Design, testing and analysis of offshore fibre ropes
FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.
CHANGES – CURRENT

General
This is a new document.

Acknowledgements
The basic spring-dashpot model was established by Mr. John Flory (Morristown, New Jersey) when developing methods for characterising the tension versus stretch behaviour of polyester rope, and Figure 2-16 was also kindly provided.

The concept of design range was presented by Mr. Frits Elkink (Arnhem, the Netherlands) when providing fundamental insights concerning the integrity of polyester yarn, and Figure 2-4 was also kindly provided.

The concept of using the nominal load-bearing linear density as basis for analysing offshore fibre ropes was proposed by Mr. Neil Schulz (Hailsham, East Sussex).

This first issue of this recommended practice is based on DNV GL’s interpretation of the findings from two joint industry projects and a joint industry project pre-study, combined with other experience gained by DNV GL:

— Joint industry project: Managing the Safe Service Life of Fiber Ropes for Mooring
— Joint industry project: Improving Fiber-Mooring Design Practices
— Joint industry project pre-study: Syrope Pilot Study.

The joint industry projects were made possible thanks to the participation of BP, Chevron, Durafiber Technologies, SBM Offshore, Sevan Marine, Petrobras, Statoil, Viking Seatech, and others.

Samples for testing have been provided by Bexco, Bridon International, and Lankhorst Euronete.

Rope manufacturers’ reference groups further consisted of DSM Dyneema, Teijin Aramid, and others.

The pre-study was commissioned by Statoil.
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SECTION 1 INTRODUCTION

1.1 Fitness for purpose
This recommended practice aims to provide recommendations on how to document that offshore fibre ropes for delivery will be fit for purpose.

It provides general recommendations and information pertaining to synthetic lines intended for offshore use. The recommended practice addresses three main areas:
— design of synthetic lines for intended offshore use
— testing of performance characteristics for synthetic lines
— analysis of synthetic lines as part of an integrated system

It provides recommendations for design, testing and analysis of synthetic lines for use in:
— offshore mooring systems as described in DNVGL-OS-E301
— deepwater deployment and recovery systems as described in DNV-OS-E407
— other offshore applications.

1.2 Fitness for designated service
This recommended practice does not address the fitness for designated service of offshore fibre ropes when in use.

The recommended practice DNV-RP-E304 aims to provide recommendations on how to maintain and document that offshore fibre ropes remain fit for designated service throughout operations.

 Guidance note: The recommended practice DNV-RP-E304 Damage Assessment of Fibre Ropes for Offshore Mooring is intended to be updated to provide more recommendations on fitness for designated service of offshore fibre ropes. It is intended to be reissued as DNVGL-RP-E304 Condition Management of Offshore Fibre Ropes.

1.3 Applicable requirements
Requirements set by DNV GL for the documentation of synthetic lines and cables for offshore use can be found in DNVGL-OS-E303 Offshore fibre ropes.

Requirements set by DNV GL for the documentation of offshore mooring systems can be found in DNVGL-OS-E301 Position mooring.

Requirements set by DNV GL for the documentation of deepwater deployment and recovery systems can be found in DNV-OS-E407 Underwater Deployment and Recovery Systems.

Requirements for offshore mooring fibre ropes have been issued by American Bureau of Shipping and Bureau Veritas.

Several company specifications have been issued.

Nothing in this recommended practice should be construed as requirement unless specifically referenced as such by a standard or specification, in which case the referenced part of this recommended practice will be a requirement of that document.

Other documents such as the API RP 2SM or the ISO 18692 will constitute requirement if referenced as such, either in part or entirely.

1.4 About this recommended practice

1.4.1 Use
This recommended practice is intended to provide information useful to users, owners, system integrators, rope manufacturers, manufacturers of load-bearing synthetic yarns and coating, and manufacturers of
termination hardware.

It is attempted to structure this document according to principles rather than application areas. It is attempted to link recommendations to specific uses only where necessary, in the hope that this will increase the versatility of the document for readers who are involved with several application areas and for readers who are unfamiliar with the topics.

### 1.4.2 Contractual reference

For contractual reference between supplier and recipient of offshore fibre rope, this document recommends adopting DNVGL-OS-E303 which is written with this in mind and which provides documentation requirements.

Guidance note:
DNVGL-OS-E303 also provides certification requirements (in chapter 3), as applied by DNV GL.

---end---of---guidance---note---

### 1.4.3 Key aspects

This recommended practice emphasises the following key aspects in this current, first issue:

- Offshore fibre rope should be analysed on the basis of amount of load-bearing material in the cross section, and the characteristics of the material used.
- The tension versus stretch behaviour of synthetic rope, which is fundamentally different to that of steel wire rope.
- The strength and endurance of synthetic rope and steel-wire rope are governed by fundamentally different mechanisms.

