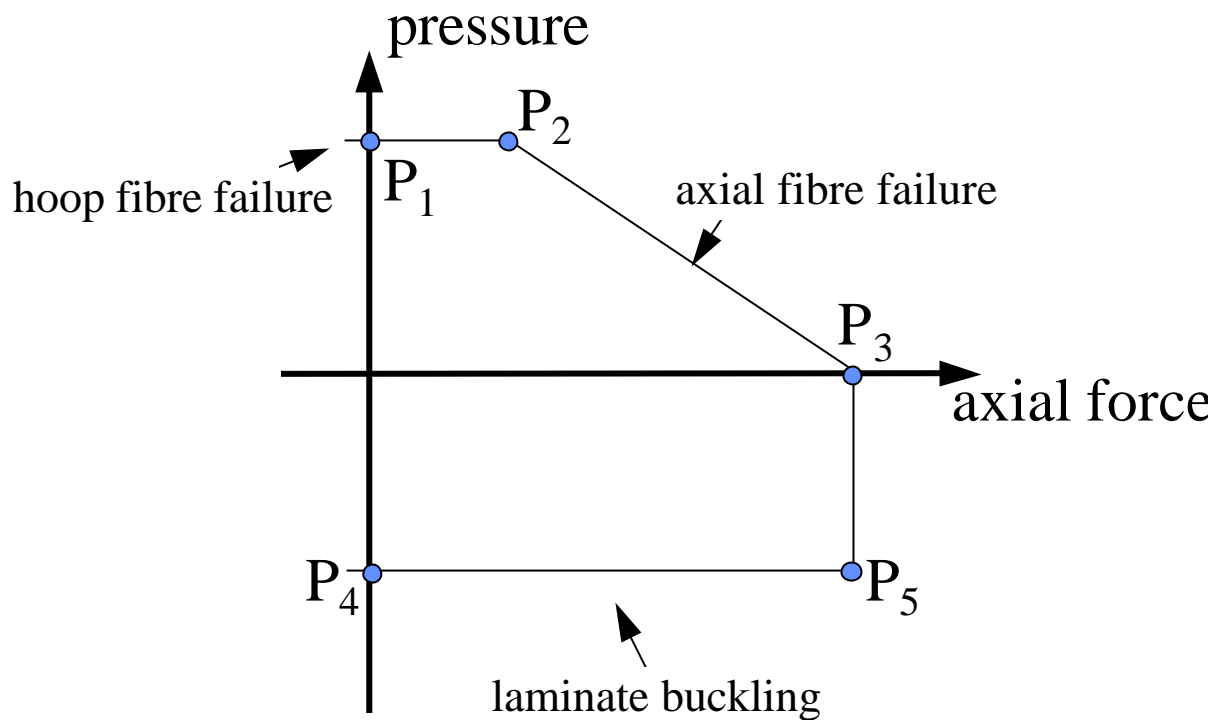


Figure 4-3: Global failure envelope for pressure and axial force.

If the riser is exposed to additional effective axial loads the stresses in the axial fibres will increase. The strength of the axial fibres has to be large enough to carry the applied axial load plus the end cap load from the pressure. This gives points P2 and P3 in the global failure criterion. P2 describes the maximum axial load under maximum pressure. P3 the maximum axial load without internal pressure. Ignoring Poisson's effects and interactions between the fibres, the failure envelope is given by lines between P1, P2 and P3.

Under external pressure, collapse is defined by a buckling criterion. The collapse pressure is shown as P4. If we assume that the collapse pressure is not effected by an axial load, P5 indicates the maximum external pressure and maximum axial load combination.

Many risers are not exposed to compressive axial loads and the failure envelope is not expanded into that direction in this example.

If the riser sees torsion, the fibres of the 0/90 laminate will not be stressed. Torsional load must be carried by the matrix. The torsional load is then proportional to the in-plane shear strength of the matrix. Figure 4-4 shows this in the global P-A-T failure envelope.

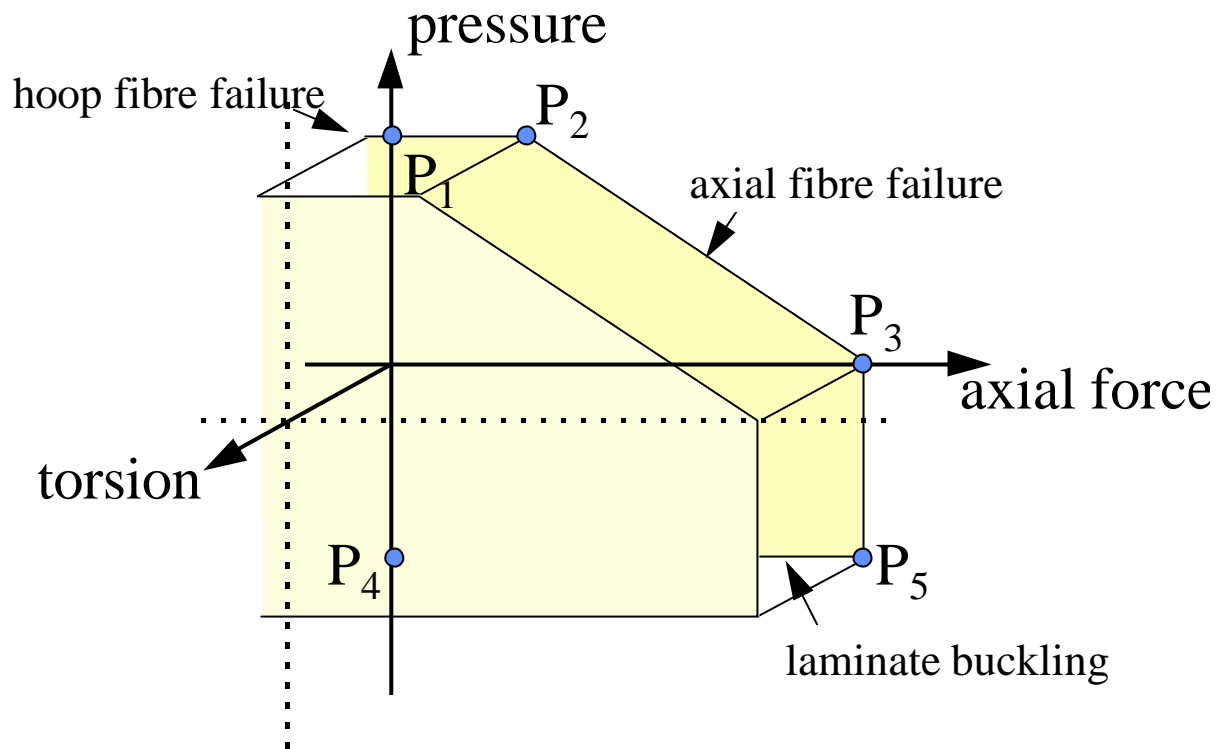


Figure 4-4: Global failure envelope for pressure, axial force and torsion

The effect of a moment can be added in a similar way. Note that the moment puts the highest stresses into the upper fibres and possibly compressive stresses into the lower fibres. In addition, in plane shear stresses are highest in the middle. These shear stresses may cause unacceptable matrix shear failure.

In reality, the failure envelopes tend to be more complicated, because fibre orientations are more complicated, three dimension stresses should be considered, and in particular the composite metal interface may behave totally differently from the simple pipe. The intention of this example was just to show the principle of the development of a global failure envelope.

End of guidance note

C 400 Fatigue and Long term Analysis for Composite Risers

- 401 The effect of cyclic loads and permanent static loads should be evaluated for composite risers.
- 402 The presence of creep, stress relaxation and stress rupture-stress relaxation in composite structures depends on the level of stresses and/or strains and the condition of the constituent materials (intact, presence of cracks or other failures). Permanent static load effects should be analysed as described in 3 K 100.
- 403 Development of fatigue failure depends on the strain amplitudes and mean levels during each cycle, as

well as the total number of cycles. Loads should be analysed as described in *3K200*.

- 404** The effect of long term loads and environments on the material properties should be considered in the analysis.

D. Local Analysis

D 100 General

- 101** In the following two local analysis methods are outlined. More details about the methods and other applicable procedures may be found in the *DNV Offshore standard OS-C-501 Composite Components*.
- 102** High pressure risers have generally thick shells and a 3D analysis is required. The region at and near the joints also requires a 3D analysis. If a 2D analysis is used it shall be shown that through thickness stresses can be neglected.

D 200 Input Data

- 201** The boundary conditions should be selected carefully in order to represent the nature of the problem in the best possible way. It should be demonstrated that the chosen boundary conditions lead to a realistic or conservative analysis of the structure.
- 202** Thermal stresses that result from production process or in service loading should be considered in all analysis.
- 203** Stresses due to swelling from absorbed fluids should be included if relevant.
- 204** The elastic properties of the materials constituting the structure should be taken as described in *DNV-OS-501 Section 4*. In particular, time-dependent stiffness properties based on the expected degradation due to environmental and loading conditions should be considered. Local variations of these conditions should also be considered.

- 205** Laminates should be analysed on the ply level. Each ply should be described by 4 elastic constants (E_1 , E_2 , G_{12} , ν_{12}) for in-plane 2-D analysis and by 9 elastic constants (E_1 , E_2 , G_{12} , ν_{12} , E_3 , G_{13} , G_{23} , ν_{13} , ν_{23}) in 3-D analysis. A nomenclature for the various elastic constants is defined in *Section 1*.
- 206** As an alternative to elastic constants, the stiffness matrix for orthotropic plies may be used.
- 207** It should be shown that the estimated stiffness gives conservative results with respect to load effects. The choice of stiffness values may be different in the cases of strength and stiffness limited design. More details are given in the sections below.
- 208** If fibres are not oriented in the principle stress directions they want to rotate into these directions. This rotation is usually prevented by the matrix. If the matrix cracks or yields, the fibres may be free to rotate slightly. This rotation is usually not modelled. However one should check that ply stresses transverse to the fibres and ply shear stresses are low in a ply with degraded matrix. Otherwise a reanalysis with rotated fibre directions may be required.

Guidance note:

The rotation of fibres may, for example, be important in filament wound pipe designed for carrying just internal pressure. In this case the fibre orientation is typically about $\pm 55^\circ$. If the pipe experiences a strong axial load in addition to pressure, the fibres want to orient themselves more into the axial direction.

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D 300 Analysis Types

- 301** Analytical and/or numerical calculations may be used in the structural analysis. The finite element (FE) method is presently the most commonly used numerical method for structural analysis, but other methods, such as finite difference or finite series methods may also be applied.

Guidance note:

While the FE method is applicable for a wide range of problems, analytical solutions and the finite series approach often put too many restrictions on laminate lay-up, geometry etc., and are thus insufficient in the design of most real world composite structures.

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- 302** Laminate analysis is an additional type of analysis that is applied to layered composites in order to derive the properties of a laminate from the properties of its constituent plies.
- 303** The structural analysis should be performed for all phases over the entire lifetime of the structure. Initial and degraded material properties should be considered if relevant.

D 400 Local Linear Analysis with Degraded Properties

- 401** In many riser applications (for example risers with liners) several failure mechanisms (e.g. matrix cracking) may be accepted, while fibre failure is the mechanism of interest. The local analysis of such

risers may be performed by this linear procedure with degraded properties. In certain applications presence of matrix cracking in the riser pipe may be acceptable (e.g. for risers with a liner). Assume that fibre failure is the only failure mechanism of interest. Then the riser may be analysed with the assumption that matrix cracking has already occurred throughout the riser. This means that the riser may be modelled with reduced stiffness for all riser elements. In most cases this is a conservative (with respect to local and/or global load effects) simplification. However, in certain displacement controlled problems (for example if the displacement of the top of the riser is dictated by prescribed movement of the platform) the simplification may be non-conservative. This effect should be carefully investigated when relevant.

- 402** The method may be applied for both 2-D and 3-D problems.
- 403** Due to the assumption of matrix cracking in the component the material properties are degraded in the entire domain by setting certain elasticity parameters to zero (default value). That is, for in-plane 2-D analysis the stiffness in the fibre direction (of each “ply”) is kept unaltered, while the rest of the properties are assumed to be changed according to *DNV-OS-501 Section 4I*. If 3-D analysis is required, the in-plane parameters are dealt with as in the 2-D analysis, while all through thickness parameters are changed if through thickness stresses cause matrix cracking or nonlinear deformation of the matrix.
- 404** This method should be mainly used for statically determined problems, as is the case for a riser pipe. Otherwise this simplified method, with degradation of material properties in the entire domain, may offer considerably incorrect stress/strain distributions. If the error cannot be analysed and included into the model factor a more refined method shall be used.

D 500 Local Progressive Analysis

- 501** Local progressive analysis, which is presented herein, provides more accurate results than obtained by the simplified method presented in *D400*. Instead of degrading almost all parameters in the entire domain, this method is based on a step-wise degradation of a limited number of parameters in bounded regions.
- 502** All kinds of local failure mechanisms may be detected by the method.
- 503** The method may be applied for both 2-D and 3-D problems.
- 504** Initially, non-degraded ply properties shall be used in the progressive failure analysis.
- 505** The boundary conditions (load effects from the global analysis) for the component are imposed in a step-wise manner. In the first step a small portion, e.g. 10 percent, of the load is applied. Based on this load level, laminate and ply stresses and strains are calculated and analysed by the relevant failure criteria (for each ply). If a failure is detected somewhere in a ply, certain material properties of that ply

shall be locally degraded, which means that the parameters shall be reduced in locations (e.g. finite elements) where the failure is detected. Then, the local analysis shall be repeated with locally degraded parameters for the same load level. If no failure is observed, the load is increased to, e.g., 0.2 times load and a similar failure analysis is performed.

- 506** When the analysis finds that the matrix is cracked, the properties should be changed according to *DNV-OS-501 Section 4I*.
- 507** The step-wise increase in loads as indicated in *505* continuous until a critical failure mechanism is observed (unacceptable design) or until the entire load is applied and no critical failure mechanism detected (acceptable design).

E. Analytical Methods

E 100 General

- 101** Analytical methods can be divided into two classes: Analytical solutions of (differential) equations or use of handbook formulae.

E 200 Assumptions and Limitations

- 201** Analytical methods shall not be used outside their assumptions and limitations.

Guidance note:

The main disadvantage of available analytical solutions is that simplifications often put too many restrictions on geometry, laminate build-up etc. and hence, are insufficient in the design of more complex composite structures.

Handbook formulae are usually too simple to cover all the design issues and are also in general not sufficient.

Simplified isotropic calculation methods should not be used, unless it can be demonstrated that these methods give valid results.

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E 300 Link to Numerical Methods

- 301** Analytical solutions or handbook formulae used within their assumptions and limitations may be used to validate finite element analysis results.

F. Finite Element Analysis

F 100 General

101 Only recognised FE programs should be used. Other programs shall be verified by comparison with analytical solutions of relevant problems, recognised FE codes and/or experimental testing.

F 200 Modelling of Structures – General

201 Element types shall be chosen on the basis of the physics of the problem

202 The choice of the mesh should be based on a systematic iterative process, which includes mesh refinements in areas with large stress/strain gradients.

203 Problems of moderate or large complexity shall be analysed in a stepwise way, starting with a simplified model.

204 Model behaviour shall be checked against behaviour of the structure. The following modelling aspects shall be treated carefully:

- loads,
- boundary conditions,
- important and unimportant actions,
- static, quasi-static or dynamic problem,
- damping,
- possibility of buckling,
- isotropic or anisotropic material,
- temperature or strain rate dependent material properties,
- plastic flow,
- nonlinearities (due to geometrical and material properties),
- membrane effects.

205 Stresses and strains may be evaluated in nodal points or Gauss points. Gauss point evaluation is generally most accurate, in particular for layered composites, in which the distribution of stresses is discontinuous, and should therefore be applied when possible.

Guidance note:

The analyst shall beware that Gauss point results are calculated in local (element or ply based) coordinates and must be transformed (which is automatically performed in most FE codes) in order to represent global results. Thus, Gauss point evaluation is more time-consuming than nodal point calculations.

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206 Support conditions shall be treated with care. Apparently minor changes in support can substantially affect results. In FE models, supports are typically idealised as completely rigid, or as ideally hinged, whereas actual supports often lie somewhere in between. In-plane restraints shall also be carefully treated.

207 Joints shall be modelled carefully. Joints may have less stiffness than inherited in a simple model, which may lead to incorrect predictions of global model stiffness. Individual modelling of joints is usually not appropriate unless the joint itself is the object of the study. See also requirements for the analysis of joints in *DNV-OS-501 Section 4*.

208 Element shapes shall be kept compact and regular to perform optimally. Different element types have different sensitivities to shape distortion. Element compatibility shall be kept satisfactory to avoid locally poor results, such as artificial discontinuities. Mesh should be graded rather than piecewise uniform, thereby avoiding great discrepancy in size between adjacent elements.

209 Models shall be checked (ideally independently) before results are computed.

210 The following points shall be satisfied in order to avoid ill-conditioning, locking and instability:

- a stiff element shall not be supported by a flexible element, but rigid-body constraints shall be imposed on the stiff element,
- for plane strain and solid problems, the analyst shall not let the Poisson's ratio approach 0.5, unless a special formulation is used,
- 3-D elements, Mindlin plate or shell elements shall not be allowed to be extremely thin,
- the analyst shall not use reduced integration rule without being aware of possible mechanism (e.g. hourglass modes).

Guidance note:

Some of these difficulties can be detected by error tests in the coding, such as a test for the condition number of the structure stiffness matrix or a test for diagonal decay during equation solving. Such tests are usually *a posteriori* rather than *a priori*.

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211 Need for mesh refinement is usually indicated by visual inspection of stress discontinuities in the stress bands. Analogous numerical indices are also coded.

212 For local analysis, a local mesh refinement shall be used. In such an analysis, the original mesh is stiffer

than the refined mesh. When the portion of the mesh that contains the refined mesh is analysed separately, a correction shall be made so the boundary displacements to be imposed on the local mesh are consistent with the mesh refinement.

- 213** For nonlinear problems, the following special considerations shall be taken into account:
- the analyst shall make several trial runs in order to discover and remove any mistake,
 - solution strategy shall be guided by what is learned from the previous attempts,
 - the analyst shall start with a simple model, possibly the linear form of the problem, and then add the nonlinearities one by one,
- 214** Computed results shall be checked for self-consistency and compared with, for example, approximate analytical results, experimental data, text-book and handbook cases, preceding numerical analysis of similar problems and results predicted for the same problem by another program. If disagreements appear, then the reason for the discrepancy shall be sought, and the amount of disagreement adequately clarified.
- 215** The analyst shall beware the following aspects:
- for vibrations, buckling or nonlinear analysis, symmetric geometry and loads shall be used with care since in such problems symmetric response is not guaranteed. Unless symmetry is known to prevail, it shall not be imposed by choice of boundary conditions,
 - for crack analysis, a quarter point element can be too large or too small, thereby possibly making results from mesh refinement worse,
 - the wrong choice of elements may display a dependence on Poisson's ratio in problems that shall be independent of Poisson's ratio,
 - if plane elements are warped, so that the nodes of the elements are not co-planar, results may be erratic and very sensitive to changes in mesh,
 - imperfections of load, geometry, supports and mesh may be far more important in a buckling problem than in problems involving only linear response.
- 216** In the context of finite element analysis (FEA) of laminate structures (one of) the following element types should be applied:
- layered shell elements with orthotropic material properties for each layer (for in-plane 2-D analysis,
 - solid elements with orthotropic material properties (for 3-D and through thickness 2-D analysis.
- The decision to use 2-D or 3-D analysis methods should be made depending on the level of significance of through thickness stresses and gradients of inplane stresses through the thickness. A 3-D analysis is usually required for risers with thick walls.

Guidance note:

There are two options for the solid elements: The modelling may be performed with (at least) two solid elements through the thickness of each ply. Alternatively, one may apply layered solid elements where the thickness of a single element includes two or more plies.

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F 300 Software Requirements

301 Selection of finite element software package shall be based on the followings:

- software availability,
- availability of qualified personnel having experience with the software and type of analysis to be carried out,
- necessary model size,
- analysis options required,
- validated software for intended analysis.

302 Useful options for the analysis of composite structures include:

- layered solid elements with orthotropic and anisotropic material behaviour,
- layered shell elements,
- solid elements with correct material models or appropriate interface elements allowing for debond (for analysis of bonded and laminated joints),
- interface elements allowing for large aspect ratio (for analysis of thin layer bonds),
- the possibility to select different co-ordinate systems in a clear and unambiguous way.

303 Depending on the area of application, additional analysis options should be available, such as:

- appropriate solver with stable and reliable analysis procedures,
- options characterising large displacements and large strains (for geometrically nonlinear analysis),
- material models describing the behaviour of, e.g., laminates beyond first failure (for materially nonlinear analysis),
- robust incremental procedures (for nonlinear analysis in general),
- tools for frequency domain analysis and/or options such as time integration procedures (for dynamic analyses),
- appropriate post-processing functionality,
- database options,
- sub-structuring or sub-modelling.

F 400 Execution of Analysis

401 FEA tasks **shall** be carried out by qualified engineers under the supervision of an experienced senior engineer.

402 Analysis shall be performed according to a plan, which has been defined prior to the analysis.

403 Extreme care shall be taken when working with different relevant co-ordinate systems, i.e. global, ply based, laminate based, element based and stiffener based systems.

404 The approach shall be documented.

F 500 Evaluation of Results

501 Analysis results shall be presented in a clear and concise way using appropriate post-processing options. The use of graphics is highly recommended, i.e. contour plots, (amplified) displacement plots, time histories, stress and strain distributions etc.

502 The results shall be documented in a way to help the designer in assessing the adequacy of the structure, identifying weaknesses and ways of correcting them and, where desired, optimising the structure.

F 600 Validation and Verification

601 FE programs shall be validated against analytical solutions, test results, or shall be benchmarked against a number of finite element programs.

602 Analysis designer shall check whether the envisaged combination of options has been validated by suppliers. If this is not the case, he shall perform the necessary validation analysis himself.

- 603** FEA results shall be verified by comparing against relevant analytical results, experimental data and/or results from previous similar analysis.
- 604** Analysis and model assumptions shall be verified.
- 605** Results shall be checked against the objectives of the analysis.
- 606** Verification whether the many different relevant co-ordinate systems have been applied correctly shall be considered.

G. Dynamic Response Analysis

G 100 General

- 101** Dynamic analysis should generally be performed when loads are time-dependent and/or when other effects such as inertia (and added mass) and damping forces are significant.
- 102** In a dynamic analysis one may be interested in the transient response of a structure due to prescribed, time-dependent loads or the eigenvalues (eigenfrequencies) of the structure.
- 103** In order to obtain an accurate transient analysis a detailed structural model and small time steps should be used, in particular for rapid varying loads.
- 104** For slowly varying loads (relative to the natural period of the riser) a quasi-static analysis may be applied. In such an analysis inertia and damping forces are neglected, and the corresponding static problem is solved for a series of time steps.
- 105** In vibration analysis one may use a coarse structural model if only the first few eigenvalues are of interest, see 202. Nevertheless, a reasonable representation of structural mass and stiffness is crucial.
- 106** If a large number of eigenfrequencies are required, one shall apply a detailed description of the structure.
- 107** Due account should be taken of fluid-structure interaction effects where these are significant. These may include vortex induced vibrations (VIV), resonance between structural response and wave excitation frequencies, or more complex, high-frequency vibration phenomena (ringing and springing of the riser or the system the riser is connected to) caused by non-linear wave loads. In some cases of fluid-structure interaction it may be necessary to perform a dynamic analysis of the coupled fluid-structure system.
- 108** In case of accidental loads, such as explosions, dynamic effects should be considered carefully.
- 109** The dependence of the material properties on strain rate should be taken into account, see *DNV-OS-501 Section 4 C1000*.

Guidance note:

Although static material properties may yield conservative predictions of displacements, a strength assessment based on static properties is not necessarily conservative since both the material strength and the material stiffness may be enhanced at high strain rates. The higher stiffness may increase the induced stress so that the benefit of the increase in the material strength may be lost. Furthermore, ductile materials often become brittle at high rates. Thus, the extra margin provided by ductile behaviour may be destroyed.

There is a lack of sophisticated material models taking the rate dependent behaviour into consideration.

---e-n-d--- o-f---G-u-i-d-a-n-c-e---n-o-t-e---

G 200 Dynamics and Finite Element Analysis

- 101** For analysis including dynamic loads with frequencies of interest up to ω_{cr} , the mesh shall be able to accurately represent modes associated with frequencies up to $3\omega_{cr}$, and a mode superposition analysis shall include frequencies up to about $3\omega_{cr}$.
- 202** For eigenvalue analysis, there should be 4 or more times as many degrees of freedom as eigenvalues to be calculated.
- 203** For direct integration methods, the following points should be ensured:
- the time step Δt should be approximately $0.3/\omega_{cr}$ or less, and should provide numerical stability if the integration method is conditionally stable,
 - there should be a match between the type of algorithm and the mass matrix,
 - abrupt changes in element size should be avoided, thereby avoiding spurious wave reflection and numerical noise.

H. Impact Response

- 101** Impact should be evaluated by testing as described in *Section 5 F 300*.

I. Thermal Stresses

- 101** Changes in temperature from the environment resulting in dimensional changes of the body shall be taken in account. The general thermal strains, e_i , can be expressed as

$$e_i = \mathbf{a}_i \Delta T,$$

where \mathbf{a}_i is the thermal expansion coefficients. Temperature is denoted by T .

- 102** Residual strains shall be calculated against the reference temperature for which \mathbf{a}_i was determined. It is usually the curing temperature
- 103** Accordingly, the stress-strain relations shall be modified to account for the stress free environmentally induced expansional strains as follows:

$$\{\mathbf{e}\} = [S]\{\mathbf{s}\} + \{e\}$$

J. Swelling Effects

- 101** Changes in gas/fluid absorption from the environment resulting in dimensional changes of the body shall be taken in account. The general swelling strains, e_i , can be expressed as

$$e_i = \mathbf{b}_i C,$$

where \mathbf{b}_i is the swelling expansion coefficients and C is swelling agent concentration inside the laminate.