These key aspects are not believed to be widely implemented in industry practices in the way they are described in this document.

Guidance note:
Fibre ropes should not be analysed on the basis of diameter, because both load-bearing capability and tension versus stretch performance are functions of the actual amount of load-bearing material in the rope cross-section. The quantity of load-bearing material in ropes of a certain nominal diameter will depend on the rope construction.

Current software tools for analysis of systems may have limitations with respect to the representation of non-linear and time-dependent stretch under tension. However, the focus of this document is to share what DNV GL finds to be the best possible information about synthetic lines and their behaviour, and which is currently available to be published.

On that basis, this document aims to provide recommendations for developers of analysis software, and for system integrators who specify requirements to software programs.

---end---of---guidance---note---

### 1.4.4 Relevance, completeness and other methods

This recommended practice provides information which DNV GL believes is relevant in connection with the documentation of a delivery of offshore fibre rope.

This document does not cover complete methods for providing the necessary documentation for a delivery of offshore fibre rope.

Recommendations provided in this document should not be regarded to exclude other methods for fulfilment of requirements.

This recommended practice uses S.I. units. Appropriate U.S. Customary units can also be used.

### 1.4.5 Further information and other recommendations

For general aspects of the making of ropes for marine use, reference is made to OCIMF Guidelines for the purchasing and testing of SPM hawsers, and to Handbook of fibre rope technology [1].

Recommendations and useful information can also be found in DNV-RP-E304 and in API RP2SM and in ISO 18692.

An overview of DNV GL documents that are relevant for offshore fibre ropes is provided in App.B.
1.4.6 Revisions and feedback

This recommended practice is intended to be revised in order to provide more recommendations and to present new knowledge. Readers are encouraged to provide comments and input to rules@dnvgl.com.

Information about ongoing development work can be obtained by sending an e-mail to rules@dnvgl.com.

1.5 Offshore fibre ropes

1.5.1 General

The design of an offshore fibre rope will depend on the intended use with designated service. Offshore fibre ropes can be made to resist torque, or made to be torque neutral. An offshore fibre rope can be manufactured as a single rope in a braided or a helical arrangement of the strands (construction). The built-in twist of the strands will depend on the production method. Offshore fibre ropes can also be manufactured as a bundle of parallel elements, being subropes or assembled yarns. Parallel-element designs rely on a jacket to hold the bundle of load-bearing elements together, and are usually intended for point-to-point loading only.

The term ‘line’ is often used to refer to offshore fibre ropes including their terminations with designated termination hardware. Normally thimbles are used in spliced eyes, and the element connecting to the thimble is outside the scope of this recommended practice.

Jackets need to be permeable to ensure that the line is free flooded. For long-term exposure to sunlight, such as in shallow water or on-shore storage, the jacket should be sufficiently dense to protect the load-bearing elements from sunlight. The line should be otherwise protected from the sunlight as required.

Guidance note:

UV damage due to sunlight is generally not considered to be of concern with polyester and HMPE fibre ropes in submersed service.

---e-n-d---of---g-u-i-d-a-n-c-e-n-o-t-e---

Illustrations of different types of constructions are shown in *Handbook of fibre rope technology* /1/. Further information can be obtained from the manufacturers. Some illustrations are provided in DNV-RP-E304.

1.5.2 Load-bearing materials

Offshore fibre ropes can be manufactured from a range of synthetic yarn materials, such as aramid, HMPE (High Modulus PolyEthylene), LCP (Liquid Chrystal Polymer), polyamide (nylon), or polyester.

1.6 Types of loading

In this recommended practice, the loading of offshore fibre ropes is categorised in two ways:

— point-to-point loading
— combined loading.

Point-to-point loading means pure, axial tension, where for example a mooring tether is part of a taut-leg mooring system, or a pendant line is used for a lifting operation.

Combined loading involves additional bending or twisting. 'Bending' is all cases where the rope is deflected under axial tension such as when it runs over a sheave in a deployment and recovery system on an offshore service vessel. Twist may be the result of relative rotation between the end terminations, or it may occur locally on the rope.
1.7 Point-to-point loading

1.7.1 Offshore mooring systems
At the time of this recommended practice, the most common type of line for offshore moorings with loading in pure tension consists of parallel subropes with spliced eyes that are held together by a braided jacket. These are called parallel-subrope tethers.

The subropes consist of strands in a helical or braided arrangement. The helical subropes typically use three or four strands, whereas the braided subropes typically use eight or twelve strands; but this can vary. The size and number of subropes to make up the load-bearing core of the line varies between manufacturers.

Rope constructions resembling those of steel-wire rope are also used, either as subropes or as single rope. These types develop torque when loaded, as do stranded steel-wire ropes.