- 102** Accordingly, the stress-strain relations shall be modified to account for the stress free environmentally induced expansional strains as follows:

$$\{\mathbf{e}\} = [S]\{\mathbf{s}\} + \{e\}$$

K. Buckling

K 100 General

- 101** The need for special buckling analysis shall be assessed carefully in every case. In particular the following aspects shall be considered in making this assessment:
- Presence of axial compressive stresses in the riser pipe
 - Presence of circumferential compressive or shear stresses in the riser pipe
 - Presence of all compressive stresses in the joint area.
- 102** All parts of the riser, like pipe, liners and fittings should be evaluated for buckling.
- 103** Two alternative approaches may be used in analysing buckling problems:
- Analysis of isolated components of standard type, such as tubular sections, beams, plates and shells of simple shape.
 - Analysis of an entire structure (or of an entire, complex structural component)

K 200 Buckling analysis of isolated components

- 201** When a member or component that is a part of a larger structure is analysed separately a global analysis

of the structure shall be first applied to establish

- the effective loading applied to the member/component by the adjoining structural parts;
- the boundary conditions for the structural member, in terms of translational and rotational stiffness components in all relevant directions.

202 For simple members or components standard formulae or tables may be used to estimate elastic critical loads (P_e), critical stresses (s_e) or critical strains (e_e), and the corresponding elastic buckling mode shapes. Alternatively these quantities may be calculated using analytical or numerical methods. It shall always be checked that the buckling mode shape is consistent with the boundary conditions.

203 An assessment shall be made of the shape and size of initial, geometrical imperfections that may influence the buckling behaviour of the member. Normally the most critical imperfection shape for a given buckling mode has a similar form to the buckling mode itself. However, any geometrical feature (including eccentricity of loading) that results in compressive forces that are not coincident with the neutral axis of the member may require consideration. The assumed form and amplitude of the imperfection shall be decided on the basis of the production process used with due consideration of the relevant production tolerances. Refer to *DNV-OS-C501 Section 6H*.

204 In some cases a geometrically non-linear analysis may be avoided as follows. The elastic critical load (without imperfections) P_e is calculated. In addition an ultimate failure load P_f is estimated at which the entire cross-section would fail by compressive fibre failure, in the absence of bending stresses at the section in question. If $P_e > P_f$ the further assessment may be based on geometrically linear analysis provided geometrical imperfections are included and the partial load effect modelling factor is increased by multiplying it by the factor

$$\frac{1}{1 - P_f/4P_e}$$

205 In cases where it is possible to establish the bending responses (stresses, strains or displacements) associated with an in-plane loading separately from the in-plane (axial) responses, a first estimate of the influence of geometrical non-linearity combined with the imperfection may be obtained by multiplying the relevant bending response parameter obtained from a geometrically linear analysis by a factor

$$\frac{1}{1 - P/P_e}, \quad \frac{1}{1 - s/s_e} \quad \text{or} \quad \frac{1}{1 - e/e_e}$$

and combining the modified bending responses with the (unmodified) in-plane responses.

206 The above procedures (205 and 204) may be non-conservative for some cases where the post-buckling behaviour is unstable. Examples include cylindrical shells and cylindrical panels under axial loading. Such cases shall be subject to special analysis and/or tests.

K 300 Buckling analysis of more complex elements or entire structures

301 Buckling analysis of more complex elements or entire structures shall be carried out with the aid of verified finite element software or equivalent.

302 Initially an eigenvalue buckling analysis shall be performed assuming initial (non-degraded) elastic properties for the laminates. This shall be repeated with alternative, finer meshes, until the lowest eigenvalues and corresponding eigenmodes are not significantly affected by further refinement. The main purposes of this analysis are to clarify the relevant buckling mode shapes and to establish the required mesh density for subsequent analysis.

303 Careful attention shall be paid to correct modelling of boundary conditions.

304 If the applied load exceeds, or is close to, the calculated elastic critical load, the design should be modified to improve the buckling strength before proceeding further.

305 A step-by-step analysis shall be carried out. Geometrical non-linearity shall be included in the model. The failure criteria shall be checked at each step. If failure such as matrix cracking or delamination is predicted, any analysis for higher loads shall be performed with properties reduced as described in *DNV-OS-C501 Section 4 I*.

306 Alternatively to the requirement in 305 a geometrically non-linear analysis may be performed using entirely degraded properties throughout the structure. This will normally provide conservative estimates of stresses and deformations. Provided reinforcing fibres are present in sufficient directions, so that the largest range of unreinforced directions does not exceed 60°, such an estimate will not normally be excessively conservative.

307 The influence of geometric imperfections should be assessed, on the basis of the production method and production tolerances. Refer to *DNV-OS-C501 Section 6H*.

L. Partial Load-Model Factor

L 100 General

101 A deterministic factor shall be assigned to each structural analysis method. It is designated in this RP as the partial load-model factor γ_{sd} .

102 The load-model factor accounts for uncertainties of the structural analysis method being used to accurately describe and quantify the response of the structure.

103 Model factors for the main structural analysis methods are given in the following sub-sections.

104 In some cases a structure is only evaluated by testing, and such an approach evaluates only the particular conditions tested. A procedure for this approach is given in *DNV-OS-C501 Section 10*.

L 200 Connection between Partial Load-Model Factor and Analytical Analysis

201 When analytical methods are used within their assumptions and limitations a model factor of 1.0 should be used.

202 If analytical methods are used outside their assumptions and limitations, it shall be documented that the magnitude of the model factor ensures that all predicted stresses and strains are higher than in reality. If the choice of model factor cannot be documented, the analytical method shall not be used.

L 300 Connection between Partial Load-Model Factor and Finite Element Analysis

301 The accuracy of FE methods is generally very good when the structure is properly modelled. The use of these methods with unsatisfactory models is much more uncertain.

302 When FE methods are used within their assumptions and limitations (and according to *Section F*) a model factor of 1.0 may be used.

303 If FE methods are used outside their assumptions and limitations, it shall be documented that the magnitude of the model factor ensures that all predicted stresses and strains are higher than in reality. If the model factor cannot be documented, the analysis method shall not be used.

304 If the boundary conditions do not exactly represent the real conditions the effect on the load model factor shall be evaluated. As a minimum a factor of 1.1 shall be used.

305 If the load-model factor cannot be determined for calculations in a critical region, e.g. a critical joint or region of stress concentrations, experimental qualification should be done (see *DNV-OS-C501 Section 10*).

L 400 Connection between Partial Load-Model Factor and Dynamic Response Analysis

401 The accuracy of the dynamic analysis shall be estimated. The load-model factor used, which is described in *Sections L200 and L300*, should include all uncertainties due to dynamic effects.

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A. GENERAL

A 100 Objective

101 The section provides the general framework for design of riser systems including provisions for checking of limit states for pipes in riser systems. Design of connectors and riser components are covered in Section 6.

A 200 Application

201 This standard provides design checks with emphasis on ULS, FLS, SLS and ALS load controlled conditions. Design principles for displacement controlled conditions are discussed in *D900*.

202 Requirements for materials, manufacture, fabrication and documentation of riser pipe, components, equipment and structural items in the riser system are given in DNV-OS-501 Section 4.

A 300 Pressure testing

301 All risers of safety class normal or high shall be pressure tested before going into service.

302 A test pressure in compliance with DNV-OS-F101 should be used unless such a pressure would introduce damage to the component that may reduce its lifetime. The maximum service pressure shall be the minimum test pressure.

303 If the riser contains non-composite parts that were designed according to a standard that requires a pressure test up to a certain test pressure p , the pressure test shall be carried out at that pressure p or the pressure required by 302, whatever is highest.

304 A detailed test programme should be defined. The following should be stated as a minimum:

- rates of pressure increase,
- holding times,
- time over which the pressure in the system shall not drop without actively applying pressure, i.e. a leakage test.

305 The test schedule should be developed for each application. The testing should allow detecting as many possible defects in the structure as possible. As a general guidance the following schedules are recommended:

- The minimum time over which the maximum test pressure in the system should not drop without actively applying pressure should be at least 10 minutes for systems that do not creep. The pressure should stay constant within 5% of the value at the start of the test.
- For systems that show creep the maximum test pressure should be kept for 1 hour applying active

pressure. The pressure should be monitored for another hour without actively applying pressure. The pressure drop should be predicted before the test and the test result should be within 10% of the prediction.

- 306** Risers of low safety class should be tested up to their service pressure. Pressures should be applied for at least 10 minutes.
- 307** Most authorities give general test requirements for pressure vessels, these may also apply to pressurised risers. The requirements of the authorities that govern the location of the application should be followed.

A 400 Limit States

401 The limit states are grouped into the following four categories:

- *Serviceability Limit State* (SLS) requires that the riser must be able to remain in service and operate properly. This limit state corresponds to criteria limiting or governing the normal operation (functional use) of the riser;
- *Ultimate Limit State* (ULS) requires that the riser must remain intact and avoid rupture, but not necessary be able to operate. For operating condition this limit state corresponds to the maximum resistance to applied loads with 10^{-2} annual exceedence probability;
- *Accidental Limit State* (ALS) is a ULS due to accidental loads (i.e. infrequent loads)
- *Fatigue Limit State* (FLS) is an ultimate limit state from accumulated excessive fatigue crack growth or damage under cyclic loading.

402 As a minimum requirement, the riser pipes and connectors shall be designed for (not limited to) the potential modes of failures as listed in Table 5-1 for all relevant conditions expected during the various phases of its life.

Table 5-1: Typical limit states for the riser system		
<i>Limit State Category</i>	<i>Limit State/Failure Mode</i>	<i>Failure definition/ Comments</i>
SLS	Clearance	No contact between e.g. riser-riser, riser-mooring line, riser-hull, surface tree- floater deck, subsea tree-seabed, surface jumper- floater deck.
	Excessive angular response	Large angular deflections that are beyond the specified operational limits, e.g. inclination of flex joint or ball joint.
	Excessive top displacement	Large relative top displacements between riser and floater that are beyond the specified operational limits for top tensioned risers, e.g. stroke of telescope joint, slick joint and tensioner, coiled tubing, surface equipment and drill floor. Note that systems can be designed for exceeding displacement limits if the structural integrity is maintained.
	Mechanical function	Mechanical function of a connector during make-up/break-out.
ULS	Bursting	Membrane rupture of the pipe wall caused by internal overpressure, possibly in combination with axial tension or bending moments
	Liquid tightness	Leakage in the riser system including pipe and components, caused by internal overpressure, possibly in combination with axial tension or bending moments
	Buckling	Buckling of the pipe cross section and/or local buckling of the pipe wall due to the combined effect of external overpressure, effective tension and bending moment.
	Propagating buckling	Propagating hoop buckling initiated by hoop buckling.
	Damage due to wear and tear	Damage to the inside or possibly to the outside of the pipe during operation or installation, resulting into burst or leakage.
	Explosive decompression	Rapid expansion of fluid inside a material or interface leading to damage that may cause leakage or burst.
	Chemical decomposition Corrosion	Chemical decomposition or corrosion of materials with time that leads to a reduction and strength, resulting into burst or leakage.
ALS	Same as ULS and SLS	Failure caused by accidental loads directly, or by normal loads after accidental events (damage conditions).
	Impact	Damage introduced by dropped objects, like drill bits etc.
	Fire	Resistance to fire, if parts are above water
FLS	Fatigue failure	Excessive Miner fatigue damage or fatigue crack growth mainly due to environmental cyclic loading, directly or indirectly.

B. Load Effects

B 100 Design Load Effects

101 Design load effects are obtained by multiplying the load effect of each category by their corresponding load effect factor.

102 A load model factor shall be determined to account for systematic errors in calculating local load effects from global loads or events as described in *Section 4L*.

B 200 Load Effect Factors

201 The design load effect is used in the design checks. Several combinations may have to be checked when load effects from several load categories enter one design check. The load effect factors shown in Table 5-2 shall be used wherever the design load effect is referred to for all limit states and safety class.

Table 5-2 Load effect factors			
<i>Limit state</i>	<i>F-load effect</i>	<i>E-load effect</i>	<i>A-load effect</i>
	γ_F ¹⁾	γ_E ²⁾	γ_A
ULS	1.1	1.3	NA
FLS	1.0	1.0	NA
SLS & ALS	1.0	1.0	1.0
NOTES			
1) If the functional load effect reduces the combined load effects, g_F shall be taken as 1/1.1.			
2) If the environmental load effect reduces the combined load effects, g_E shall be taken as 1/1.3.			

B 300 Load model factors

101 Load model factors γ_{sd} account for inaccuracies, idealisations, and biases in the engineering model used for representation of the real response of the structure. Effects of geometric tolerances shall also be included in the load model factor. The factor is treated here as a deterministic parameter.

302 Details about the load model factor are given in *Section 4L*.

C. Resistance

C 100 Resistance Factors

101 The following resistance factors apply:

- material resistance factor γ_m to account for material and resistance uncertainties.
- a resistance model factor to account for possible inaccuracies in the failure criteria used
- a system factor

102 The resistance factors applicable to ultimate limit states (ULS) are specified in Tables 5-3 to 5-4. The factors are linked to the safety class to account for the consequence of failure. Failure types are described in *Section 2C200* and specified in *Section DNV-OS-C501 Section 6A200* for all failure criteria.

Table 5-3: Brittle failure type			
Safety Class	COV of the strength		
	COV < 10 %	10 %-12.5 %	12.5 %-15 %
Low	1.22	1.33	1.49
Normal	1.34	1.53	1.83
High	1.47	1.75	2.29

Table 5-4: Plastic/ Ductile failure type			
Safety Class	COV of the strength		
	COV < 10 %	10 %-12.5 %	12.5 %-15 %
Low	1.11	1.16	1.23
Normal	1.22	1.33	1.49
High	1.34	1.53	1.83

- 103** The resistance factors applicable to accidental limit states (ALS) are identical to the factors for ULS, specified in the tables in 102 (above).
- 104** The resistance factors applicable to serviceability limit states (SLS) are specified in Table 5-5. The factors are linked to the safety class to account for the consequence of failure.

Table 5-5: SLS			
Safety Class	COV of the strength		
	COV < 10 %	10 %-12.5 %	12.5 %-15 %
Normal	1.11	1.16	1.23
High	1.22	1.33	1.49

Guidance note:

For SLS, the set of resistance factors can be defined by the owner, see G.

For ALS, the set of safety factors depends on the frequency of occurrence and is to be defined from case to case, see F. In cases, where the inherent uncertainty related to the accidental load is negligible and, where a conservative estimate is applied, the material resistance factor in Tables 5-3 to 5-5 can be reduced by 10%.

end - of - Guidance - note

C 200 Geometrical Parameters

- 201** Nominal dimensions shall be used for all calculations related to FRP laminates or polymers
- 202** For metals, the dimensions as described in the related metal standards like DNV-OS-F201 for dynamic risers shall be used.

C 300 Material Strength

- 301** The characteristic material strength as described in DNV-OS-501 Section 4 shall be used for all calculations.
- 302** Both characteristic short term properties and characteristic long term properties up to the design life shall be considered. How to obtain long term properties is described in DNV-OS-501 Section 4.

Guidance note

If all long term properties are lower than short term properties, one analysis with long term properties is usually sufficient. However, in some instances stresses may be distributed differently at the beginning of the design life than at the end. In that case two analysis may be required.

End of guidance note

- 103** If the strength of the material is temperature dependent or dependent on the surrounding environment within the range of operational conditions, the analysis should consider the range of strength using the same principles as given in 302.

C 400 Resistance model factors

- 101** Resistance model factors γ_{Rd} account for differences between true and predicted resistance values given by the failure criterion.

402 Model factors shall be used for each failure criteria. The factors are given in *DNV-OS-C501* Section 6. A summary is given in Table 5-6.

<i>Failure Criterion</i>	<i>Model factors g_{Rd}</i>	<i>Reference in DNV-OS-C501</i>
Fibre Failure	1.0 or γ_A	6-C202
Matrix Cracking	1.0-1.15	6-D100-400
Delamination	1.0-2.0	6-E
Yielding	1.0	6-F
Ultimate failure of orthotropic homogenous materials	1.25	6-G
Buckling	Same range as all other criteria.	6-H
Displacements	1.0	6-I
Stress Rupture	0.1-1.0	6-J400
Fatigue	0.1-1.0	6-K300

C 500 System effect factor

501 The safety factors are given for the entire system. Depending on how the components are connected to form a system, the target probability of failure for individual components may need to be lower than the target probability of failure of the entire system.

502 In order to take this system effect into account, a system effect factor γ_S shall be introduced. If the system effect is not relevant, $\gamma_S = 1.0$. Otherwise a system factor shall be documented. A value of $\gamma_S = 1.10$ can be used as a first approach.

Guidance note:

E.g. In the case of a riser string, the failure of one section (i.e. plain pipe or end connector) is equivalent to the failure of the entire system. This is a chain effect in which any component of the string can contribute. As a consequence, the target safety of individual section should be higher than the target safety of the entire system, in order to achieve the overall target safety.

---e-n-d--- o-f---G-u-i-d-a-n-c-e---n-o-t-e---

Guidance note:

A continuous spoolable riser has only two end connectors (one at each end). Failure of an end connector is also a system failure. However, since there are only two connectors it is not a chain effect and $\gamma_S = 1.0$ can be used.

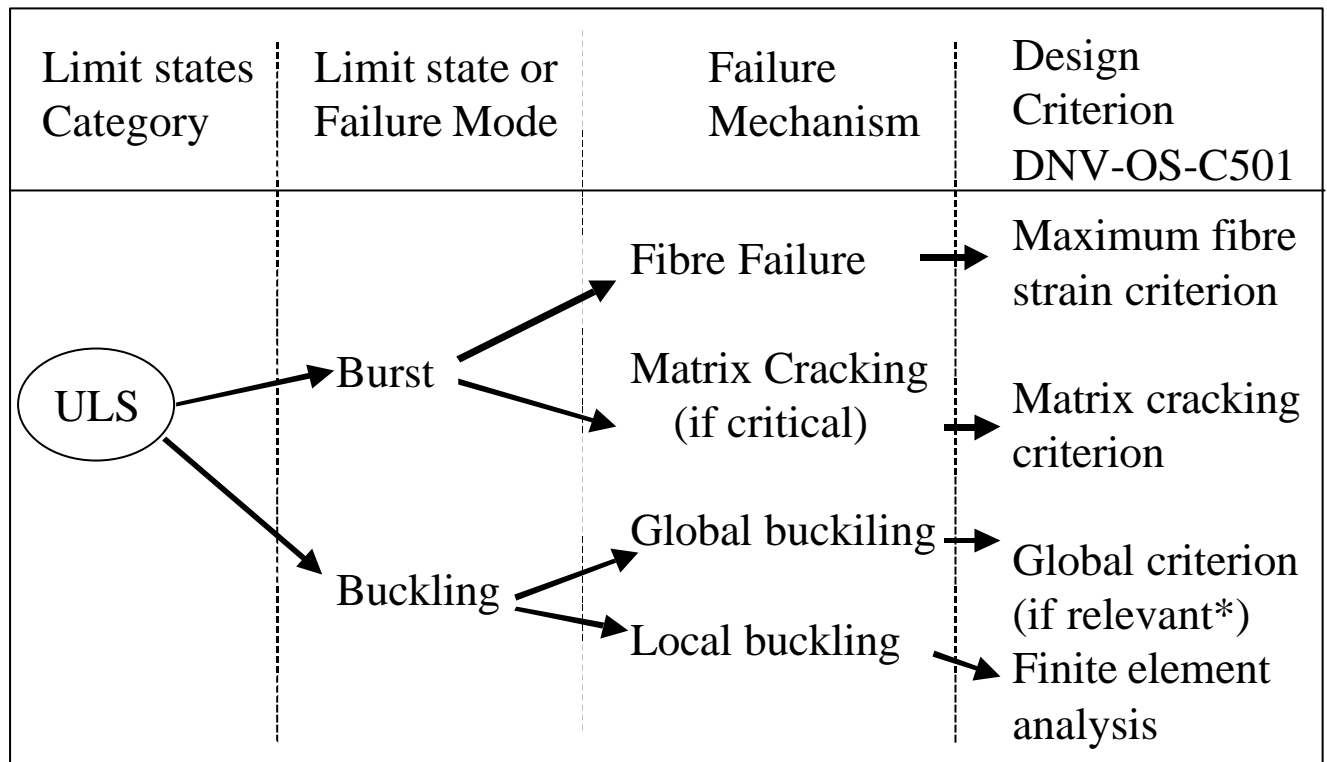
---e-n-d--- o-f---G-u-i-d-a-n-c-e---n-o-t-e---

- 503** In some cases a system may consist of parallel components that support each other and provide redundancy, even if one component fails. In that case a system factor smaller than 1 may be used if it can be based on a thorough structural reliability analysis.

D. Ultimate Limit State

D 100 General

- 101** The riser pipe shall be designed against relevant modes of failure listed in Table 5-1.
- 102** This section provides design checks with emphasis on load controlled conditions. Design principles for displacement controlled conditions are discussed in D 900.
- 103** Loading conditions for the limit state checks are obtained as described in *Section 4*. Risers are typically evaluated for internal/external pressure, axial tension, bending and all possible combinations of these loads. Composite risers may be very sensitive to small torsional loads and small axial compressive loads, depending on the laminate and end-fitting design. All loads should be considered in the limit state analysis.
- 104** An example of the sequence of steps in evaluating a limit state is shown in the Figure 6-1. Each limit state can be related to various failure mechanisms. For each failure mechanism a relevant mathematical description, i.e. a failure criterion, has to be found.
- 105** Failure criteria are given directly in this section or reference is made to relevant failure criteria in DNV Offshore Standard for Composite Components DNV-OS-C501.



* usually risers are designed that they do not experience compressive loads.

Figure 6-1: Example to illustrate flow from limit state to design criterion.

D 200 Bursting

- 201** Bursting of the pipe may be caused by internal overpressure, possibly in combination with axial tension or bending moments.
- 202** The global analysis of the riser shall provide the worst combination of the above loads for local analysis. The local analysis shall establish load effects (stresses or strains) on the ply level.
- 203** The analysis shall check all failure mechanisms listed in DNV-OS-C501 Section 6A501.
- 204** Fibre failure shall always be analysed (DNV-OS-C501 Section 6 C). Fibre failure defined here as ply failure in the fibre direction, as described in DNV-OS-501 Section 4. Fibre failure is not acceptable.
- 205** Matrix cracking of the laminate may be acceptable as long as a fluid barrier remains intact. Typically matrix cracking is acceptable for riser pipes with a liner. See *Section 6 D* for requirements for the liner.
- 206** If the riser does not have a liner or fluid barrier, fluid tightness in the presence of matrix cracks should be documented. Usually a laminate leaks only after a certain number or density of matrix cracks has developed. It is recommended to determine the point of leakage experimentally by component testing

(DNV-OS-C501 Section 10).

- 207** Matrix cracking may reduce the compressive strength under some conditions (DNV-OS-C501 Section 6 C400). The possible consequences of such a strength reduction should be considered.
- 208** Fluid tightness can also be documented by showing that the matrix does not crack (DNV-OS-C501 Section 6 D).
- 209** Delaminations in the laminate may be acceptable if through thickness stresses must not be carried by the laminate. However, delaminations may reduce the buckling strength.
- 210** Yielding is not a failure mode for most fibre reinforced laminates. If yielding can happen two options may be used. The design does not allow yielding (DNV-OS-C501 Section 6 F). Alternatively, a fully nonlinear analysis may be done considering the effects of yielding. See *Section 6 D* for requirements for the liner.
- 211** Buckling may happen locally under bending of the riser. Buckling is not acceptable. Requirements for buckling are given in *D400*.
- 212** Large displacements or deformations due to high loads do usually not cause burst. Large deformations may waken composite metal interfaces.
- 213** Materials shall be chosen in a way that they do not decompose chemically over the lifetime. Such decomposition would weaken the material and may cause burst (DNV-OS-C501 Section 6 Q).

D 300 Liquid Tightness - Leakage

- 301** Leakage of a riser is similar to burst, but a more gradual process. All considerations for burst also apply for leakage.
- 302** Diffusion or permeability of the fluid shall be low enough that no or minimal amounts of fluid get out of the system.
- 303** If the riser has a liner it is sufficient to show that the liner itself can contain the fluid. Properties of the laminate shall be checked if there is no liner or if the liner is not fluid tight.

D 400 Buckling

401 Buckling of the riser tube shall be considered as a possible failure mechanism.

402 Relevant load conditions that may induce buckling of the riser tube are
 axial compression
 bending of the riser tube as a beam (i.e. such that the axis of the riser tube bends)
 torsion of the tube about its own axis
 external overpressure

It may be relevant to consider the simultaneous presence of axial tension along with bending, torsion or external pressure, or of internal overpressure along with axial tension/compression, bending or torsion.

403 Buckling shall be evaluated as described in Section *DNV-OS-C501 Section 6 H* taking due account of geometric imperfections.

404 For liner buckling refer to *6D400*.

405 If analytical formulae are used for estimating critical buckling loads, due account shall be taken of the anisotropic properties of the riser wall. Sections 406 to 410 below provide some formulae that may be used to estimate the elastic critical loads for the load cases listed in 402. These should be used with knock-down factors to give the buckling strength allowing for geometric imperfections, as indicated. The criterion to be checked is given in 411. Combined loads may be considered in accordance with 412.