Synthetic mooring lines are normally protected by an outer sheathing. A filter can be incorporated in this sheathing to protect the load-bearing elements from particles that can contribute to internal wear.

In mooring legs containing chain or torque-neutral wire rope, the synthetic line should also be torque neutral. The parallel-element tether is suited towards this purpose. Torque-neutral tethers either have braided subropes which are inherently torque-neutral, or they have helical subropes where 50% are S-lay and 50% Z-lay.

1.7.2 Lifting slings
Lifting slings can be manufactured either as single ropes or in a parallel-element construction.

Lifting slings need to be protected from damage to the load-bearing elements, and handled and stored appropriately.

Discard criteria should be stated or referenced on the sling label.

The sling label should state the applicable requirements to the bearing points, such as surface requirements and bending radius, and requirements to loading configuration.

1.8 Combined loading

1.8.1 Deepwater deployment and recovery systems
Compared to the types of lines discussed above, lifting lines for deepwater deployment and recovery systems (DDRS) will be working as part of a hoisting device. This entails working of the rope over sheave(s) and thus it is loaded more complexly than in pure tension. The loading will include both bending and twisting.

Lifting lines should be made in a construction of load-bearing strands to keep the rope together when it is loaded in tension, bending or twisting. The rope should not rely on a jacket to keep its elements together. On that basis, parallel-element lines are generally not considered suited as DDRS lifting lines; however specially engineered exceptions might exist.

1.8.2 Offshore mooring systems
Synthetic mooring lines should be constructed with similar torque/twist characteristics as the remainder of the mooring leg.

Such ‘torque-matching’ is primarily performed in order to better the cyclic endurance of connecting steel-wire rope, as wire rope un-laying (and re-laying) can affect its fatigue life.
1.9 References

1.9.1 DNV GL references

Relevant reference publications from DNV GL are provided below.

Table 1-1 DNV GL Rules for classification - Offshore units

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-RU-OU-0101</td>
<td>Offshore drilling and support units</td>
</tr>
<tr>
<td>DNVGL-RU-OU-0102</td>
<td>Floating production, storage and loading units</td>
</tr>
</tbody>
</table>

Table 1-2 DNV Service specification

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV-DSS-401</td>
<td>Technology Qualification Management</td>
</tr>
</tbody>
</table>

Table 1-3 DNV GL and DNV Offshore standards

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-OS-B101</td>
<td>Metallic Materials</td>
</tr>
<tr>
<td>DNVGL-OS-C401</td>
<td>Fabrication and Testing of Offshore Structures</td>
</tr>
<tr>
<td>DNV-OS-C501</td>
<td>Composite Components</td>
</tr>
<tr>
<td>DNVGL-OS-E301</td>
<td>Position Mooring</td>
</tr>
<tr>
<td>DNVGL-OS-E302</td>
<td>Offshore Mooring Chain</td>
</tr>
<tr>
<td>DNVGL-OS-E303</td>
<td>Offshore Fibre Ropes</td>
</tr>
<tr>
<td>DNVGL-OS-E304</td>
<td>Offshore Mooring Steel Wire Ropes</td>
</tr>
<tr>
<td>DNV-OS-E407</td>
<td>Underwater Deployment and Recovery Systems</td>
</tr>
<tr>
<td>DNV-OS-H101</td>
<td>Marine Operations, General</td>
</tr>
<tr>
<td>DNV-OS-H102</td>
<td>Marine Operations, Design and Fabrication</td>
</tr>
<tr>
<td>DNV-OS-H201</td>
<td>Load Transfer Operations</td>
</tr>
<tr>
<td>DNV-OS-H203</td>
<td>Transit and Positioning of Offshore Units</td>
</tr>
<tr>
<td>DNV-OS-H204</td>
<td>Offshore Installation Operations (VMO Standard Part 2-4)</td>
</tr>
<tr>
<td>DNV-OS-H205</td>
<td>Lifting Operations (VMO Standard Part 2-5)</td>
</tr>
</tbody>
</table>

Table 1-4 DNV Recommended practices

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
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<tbody>
<tr>
<td>DNV-RP-A203</td>
<td>Technology Qualification</td>
</tr>
<tr>
<td>DNV-RP-E304</td>
<td>Damage Assessment of Fibre Ropes for Offshore Mooring</td>
</tr>
</tbody>
</table>

Table 1-5 DNV Programmes for Approval of Manufacturers

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>321</td>
<td>Manufacturers of Offshore Fibre Ropes</td>
</tr>
<tr>
<td>322</td>
<td>Manufacturers of Offshore Fibre Yarns</td>
</tr>
</tbody>
</table>

The DNV GL service documents are available at http://www.dnvgl.com/rules-standards. An overview of DNV GL documents that are relevant for offshore fibre ropes is provided in App.B.