106 A negative effective tension may cause a riser to buckle in compression. Buckling may take the form of global beam-column buckling or local buckling of the riser wall, or a combination of the two. For axial compression the critical values of the mean axial compressive stress for elastic buckling in the global and local modes, $s_{cr\ global}$ and $s_{cr\ local}$, and the buckling resistance, $\hat{S}_{buckling}$, may be derived as follows:

$$\frac{1}{\hat{S}_{buckling}} = \frac{1}{\hat{S}_{buck\ global}} + \frac{1}{\hat{S}_{buck\ local}}$$

where

$$\hat{S}_{buck\ global} = k_{A\ global} s_{cr\ global} = \frac{R^2 k_{A\ global} p^2 E_{xx}}{L^2 2}$$

and

$$\hat{S}_{buck\ local} = k_{A\ local} s_{cr\ local} = \frac{t k_{A\ local} E_{xx} K_1}{R [3(1 - \nu_x \nu_{?x})]^{1/2}}$$

In the above, L is the effective length of the riser tube for global buckling as a beam-column, R and t are the radius and thickness of the riser tube, the suffices x and $?$ refer to the axial and circumferential directions, E and ν are modulus and Poisson's ratio, and K_1 is an anisotropy factor given by

$$K_1 = \left\{ 2 \left[1 + \nu_{x\theta} \left(\frac{E_{\theta\theta}}{E_{xx}} \right)^{1/2} \right] \left(\frac{E_{\theta\theta}}{E_{xx}} \right)^{1/2} \frac{G_{x\theta}}{E_{xx}} \right\}^{1/2}$$

E_{xx} , $E_{\theta\theta}$ and $G_{x\theta}$ are the laminate elastic engineering moduli for in-plane deformations. Note that the engineering constants are only defined for symmetric laminates.

The knock-down factors to account for geometric imperfections, $k_{A \text{ global}}$ and $k_{A \text{ local}}$, should be taken as 0.67 and 0.5, respectively, unless higher values can be demonstrated.

Global buckling under conditions of displacement-controlled loading may be permitted, provided it does not result in other failure modes such as local buckling, unacceptable displacements, or unacceptable cyclic effects. In such cases only the local buckling mode need be considered in the above formulae.

The above formulae apply to the true wall compression for the case when the external and internal pressures on the tube wall are equal. Cases of simultaneous axial compression and external overpressure shall be treated in accordance with 412.

Guidance note:

It is essential that an appropriate tensioned-beam model is used for the analysis of global buckling. The consequence of a too-small positive effective tension is excessive curvature and bending moment near the location of minimum effective tension.

Note that members above the tension joint for top tensioned risers may be subjected to compressive forces for some riser types

- end - of - Guidance - note -

- 407** For bending of the riser tube the critical bending moment for elastic buckling, M_{cr} , and the buckling resistance moment, $\hat{M}_{\text{buckling}}$, may be derived from

$$\hat{M}_{\text{buckling}} = k_M M_{cr} = \frac{1.3 k_M \rho R t^2 E_{xx} K_1}{[3(1 - \nu_{x\theta} \nu_{\theta x})]^{1/2}}$$

in which R and t are the radius and thickness of the riser tube, the suffices x and θ refer to the axial and circumferential directions, E and ν are modulus and Poisson's ratio, and K_1 is an anisotropy factor as defined in 406. The knock-down factor k_M to account for geometric imperfections should be taken as 0.5 unless a higher value can be demonstrated.

408 Special care shall be given when a small decrease in top tension of a top-tensioned riser could cause excessive bending moment. In that case, the designer shall establish a minimum effective tension that gives a margin above the tension that is predicted to cause excessive bending moments.

409 For the case of torsional loading about the riser's longitudinal axis, the critical torsional moment for elastic buckling, M_{Tcr} , and the buckling resistance torsional moment, $\hat{M}_{T \text{ buckling}}$, may be estimated from

$$\hat{M}_{T \text{ buckling}} = k_T M_{Tcr} = 21.7 k_T D_{??} \frac{R^{5/4}}{L^{1/2} t^{3/4}} \left[\frac{(A_{xx} A_{??} - A_{x?}^2) t^2}{A_{??} D_{??}} \right]^{3/8}$$

in which R , L and t are the radius, length and thickness of the riser tube, A_{xx} , $A_{??}$ and $A_{x?}$ are the laminate elastic constants for in-plane deformations, D_{xx} , $D_{??}$ and $D_{x?}$ are the laminate elastic constants for bending deformation, and the suffices x and $?$ refer to the axial and circumferential directions respectively. The knock-down factor k_T to account for geometric imperfections should be taken as 0.67 unless a higher value can be demonstrated. This formula is valid only when the coupling coefficient $B_{??}$ is small or zero (as in the case of a symmetric laminate lay-up), and when

$$\frac{1}{L^2} \leq \left(\frac{D_{??}}{D_{xx}} \right)^{5/6} \left[\frac{(A_{xx} A_{??} - A_{x?}^2) t^2}{12 A_{??} D_{xx}} \right]^{1/2} \left(\frac{500}{Rt} \right)$$

410 For the case of external pressure loading the critical pressure for elastic buckling, p_{cr} , and the buckling resistance pressure, $\hat{p}_{\text{buckling}}$, may be estimated from

$$\hat{p}_{\text{buckling}} = k_p p_{cr} = \frac{3 k_p \left(D_{??} - \frac{B_{??}^2}{A_{??}} \right)}{R^3}$$

in which the notation used is as defined in 409. The knock-down factor k_p to account for geometric imperfections should be taken as 0.75 unless a higher value can be demonstrated. The above formula applies for long tubes. For shorter lengths of tube the following formula should be used if this gives a higher value:

$$\hat{p}_{\text{buckling}} = k_p p_{cr} = \frac{5.5 k_p D_{??}}{L R^{3/2} t^{1/2}} \left[\frac{(A_{xx} A_{??} - A_{x?}^2) t^2}{A_{??} D_{??}} \right]^{1/4}$$

in which L is the length of the tube. This formula assumes a symmetric lay-up and is valid only when

$$\left(\frac{D_{??}}{D_{xx}} \right)^{3/2} \left[\frac{(A_{xx} A_{??} - A_{x?}^2) t^2}{12 A_{??} D_{xx}} \right]^{1/2} \left(\frac{L^2}{Rt} \right) \geq 500$$

Guidance note:

p_{cr} is the local minimum internal pressure taken as the most unfavourable internal pressure plus static head of the internal fluid. For installation p_{\min} equals zero. For installation with water-filled pipe, p_{\min} equals p_e .

- end - of - Guidance - note -

411 The failure criterion for buckling when the resistance is determined by use of the above formulae is as follows:

$$g_F \cdot g_{Sd} \cdot F \leq \frac{\hat{F}_{buckling}}{g_{Mbuckle} g_{Rdbuckle}}$$

where:

F	Characteristic value of the induced stress or stress resultant (s , M , T or p)
$\hat{F}_{buckling}$	Characteristic value of the resistance obtained from the tests
g_F	Partial load or load effect factor
g_{Sd}	Partial load or load effect model factor
$g_{Mbuckle}$	Partial resistance factor
$g_{Rdbuckle}$	Partial resistance-model factor

The partial resistance factor $g_{Mbuckle}$ and $g_{Rdbuckle}$ may be taken as 1.0 if the knock-down factors given in the above sections are adopted.

The load effect model factor g_{Sd} shall take account of the accuracy of representation of geometrical imperfections and boundary conditions. The value shall be determined from Section 4bL.

412 For cases of combined loadings a conservative assessment may be performed by assuming a linear interaction relationship:

$$\frac{F}{\hat{F}_{buckling}} = \frac{s}{\hat{s}_{buckling}} + \frac{M}{\hat{M}_{buckling}} + \frac{M_T}{\hat{M}_{T buckling}} + \frac{p}{\hat{p}_{buckling}} \leq \frac{1}{g_F \cdot g_{Sd} g_{Mbuckle} g_{Rdbuckle}}$$

where s , M , T and p are the characteristic values of the axial compressive stress, the bending moment, the torsional moment and the external pressure when considered in combination.

D 500 Propagating Buckling

501 Propagation buckling is not considered for composite risers, since local buckling is already not acceptable.

D 600 Wear and Tear

- 601** The riser pipe shall have sufficient resistance to wear and tear from the fluids or equipment running through the pipe. (See also DNV-OS-C501 Section 6 M).
- 602** Composite riser have often an internal liner. In this case wear resistance of the liner shall be demonstrated.
- 603** If the composite riser does not have a liner wear resistance of the laminate shall be demonstrated.
- 604** The riser shall not leak and the laminate shall keep its load carrying capacity after degradation due to wear and tear.

D 700 Explosive decompression

- 701** Explosive decompression may happen if fluid is entrapped under pressure within the material or the interface. A sudden reduction of pressure in the system may cause the fluid to expand and cause severe damage.
- 702** If the fluid can diffuse into any riser materials explosive decompression shall be considered (*DNV-OS-C501 Section 6O*).
- 703** Fluids in risers with a tight metal inner liner cannot diffuse through the metal and explosive decompression due to the internal fluids does not have to be considered.

D 800 Chemical decomposition / Corrosion

- 801** Materials shall be chosen which do not decompose chemically in the design environment within the lifetime of the riser (*DNV-OS-C501 Section 6 Q*).
- 802** Glass, aramid and carbon reinforced laminates made of polyester, vinyl ester or epoxy have not shown chemical decomposition in marine environments. However, they do age as described in 7C-E.
- 803** Possible corrosion of the constituent materials should be considered. Carbon fibres in contact with metals may cause galvanic corrosion.

D 900 Displacement Controlled Conditions

- 901** Displacement controlled conditions can be addressed as described in the standard for dynamic risers DNV-OS-F201.
- 902** Accumulated yielding is usually not relevant for composite laminates, but it should be considered for all other components, like metal or thermoplastic liners etc.

E. Fatigue Limit State

E 100 General

- 101 Cyclic fatigue and static fatigue (or stress rupture) should be considered for composite risers.
- 102 All failure modes that were evaluated in static analysis shall also be evaluated for possible fatigue failures. A few exceptions are given in the failure criteria in *Section DNV-OS-C501 Section 6 J and K*.
- 103 The effects of possible creep or stress relaxation on the riser system should be evaluated.
- 104 All critical sites of each unique component along the riser shall be evaluated. These sites normally include details that causes stress concentrations or load introduction points.
- 105 Possible changes in stiffness with time shall be considered for cyclic and static fatigue (*Section DNV-OS-C501 Section 6 J200 and K200*)

E 200 Cyclic Fatigue

- 201 The riser system shall have adequate safety against cyclic fatigue within the service life of the system. Reference is made to *DNV-OS-F201 Section 4 and Appendix B* for more details with respect to fatigue design and analysis.
- 202 All cyclic loading imposed during the entire service life, which have magnitude and corresponding number of cycles large enough to cause fatigue damage effects, shall be taken into account. Temporary phases like transportation, towing, installation, running and hang-off shall be considered. Loads shall be described as stated in *Section 3 F300*.
- 203 Normally, the methods based on S-N curves and reduction of strength with time are used during design for fatigue life assessment (*Section DNV-OS-C501 Section 6 K*). SN curves should be obtained as described in *DNV-OS-501 Section 4 C*.
- 204 If representative fatigue resistance data are not available, direct fatigue testing of the actual components shall be performed with due regard of the chemical composition of the internal and external environment (*DNV-OS-C501 Section 10*).
- 205 The stress to be considered for fatigue in a riser is the *cyclic* (i.e., time-dependent) stress. Mean value and amplitude should be obtained.
- 206 This combined stress varies around the circumference of the riser pipe. For cases where the waves are incident from several different directions, the fatigue damage must hence be calculated at a number of regularly spaced points to identify the most critical location.

E 300 Stress rupture

- 301 The riser system shall have adequate safety against stress rupture (or static fatigue) within the service life of the system.

- 302** All long term permanent loads during the entire service life, which have magnitude large enough to cause stress rupture effects, shall be taken into account. Temporary phases like transportation, towing, installation, reeling, running and hang-off shall be considered. Loads shall be described as stated in *Section 3 F200*.
- 303** Normally, the methods based on long term stress rupture curves and reduction of strength with time are used during design for fatigue life assessment (*Section DNV-OS-C501 Section 6 K*). Material data should be obtained as described in *DNV-OS-501 Section 4 C*.
- 304** If representative stress rupture resistance data are not available, direct testing of the actual components shall be performed with due regard of the chemical composition of the internal and external environment (*DNV-OS-C501 Section 10*).
- 305** The stress to be considered for stress rupture in a riser is the *long term static* stress.
- 306** This stress may vary around the circumference of the riser pipe. For cases where the waves are incident from several different directions, the stress rupture analysis must hence be calculated at a number of regularly spaced points to identify the most critical location.

E 400 Factors for Static and Dynamic Fatigue Analysis

- 401** The factors γ_{fat} in Table 5-7 shall be used for the prediction of failure due to cyclic fatigue or due to long term static loads. The factors shall be used with the failure criteria in *DNV-OS-C501 Section 6 J and K*.

Table 5-7: Factor for fatigue calculations g_{fat}		
Safety class		
Low	Normal	High
15	30	50

- 402** When using the factors in Table 5-7, no in service inspection is required.
- 403** In service inspection may be used if it can be combined with damage growth and failure predictions to optimise a fatigue analysis.

F. Accidental Limit State

F 100 General

101 The same considerations apply to composite risers as given in the DNV offshore standard for dynamic risers DNV-OS-F201.

F 200 Resistance against fire

201 If the riser is used above the water line resistance against fire shall be demonstrated. A full scale fire test with a representative fire is the recommended option to demonstrate fire performance.

202 It is recommended to use composite risers made of flammable materials only below the water line. Metal riser sections can be used above the water line. In that case it is not necessary to demonstrate fire resistance of the composite riser.

F 300 Resistance against dropped objects - impact

301 Demonstration of resistance against dropped objects, like drill-bits may be required. The impact scenario should be defined by the local authorities or the user.

302 It shall be shown that the riser remains leak tight after an impact of the defined scenario.

303 When considering the effects of impact, it should be documented that no unintended failure mechanisms will happen due to impact.

304 The resistance of the riser to impact should be tested experimentally. This can be done in two ways.

- The material or a small section is exposed to a relevant impact scenario. The strength of the material with the impact damage should be determined. This strength can be used for further design of the riser.
- The full riser is exposed to a relevant impact scenario. The riser is tested afterwards to show that it can still tolerate the critical loads.

305 Impact failure criteria may be used if experimental evidence shows that they are applicable for the application.

F 400 Impact testing

401 If the testing option is chosen in 303, the riser should be tested lying on the ground under normal operating pressure and axial tension. A higher pressure than operating pressure may be used to simulate the axial tension.

402 The riser pipe should be impacted in the middle and close to the joint.

403 It should be evaluated whether the riser should be able to withstand more than one impact scenario. In

that case the riser should be exposed to the expected number of impact events.

F 500 Evaluation after impact testing

- 501** The impact tests should demonstrate that no unacceptable damage is introduced into the riser. Once the riser has been exposed to impact it should be carefully inspected to ensure that no unexpected failure mechanisms occurred that may reduce the riser's performance, in particular long term performance. If the riser will be taken out of service after an impact, long term considerations do not have to be made.
- 502** It shall be shown further that the riser can carry all relevant loads after impact until it can be taken out of service for repair or replacement. This can be done by demonstrating that the riser remains pressure tight for the time it takes to take the riser out of service. The riser should remain pressure tight for at least 1 hour.
- 503** If the riser may be exposed to impact but can or should not be repaired afterwards, it should be shown that the riser can withstand all long-term loads with the damage induced by the impact. This can be done by analysis taking the observed impact damage into account, by testing, or a combination of analysis and testing. Testing should be done according to DNV-OS-C501 *Section 10*.

G. Serviceability Limit State

G 100 General

- 101** The same considerations apply to composite risers as given in the DNV offshore standard for dynamic risers DNV-OS-F201.

H. Special Considerations

H 100 Interference

- 101** The same considerations apply to composite risers as given in the DNV offshore standard for dynamic risers DNV-OS-F201.

H 200 Unstable Fracture and Gross Plastic Deformation.

- 201** Metal parts should fulfil the same requirements as given in *DNV-OS-F201 Sect. 5 H200*.
- 202** Composite laminates should have a certain minimum fracture toughness to prevent unstable fracture growth.
- 203** Laminates with all of the properties listed below have sufficient fracture toughness:
- Laminates that have somewhere layers with fibre directions that are at least 30 degrees apart.
 - The thickness of layers with fibres in one direction is less than 0.6 mm.
- Layers of interwoven fibres with fibres in two directions with are at least 30 degrees apart may have any thickness.
- 204** If 203 does not apply the notch sensitivity of a laminate shall be at least 0.8 in all directions. Notch sensitivity is defined here as the strength of a laminate with notches divided by the ultimate strength. The ratio of crack length to specimen width shall be at least 0.375. The thickness of the notch shall be not more than 0.5 mm. It is recommended to test notch sensitivity with double edge notched specimens, where notches are cut into the specimen on each side.

SECTION 6 CONNECTORS AND LINERS

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A. General

A 100 Objective

101 This section gives requirements to connectors, components and liners. Metal parts shall fulfil all

requirements given in DNV-OS-F201 Dynamic risers, in particular Section 6 of that standard. This section covers composite and plastic components and gives additional requirements for metal components.

- 102** The aim of the design is to ensure that the riser with its connectors, liner and riser components has adequate structural resistance, leak tightness and fatigue resistance for all relevant load cases. Resistance against accidental loads such as fire and impact shall also be considered when applicable.
- 103** Risers and connectors shall achieve the same or higher level of reliability as the structure of which they are part of.
- 104** All connectors, components and interfaces shall be evaluated against the same limit states as described for the riser pipe in *Section 5*.
- 105** Connectors and components made of fibre reinforced plastics can in principle be analysed and tested the same way as a structure or component. However, some special considerations are described in the following sections.

A 200 Definition of joint

- 201** The term "joint" is used in this section as a connection between two parts, like a mechanical joint or an adhesive joint. It is not used as a riser joint, describing a section of riser pipe with two end connectors.

B. Connector Designs

B 100 Functional Requirements

- 101** Riser connectors shall allow for multiple makeup and breakout in a reliable manner. The connector may permit for interchangeability between connector halves to allow riser joints to be run in any sequence.
- 102** The basic requirements given for the performance of connectors in *DNV-OS-F201 Dynamic* risers apply also for composite risers.

B 200 Design and Qualification Considerations

- 201** It is recommended to make the connectors of metallic materials. If the connector is made of composite great care should be taken to analyse the complicated stress states and stress concentrations. Through thickness stresses away from the fibre directions tend to be critical and as a consequence through thickness material properties. Extensive testing is most likely needed to qualify a composite connector.
- 202** If the connector is made of metal all requirements given in *DNV-OS-F201 Dynamic* risers apply. Special consideration should be given for the composite metal interface between the connector and the riser pipe, see *Section C*.

C. Composite - Metal Connector Interface

C 100 General

- 101** The interface between the metal connector and the composite pipe is a critical part of the riser design. The interface is basically a joint and all general requirements given in *F* should be considered.
- 102** The fibres run usually in a complicated 3-D pattern at the joint. The analysis should model the fibre arrangement properly. In an FE-analysis, the elements should follow the direction of the fibres.
- 103** The composite metal connector interface shall be strong enough to transfer all loads considered for the connector and the pipe section.
- 104** If the riser has a liner, the liner is usually also connected to the metal connector in some way. This connection shall not inhibit the functions of the liner in any way and shall be as reliable as the liner itself.

Guidance note:

The composite metal connector interface is typically a mechanical joint. Adhesive joints may be used, but it is difficult to demonstrate reliable long-term performance of the adhesive joint.

End of guidance note

- 105** The performance of the composite metal interface shall be verified by testing. Minimum requirements are given in *G*.

C 200 Limit states

- 201** The composite metal connector interface shall be at least analysed for the same limit states as the riser pipe.
- 202** A local analysis should be carried out based on loads and boundary conditions from the global analysis of the riser system.
- 203** A careful analysis of all possible failure modes shall be made. It shall be shown for all failure modes that they either will not occur or are not critical for the performance of the riser system.
- 204** The possible mismatch of thermal properties of materials shall be considered in the analysis.
- 205** Internal or external pressure on the riser system may be beneficial or detrimental to the performance of the joint. This effect shall be considered in the analysis.

- 206** Creep of any of the materials used in the joint may reduce friction, open up potential paths for leakage or lead to cracks. Effects of creep shall be carefully considered.

Guidance note

It is highly recommended to design the joint in a way that it also functions if the matrix of the composite laminate is completely degraded. In that case the joint can perform as long as the fibres are intact and sufficient friction between fibres and the fibre metal interface exists. Such a joint does not rely on the usually uncertain long-term properties of the matrix.

End of guidance note.

- 207** Metal parts should be designed in a way that they do not yield to ensure no changes in the geometric arrangement of the joint. If any yielding can occur a nonlinear analysis shall be done taking all relevant load histories and accumulated plastic deformations into account.
- 208** Possible effects of corrosion on metals and interfaces shall be evaluated.
- 209** Possible galvanic corrosion between different materials shall be considered. An insulating layer between the different materials can often provide good protection against galvanic corrosion.
- 210** Leak tightness of the joint shall be carefully evaluated. In particular possible flow along interfaces should be analysed.

D. Inner Liner

D 100 General

- 101** Most composite risers have an inner liner as a fluid barrier. This inner liner is typically made of metal or polymeric materials.
- 102** It shall be shown that the inner liner remains fluid tight throughout the design life, if it is used as a fluid barrier.

D 200 Mechanical performance

- 201** The inner liner may contribute to the overall stiffness and strength of the riser system depending on its stiffness and thickness.
- 202** The inner liner usually follows the deformations of the main load bearing laminate. It shall be shown that the inner liner has sufficiently high strains to failure and yield strains to follow all movements of the riser

system.

- 203** Mismatch in thermal properties between inner liner and laminate should be considered. The mismatch may introduce high stresses or strains.
- 204** The inner liner should be operated in its linear range. Neither operational conditions nor test conditions should bring it to yield. An exception is the first pressure loading *D300*.
- 205** In addition to the requirements given here, metal inner liners and their welds shall be evaluated according to *DNV-OS-F201* for strength, fatigue life, and capability to follow system deformations.
- 206** Polymeric inner liners, like thermoplastic inner liners may be evaluated against the yield criterion in *DNV-OS-C501* Section 6 F.

D 300 Autofretage

- 301** It is common practice to pressurise the riser pipe initially at the factory to such a high pressure that the inner liner yields. After removing the pressure the inner liner will be compressed by the outer laminate. This procedure ensures a tight fit between inner liner and laminate.
- 302** The yielding of the inner liner also causes the welds to yield. This may reduce stress concentrations, but it can also cause local thinning around the weld. Any thickness variations in the inner liner may cause localised yielding. The weld zone may have lower yield strength than the main part of the inner liner. Due to this the inner liner may yield locally close to the welds. The strain in the localised yield region can be very high, possibly leading to instant rupture, lower fatigue performance, enhanced creep. The inner liner and its welds shall be analysed taking all these effects into account.

Guidance note

A small thin area in the inner liner can be worse than a larger thin area, because the inner liner may only deform by yielding in the thin section. In that case the small thin section will have much higher strains than the large section, if the total deformation is the same.

End of guidance note

- 303** If the inner liner material can creep, than creep will happen especially in the thin highly strained regions. The effect of creep with respect to fatigue, stress rupture and buckling should be evaluated.
- 304** If the inner liner is under compression, local yielding may create deformations resulting in local or global buckling.
- 305** Inner liner specifications with respect to acceptable thickness variations, weld quality, and maximum misalignments should be consistent with the worst cases evaluated in the analysis.

D 400 Liner buckling

- 401** Buckling of the liner due to hoop compression shall be considered as a potential failure mechanism. The following four slightly different phenomena should be considered:
- Buckling due to internal under pressure, i.e., vacuum, without external pressure should always be evaluated.
 - Buckling of the liner due to external pressure as a consequence of compression of the main laminate due to external pressure. This effect should be always evaluated.
 - Buckling of the liner due to external water pressure. This is only relevant if the pressure of the outside water can reach the outer surface of the inner liner. The laminates are usually not pressure tight, but the presence of an outer liner can make it pressure tight.
 - Explosive decompression causes a pressure to build up suddenly between the liner and the composite riser tube, at the same time as the pressure inside the liner suddenly drops. This effect can happen if gas or liquid can diffuse through the inner liner and accumulate in the interface between liner and laminate or inside the laminate. This effect can be ignored for metal liners, since they are diffusion tight, provided no other diffusion path through seals etc. exists in the system.
 - As a result of the sustained internal pressure, the liner yields plastically (or undergoes creep deformation) in tension in the hoop direction. Decompression causes the composite riser tube to contract, compressing the liner and causing it to buckle. This effect can be prevented by using initially the autofretage process (*D300*) and by keeping the liner below yield during operation.
- 402** Possible buckling of the liner as a result of other loading conditions on the riser shall also be evaluated. In particular buckling of the liner associated with bending of the riser tube as a beam should be considered.
- 403** Buckling may be evaluated by treating the inner liner as an independent tube. This is a very conservative approach, because the support of the laminate outside the liner is not considered. It may be a convenient approach to document that the liner can withstand an internal vacuum.
- 404** When considering either of the effects described in *401* the tightness of the fit between the liner and the riser tube shall be taken into account. A relevant parameter is the liner fit parameter

$$h = \frac{R_{o \text{ (liner)}} - R_{i \text{ (riser tube)}}}{R_{o \text{ (liner)}}$$

where $R_{o \text{ (liner)}}$ and $R_{i \text{ (riser tube)}}$ are respectively the outer radius of the liner and the inner radius of the riser tube in conditions where the two components are considered separately without mechanical loading and at the temperature prevailing at the time of decompression. The case $h > 0$ is that of a tight fit such that the liner is in a state of circumferential (hoop) compression when fitted in the riser tube. If the liner has undergone plastic or creep deformation as a result of the prior internal pressure the effective value of h may be different from that at initial assembly of the riser. The fit parameter is also dependent on the temperature prevailing at the time of the decompression event.

- 405** The following aspects may also have a fundamental influence and shall be considered when evaluating liner buckling:
- The extent to which the liner is and remains bonded to the riser tube (see also *408*). Its recommended to treat the liner as unbonded, because it is difficult to demonstrate bonding over

the lifetime of the riser, unless liner and laminate are made of the same material (407).

- Initial geometric out-of roundness or other unevenness in the liner (or in the inner surface of the riser tube). In particular, a longitudinal seam in a liner may have a large effect on the buckling resistance.
- Plastic as well as elastic deformation in the liner during buckling.
- The temperature at which the failure event is considered to occur. As well as influencing the liner fit parameter γ , the temperature in the liner material may significantly affect both its elastic properties and its plastic yield properties.
- The mismatch of thermal properties between liner and laminate
- Possible degradation of the liner properties prior to the event, e.g. due to hydrolysis.

406 The buckling phenomena shall be evaluated by means of non-linear analysis and/or testing in accordance with *Section 4K*. In the case of non-linear analysis, an appropriate finite element method shall be applied using contact elements at the liner/tube interface.

407 If the only difference between liner and structural laminate is that the one has reinforcement and the other does not, i.e., they were made of the same matrix material, there is basically no interface between liner and matrix. In this case the liner and laminate can be treated as bonded provided:

- Inner liner and laminate were not connected by a secondary bond.
- Through thickness testing (at least 3 tests) of the laminate with liner shows that the combined material does not fail at the connection between liner and laminate for more than 30% of the tests.
- The combined material has the same strength as the through thickness strength of the laminate within 10%.

408 Special attention shall be paid to the possibility of a fluid pressure occurring between the liner and riser tube in a region with a debond between the two components, and a subsequent rapid growth of the debond (Fig. 1). This is essentially a problem involving bending of the liner combined with growth of a crack at the interface and is not a buckling problem as such.

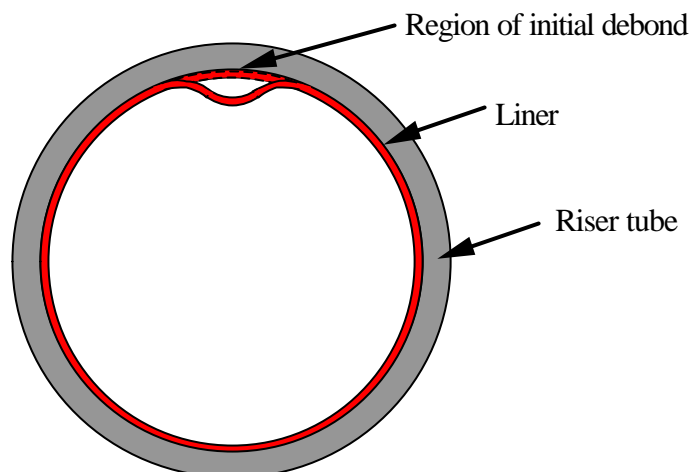


Fig. 1 Possible fluid pressure build-up in the interface between liner and riser tube causing rapid growth of initial debond.

D 500 Liner composite interface

- 501** The liner may be bonded to the composite laminate or it may be unbonded.
- 502** A different layer of material may also be placed between the laminate and the liner.
- 503** All possible failure modes of the interface and their consequence to the performance of the system shall be evaluated.
- 504** If a bond is required between laminate and liner, for example to obtain good buckling resistance of the liner, the performance of the bond shall be tested *G500*.
- 505** If interfaces only touch each other friction and wear should be considered (*DNV-OS-C501 Section 6M*).
- 506** Fluids may accumulate between interfaces. They may accumulate in voids or debonded areas and/or break the bond of the interface. The effect of such fluids should be analysed. Possible effects of rapid decompression of gases should be considered.
- 507** If the laminate may have matrix cracks, but the liner shall not crack (or vice versa), it shall be shown that cracks cannot propagate from one substrate across the interface into the other substrate. Possible debonding of the interface due to the high stresses at the crack tip should also be considered.
- 508** It is recommended to demonstrate by experiments that cracks cannot propagate across the interface from one substrate to the other. It should be shown that by stretching or bending both substrates and their interface that no cracks form in the one substrate even if the other substrate has the maximum expected crack density.

Guidance note

A weak bond between the substrates is beneficial to prevent crack growth across the interface. However, it means that debonding may happen easily.

End of guidance note.

D 600 Liner to end connector interface

- 601** All requirements of *Section D* apply.
- 602** The interface will be exposed to pressure, axial, and bending loads.
- 603** Fluid tightness of the liner connector interface shall be carefully insured.
- 604** Special attention shall be given to welds or seals, ensuring that the different movements of end connector and liner can be followed.
- 605** Aspects related to joints in general, *Section G*, should also be considered.

D 700 Wear and tear

- 701** It should be demonstrated that the liner material could withstand the operating conditions with respect to wear and tear.
- 702** Wear and tear should never destroy the fluid tightness of the liner.
- 703** It may be good practice to add extra thickness to the liner or to provide a separate layer for wear and tear protection.
- 704** The inner liner should be strong enough to withstand possible shear, scraping and torsional loads from equipment running inside riser. This is particularly important for drilling risers.

E. Outer liner

E 100 General

- 101** An outer liner is usually applied for keeping out external fluids, for protection from rough handling and the outer environment and for impact protection.
- 102** If no outer liner is applied the outer layers of the laminate have to take the functions of the outer liner.
- 103** The outer liner material shall be chosen that it is resistant to the external environment, e.g., seawater temperature, UV etc.
- 104** If the outer liner is exposed to UV radiation in service or during storage, it should be UV resistant.

E 200 Mechanical performance

- 201** Outer liners are not exposed to autofretage. They should be kept below yielding.
- 202** Resistance of the outer liner to handling and the external environment shall be considered. The outer liner may get some damage from handling, but the structural layer underneath should not be effected.
- 203** If the outer liner shall ensure that no water comes into the laminate and the inner liner does not have to be analysed for collapse under external water pressure the outer liner should meet the following requirements:
 - The outer liner must be watertight.
 - It should be demonstrated that no path exist for the water to flow into the laminate. The seals at the end of the outer liner, usually against the end connector should be carefully evaluated.
 - Water tightness should be demonstrated even when some external damage from handling is present.
 - It is recommended to apply an extra layer for protection against handling.
- 204** The performance requirements to the outer liner should not be effected by a possible impact scenario.

F. Joints of materials or components - general aspects

F 100 Analysis and testing

- 101** The same design rules as applied for the rest of the structure shall be applied to joints, as relevant.
- 102** Joints are usually difficult to evaluate, because they have complicated stress fields and the material properties at the interfaces are difficult to determine.

103 Joints may be designed according to three different approaches:

- An analytical approach, i.e. the stress/strain levels at all relevant parts of the joint including the interface are determined by means of a stress analyses (e.g. a FEM-analyses) and compared with the relevant data on the mechanical strength.
- Design by qualification testing only, i.e. full scale or scaled down samples of the joint are tested under relevant conditions such that the characteristic strength of the complete joint can be determined.
- A combination of an analytical approach and testing, i.e. the same approach specified in *DNV-OS-C501 Section 10C* for updating in combination with full scale component testing.

104 The options marked in Table 6-1 may be used for the different types of joints:

Type of joint	Analytical approach	Qualification testing	Analyses combined with testing (updating)
Laminated joint	x	x	x
Adhesive joint		x	x
Mechanical joint		x	x

Table 6-1 Design approaches for different categories of joints

- 105** The level of all stress (strain) components in all relevant areas of the joint, including stress concentrations, shall be determined according to the same procedures as specified for the rest of the structure. Special emphasis shall be put on possible stress concentrations in the joint. It shall be recognised that the stress concentrations in the real structure may be different than determined through the analyses due to e.g. simplifications made, effects of FEM-meshing etc.
- 106** An analytical analysis is sufficient, if the stress field can be determined with sufficient accuracy, i.e., all stress concentrations are well characterised and a load model factor γ_{sd} can be clearly defined. In all other cases experimental testing according to *DNV-OS-C501 Section 10* shall be carried out to confirm the analysis.
- 107** If the material properties, especially of the interface cannot be determined with sufficient accuracy, experimental testing according to *DNV-OS-C501 Section 10* shall be carried out. Scaled testing may be possible, as described in *F200*.
- 108** Long term performance of a joint may be determined based on long-term materials data, if a clear link between the material properties and joint performance can be established. The requirements of *102* and *103* also apply for long term performance.
- 109** The load cases should be analysed with great care for joints. Relatively small loads in unfavourable directions can do great harm to a jointed connection. Especially loads due to unintended handling, like bending, stepping on a joint etc. should not be forgotten.
- 110** Joints may be analysed by testing alone as described in *DNV-OS-C501 Section 10B*.
- 111** The most practical approach is likely to use a combination of analysis and testing. Since a large conservative bias may be necessary in the analysis to account for the many uncertainties in a joint design it is recommended to use the updating procedures of *DNV-OS-C501 Section 10C400* to obtain a better utilisation of the joint. The purpose of this approach is to update the predicted resistance of the joint with the results from a limited number of tests in a manner consistent with the reliability approach of

the guideline.

F 200 Qualification of analysis method for other load conditions or for scaled joints

- 201** If an analysis method predicts the tested response and strength of a joint based on basic independently determined material properties according to *DNV-OS-C501 Section 10C*, the analysis works well for the tested load conditions. The same analysis method may be used:
- For the same joint under different load conditions, if the other load conditions do not introduce new stress concentrations in the analysis.
 - For a joint that is similar to an already qualified joint, if all local stress concentration points are similar to the already qualified joint and all material properties are known independently.
- 202** Local stress concentrations are similar if the local geometries of the two joints and the resulting stress fields at these local points can be scaled by the same factor.
- 203** An analysis method that predicts the test results properly but not entirely based on independently obtained materials data can only be used for other load conditions or joint geometries if it can be demonstrated that the material values that were not obtained by independent measurements can also be applied for the new conditions.

F 300 Multiple failure modes

- 301** Most joint designs can fail by various failure modes. All possible failure modes shall be carefully identified and analysed. See *DNV-OS-C501 Section 10D*.

F 400 Evaluation of in-service experience

- 401** In service experience may be used as experimental evidence that a joint functions well.
- 402** This evidence shall only be used if the load and environmental conditions of the in-service experience can be clearly defined and if they match or are conservative for the new application.
- 403** Material properties of the joints to be compared should be similar. The analysis method should be able to address all differences between the joints according to B100 and 200.

F 500 Laminated Joints

- 501** Laminated joints rely on the strength of the interface for load transfer. The interface has resin dominated strength properties. Defects in the interface tend to be more critical than defects in the interface of plies of laminate, because the joint interface is the only and critical load path.
- 502** The strength of the joint may be different from the through thickness matrix properties of the laminate, because the joint may be a resin rich layer and the joint may be applied to an already cured surface

instead of a wet on wet connection. (see manufacturing). The strength of the joint should be documented.

- 503** Laminated joints are very sensitive to peel conditions. Peel stresses should be avoided
- 504** For the interface between the joining laminates the matrix design rules given in Section 5 apply. The resistance of the interface shall be determined with the same level of confidence as specified in *section 4 A600*. It shall be recognised that the resistance of the interface between the laminates may not be the same as the corresponding resistance parameter of the joining laminates. Resin rich layers may even have to be analysed by different failure criteria, e.g., the yield criterion in *section 6 F*.
- 505** The laminates themselves, including possible overlaminations, shall be analysed like regular laminates.

F 600 Adhesive Joints

- 601** All issues related to laminated joints also apply to adhesive joints.
- 602** Geometrical details should be clearly specified, especially at points of stress concentrations like the edges of the joints.
- 603** The relationship between all elastic constants of both substrates and the adhesive should be carefully considered. Mismatches may introduce stresses or strains that can cause failure of the joint.
- 604** Thermal stresses should be considered.
- 605** Long term performance of adhesive should be established with great care. The long-term performance is not only influenced by properties of the substrate, the adhesive and the interface, but also by the surface preparation and application method.
- 606** Relevant long-term data shall be established exactly for the combination of materials, geometries, surface preparation and fabrication procedures used in the joint.
- 607** An adhesive joint may also introduce local through thickness stresses in the composite laminate that can lead to failure inside the laminate in the joint region.

F 700 Mechanical Joints

- 701** Mechanical joints are often very sensitive to geometrical tolerances.
- 702** Creep of the materials shall be considered.
- 703** The pretension of bolted connections shall be chosen by considering possible creep of the material under the bolt.
- 704** It is preferred to design the joint in a way that its performance is independent of the matrix. This way matrix cracking or degradation of matrix properties are not important for the performance of the joint.

G. Test requirements

G 100 General

- 101** Due to the uncertainties in designing connectors and liners some testing is required to confirm predicted performance.
- 102** Testing should be done whenever uncertainties in the analysis cannot be resolved. These uncertainties may be related to the structural analysis, boundary conditions, modelling of local geometry, material properties, properties of interfaces, etc. The procedure given in DNV-OS-C501 should be followed for testing.
- 103** The predicted performance of the Composite Metal connector Interface CMI and the resistance of the riser to external pressure shall be confirmed by testing. Minimum test requirements are given in Table 6-1.

Table 6-1: Summary of test requirements			
Design Phase	High safety class	Normal safety class	Reference
Axial test / pressure test	1 test to failure	1 test to failure	<i>G200</i>
Axial or bending fatigue of CMI	2 tests to 5x actual number of cycles or survival test to about 100000 cycles	1 test to 5x actual number of cycles or survival test to about 100000 cycles	<i>G300</i>
Stress rupture test of CMI if matrix properties are critical or fibres can creep	2 tests to 5x actual lifetime or survival test to about 1000 hours	1 test to 5x actual lifetime or survival test to about 1000 hours	<i>G400</i>
If the inner liner is bonded to the laminate	Test bond between liner and laminate	Test bond between liner and laminate	<i>G500</i>
External pressure test	Use specimen after fatigue test and expose to maximum external pressure	Use specimen after fatigue test and expose to maximum external pressure	<i>G500</i>
If impact requirement	Impact tests	Impact test	<i>Section 5 F300-500</i>
After fabrication			
Pressure test	Test to a given internal pressure for each riser component	Test to a given internal pressure for each riser component	<i>Section 5 A300</i>

- 104** Testing may be done at room temperature and with water as a pressure medium if the effect of temperature changes and fluid changes can be well described. If the effect of changing the environmental conditions is uncertain, testing should be carried out in the worst conditions.

G 200 Axial/Pressure test of riser with composite metal interface

- 201** One axial tensile test to failure shall be carried out. The axial tensile test can be replaced by a pressure test if the axial load created by the pressure test exceeds the maximum service load of the riser.
- 202** The failure load or pressure should be at least the predicted $\mu-2\sigma$ for high safety class and $\mu-\sigma$ for normal safety class, where μ is the mean prediction and σ is one standard deviation of the predicted load. If more than one test is done the requirements are given in *DNV-OS-C501 Section 10C200*.
- 203** If the performance of the CMI is very dependent on the internal pressure it should be evaluated if axial testing with and without internal pressure is required to demonstrate the performance of the CMI. The evaluation should be based on how well the strength can be predicted by modelling for the two conditions.

G 300 Cyclic fatigue testing for end fittings and composite metal interface

- 301** Fatigue testing should be performed in axial tension or in bending. The most relevant test should be found by evaluating the design analysis.
- 302** For high safety class at least two survival tests shall be carried out. The specimen should not fail during the survival test and it should not show unexpected damage. The requirements to the testing are:
- Tests should be carried out up to five times the maximum number of design cycles with realistic amplitudes and mean loads that the component will experience.
 - If the anticipated lifetime exceeds 10^5 cycles testing up to 10^5 cycles may be sufficient. The load levels should be chosen such that testing of the two specimens is completed after at least 10^4 and 10^5 cycles respectively. The two test results shall fall within $\mu-2\sigma$ of the anticipated number of cycles to failure, where μ is the mean prediction and σ is one standard deviation of the predicted lifetime. If more tests are made the requirements are given in *DNV-OS-C501 Section 4H806*.
- 303** For normal safety class at least one survival test shall be carried out. The specimen should not fail during the survival test and it should not show unexpected damage. The requirements to the testing are:
- Tests should be carried out up to five times the maximum number of design cycles with realistic amplitudes and mean loads that the component will experience.
 - If the anticipated lifetime exceeds 10^5 cycles testing up to 10^5 cycles may be sufficient. The load levels should be chosen such that testing of the two specimens is completed after at least 10^4 and 10^5 cycles respectively. The test results shall fall within $\mu-\sigma$ of the anticipated number of cycles to failure, where μ is the mean prediction and σ is one standard deviation of the predicted lifetime. If more tests are made the requirements are given in *DNV-OS-C501 Section 4H806*.

- 304** For low safety class long term testing is not required.
- 305** The sequence of the failure modes in the test shall be the same as predicted in the design. If the sequence is different or if other failure modes are observed, the design shall be carefully re-evaluated.
- 306** Fatigue tests should be carried out with a typical load sequence or with constant load amplitude. If a clearly defined load sequence exists, load sequence testing should be preferred.
- 307** In some cases high amplitude fatigue testing may introduce unrealistic failure modes in the structure. In other cases, the required number of test cycles may lead to unreasonable long test times. In these cases an individual evaluation of the test conditions should be made that fulfils the requirements of 302 or 303 as closely as possible.
- 308** Additional tests may be required if resistance to a failure mode cannot be shown by analysis with sufficient confidence and if this failure mode is not tested by the tests described above.

G 400 Stress rupture testing for end fittings and composite metal interface

- 401** Only if the performance of the metal composite interface depends on matrix properties or adhesives, or if the fibres in the laminate can creep, long term static testing should be performed. Two survival tests should be carried out for high safety class applications and one survival test for normal safety class applications. If it can be shown that the CMI keeps its strength if the matrix in the laminate is cracked and degraded and the fibres do not creep, long term static testing is not required.
- 402** For high safety class at least two survival tests shall be carried out. The specimen should not fail during the survival test and it should not show unexpected damage. The requirements to the test results are:
- Tests should be carried out up to five times the maximum design life with realistic mean loads that the component will experience.
 - If the anticipated lifetime exceeds 1000 hours testing up to 1000 hours may be sufficient. The load levels should be chosen such that testing is completed after 10^3 hours. The two test results shall fall within $\mu - 2\sigma$ of the anticipated lifetime, where μ is the mean prediction and σ is one standard deviation of the predicted lifetime. If more tests are made the requirements are given in *DNV-OS-C501 Section 4H806*.
- 403** For normal safety class at least one survival test shall be carried out. The specimen should not fail during the survival test and it should not show unexpected damage. The requirements to the test results are:
- Tests should be carried out up to five times the maximum design life with realistic mean loads that the component will experience.
 - If the anticipated lifetime exceeds 1000 hours testing up to 1000 hours may be sufficient. The load levels should be chosen such that testing is completed after 10^3 hours. The two test results shall fall within $\mu - \sigma$ of the anticipated lifetime, where μ is the mean prediction and σ is one standard deviation of the predicted lifetime. If more tests are made the requirements are given in

DNV-OS-C501 Section 4H806.

- 404** For low safety class long term testing is not required.
- 405** The sequence of the failure modes in the test shall be the same as predicted in the design. If the sequence is different or if other failure modes are observed, the design shall be carefully re-evaluated.
- 406** Stress rupture tests should be carried out with a typical load sequence or with a constant load. If a clearly defined load sequence exists, load sequence testing should be preferred.

G 500 Inner liner test requirements

- 501** If the design relies on a bond between liner and composite laminate, the quality of the bond shall be tested. Tests can be done on the pipe or representative smaller specimens. If the laminate may have cracks, but the liner not, the requirements in D507 should be considered
- 502** If the riser may be exposed to external pressures its resistance to buckling should be tested. The test shall be carried out by applying maximum external pressure to the riser. The riser and liner shall be produced with controlled and representative tolerances. Testing shall be carried out according to the requirements in *DNV-OS-C501 Section 10*. External pressure testing shall be carried out on test specimens that have previously been exposed to high loads and have developed representative degradation of material properties. The fatigue tests specified in *G200* can most likely also be used to introduce representative damage.
- 503** Testing of a bent riser under external pressure should be considered if:
 - If the riser can be bent in service and this bending could reduce the resistance to internal pressure (e.g. due to ovalisation).
 - If the effect of ovalisation on the buckling resistance cannot be predicted by calculations with sufficient confidence.

G 600 Specimen geometry - Scaled Specimen

- 601** The specimen geometry for testing may be chosen to be different from the actual under certain conditions.
- 602** Specimens may be shorter than in reality. The free length of the riser pipe between end-fittings should be at least 6 diameters.
- 603** Most test specimens have a relevant CMI at both ends of the riser pipe. In this case testing one riser pipe with two CMIs can be used to fulfil the requirement of two survival tests for the CMI, provided both CMIs are exposed to the same loading conditions.
- 604** Scaled specimens may be used if analytical calculations can demonstrate that:

- All critical stress states and local stress concentrations in the joint of the scaled specimen and the actual riser are similar, i.e., all stresses are scaled by the same factor between actual riser and test specimen.
 - The behaviour and failure of the specimen and the actual riser can be calculated based on independently obtained material parameters. This means no parameters in the analysis should be based on adjustments to make large scale data fit.
 - The sequence of predicted failure modes is the same for the scaled specimen and the actual riser over the entire lifetime of the riser.
 - An analysis method that predicts the test results properly but not entirely based on independently obtained materials data, may be used for other joint geometries. In that case it should be demonstrated that the material values that were not obtained by independent measurements can also be applied for the new conditions.
- 605** Tests on previous risers may be used as testing evidence if the scaling requirement in *604* is fulfilled. Materials and production process should also be identical or similar. Similarity should be evaluated based on the requirements in *DNV-OS-C501 Section 4*.

SECTION 7 MATERIALS

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A. General

A 100 Objective

101 This section specifies the requirements for materials, manufacture, fabrication and documentation of riser pipe, components, equipment and structural items in the riser system, with regard to the characteristic properties of materials. The requirements are relevant both for pressure containing and for load carrying parts.

A 200 Material Description

201 The materials selected shall be suitable for the intended use during the entire service life. The materials for use in the riser system shall have the dimensions and mechanical properties, such as strength, ductility, toughness, corrosion and wear resistance, necessary to comply with the assumptions made in the design.

202 The materials selected shall be suitable for the intended use during the entire service life. The materials for use in the riser system shall have the dimensions and mechanical properties, such as strength, ductility, toughness, corrosion and wear resistance, necessary to comply with the assumptions made in the design.

203 Composite material properties shall be described and tested as given in DNV Offshore standard for composite components *DNV-OS-C501 Section 4*.

204 Metal properties shall be described and tested as given in DNV Offshore standard for dynamic risers *DNV-OS-F201*.

205 Titanium parts should be described and tested as given in *DNV-RP-F201 "Titanium Risers"*.

SECTION 8 DOCUMENTATION AND VERIFICATION

SECTION 8 DOCUMENTATION AND VERIFICATION	1
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A. General

101 All requirements given in DNV-OS-F201 apply also to composite risers.

SECTION 9 OPERATION, MAINTENANCE, REASSESSMENT, REPAIR

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A. General

A 100 Objective

101 The objective of this section is to provide requirements for operation and in-service inspections. This section also provides general guidance on structural integrity assessment of risers to demonstrate fitness for purpose in case deviations from design appear during operation.

B. In-service Inspection, Replacement and Monitoring

B 100 General

101 The requirements for composite risers are the same as given in *DNV-OS-F201 Dynamic Risers*.

102 Some special considerations apply for inspection methods.

B 200 Inspection methods

201 If the riser is designed according to this document and if the predicted time to failure divided by the

fatigue safety factor from *Section 5* is longer than the intended service life, inspection is not expected to be necessary and need not be included in the in the operation and maintenance documents. However, if the intended service life is exceeded or if load or environmental conditions were worse than planned, then the component should be inspected and refurbished if necessary or replaced.

- 202** Available inspection methods can often not detect all critical failure mechanisms. However, the methods may detect preceding failure mechanisms. A link between detectable failure mechanisms and critical failure mechanisms shall be established.
- 203** In many cases a complete inspection programme cannot be developed due to the limited capabilities of available NDE equipment. In that case the following alternatives may be used:
- 204** Inspection of components during or right after manufacturing may be replaced by well documented production control.
- 205** Inspection to detect damage due to accidental loads or overloads may be compensated for by monitoring the loads and comparing them to the design loads.

C. Reassessment

C 100 General

- 101** The requirements for composite risers are the same as given in *DNV-OS-F201 Dynamic Risers*. *The only exception are references to corrosion allowance. These are not relevant for composite materials.*

D. Repair

D 100 General

- 101** This section applies to repairs of defects that influence the structural integrity or a functional requirement, e.g. tightness.
- 102** Cosmetic, non-structural and non-functional repairs do not need to be qualified.

D 200 Repair procedure

- 201** A repair procedure shall be given for each component.
- 202** A repair shall restore the same level of safety and functionality as the original structure, unless changes are accepted by all parties in the project.
- 203** An acceptable repair solution is to replace the entire component if it is damaged. This approach

requires that the component can be taken out of the system.

- 204** It may also be acceptable to keep a component in service with a certain amount of damage without repairing it. The size and kind of acceptable damage shall be defined and it must be possible to inspect the damage. The possible damage shall be considered in the design of the structure.
- 205** If local damage may happen to the structure detailed procedures to repair such anticipated damage shall be given.
- 206** If the damage is due to an unknown loading condition or accident, an analysis of the damage situation shall be carried out. The analysis shall identify whether the damage was due to a design mistake or an unexpected load condition. If the unexpected load may reoccur a design change may be required.

D 300 Requirements for a repair

- 301** A repair should restore the stiffness and strength of the original part. If the stiffness and/or strength cannot be restored, the performance of the component and the total system under the new conditions shall be evaluated.
- 302** It shall be documented that local reduction in strength may not be critical for the total performance of the structure.

D 400 Qualification of a repair

- 401** A repair is basically a joint introduced into the structure. The repair shall be qualified in the same way as a joint (see *Section 6b*).
- 402** The repair procedure used to qualify the joint shall also be applicable for each particular repair situation.
- 403** Suitable conditions for repair work shall be arranged and maintained during the repair. This is mandatory, irrespective of whether the repair is carried out on site or elsewhere. If suitable conditions cannot be arranged and maintained on site, the component should be moved to a more suitable site.