1.9.2 Other codes

The below documents contain information which can be useful to the reader of this recommended practice.

Table 1-6 Other codes

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Guidance Notes on the Application of Fiber Rope for Offshore Mooring</td>
</tr>
<tr>
<td>API RP25M</td>
<td>Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring</td>
</tr>
<tr>
<td>BV</td>
<td>Certification of Fibre Ropes for Deepwater Offshore Services – Guidance Notes</td>
</tr>
<tr>
<td>CI 1500</td>
<td>Test Methods for Fiber Rope</td>
</tr>
</tbody>
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Table 1-6  Other codes (Continued)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
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<tbody>
<tr>
<td>CI 1503</td>
<td>Test Method for Yarn-on-Yarn Abrasion</td>
</tr>
<tr>
<td>CI 2009N</td>
<td>Performance Requirements for Marine Grade Nylon Yarn For Fiber Rope</td>
</tr>
<tr>
<td>CI 2009P</td>
<td>Performance Requirements for Marine Grade Polyester Yarn For Fiber Rope</td>
</tr>
<tr>
<td>ISO 1968</td>
<td>Fibre ropes and cordage – Vocabulary</td>
</tr>
<tr>
<td>ISO 3344</td>
<td>Reinforcement products – Determination of moisture content</td>
</tr>
<tr>
<td>ISO 18692</td>
<td>Fibre ropes for offshore stationkeeping – Polyester</td>
</tr>
<tr>
<td>OCIMF</td>
<td>Guidelines for the purchasing and testing of SPM hawsers</td>
</tr>
</tbody>
</table>

Table 1-7  Enterprise abbreviations

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>American Bureau of Shipping</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BV</td>
<td>Bureau Veritas</td>
</tr>
<tr>
<td>CI</td>
<td>Cordage Institute</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>OCIMF</td>
<td>Oil Companies International Marine Forum</td>
</tr>
<tr>
<td>RPSEA</td>
<td>Research Partnership to Secure Energy for America</td>
</tr>
</tbody>
</table>

1.9.3  Other references

The below documents contain are referenced within this recommended practice.

Table 1-8  Other references

<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>/1/</td>
<td>McKenna HA, Hearle JWS, O’Hear N. Handbook of fibre rope technology. Woodhead Publishing Ltd 2004</td>
</tr>
<tr>
<td>/2/</td>
<td>Bosman RLM. On the Origin of Heat Build-up in Polyester Ropes. MTS-Oceans, Fort Lauderdale. 1998</td>
</tr>
<tr>
<td>/6/</td>
<td>Vlasbloom MP, Bosman RLM. Predicting the Creep Lifetime of HMPE Mooring Rope Applications. Technical paper IEEE 2006</td>
</tr>
<tr>
<td>/7/</td>
<td>Statoil requirements to cut-resistant jackets on polyester mooring lines for permanent installations. February 2011</td>
</tr>
<tr>
<td>/8/</td>
<td>Ayers R. Final Effects of Fiber-Rope/Seabed Contact on Subsequent Rope Integrity. RPSEA Doc. No.: 10121.4406.01. Stress Engineering Services Inc. October 2014.</td>
</tr>
</tbody>
</table>
### 1.9.4 Definitions

Terms defined in DNVGL-OS-E303 are applicable to this recommended practice. Further terms that are applicable to this recommended practice are provided below.

**Table 1-9 Terms**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-T utilisation assessment</td>
<td>assessment of residual service life based on an appropriate design curve for 3-T endurance. Recommendations concerning 3-T Utilisation Assessment will be provided in revisions of DNV-RP-E304.</td>
</tr>
<tr>
<td>aramid</td>
<td>para-aramid</td>
</tr>
<tr>
<td>combined loading</td>
<td>in addition to axial loading, combined loading includes bending or twisting, or both</td>
</tr>
<tr>
<td>condition management programme</td>
<td>programme for monitoring, inspection and maintenance during the service life in order to assure that the offshore fibre rope remains fit for designated service</td>
</tr>
<tr>
<td>core</td>
<td>parallel bundle of load-bearing subropes or assembled yarns in an offshore fibre rope</td>
</tr>
<tr>
<td>construction strain</td>
<td>semi-permanent strain which is related to the compaction and rearrangement of the rope structure for increasing tension</td>
</tr>
<tr>
<td>contraction</td>
<td>delayed decrease in line length due to a decrease in tension</td>
</tr>
<tr>
<td>creep failure</td>
<td>transition between stage II and stage III creep</td>
</tr>
<tr>
<td>cyclic endurance</td>
<td>ability to withstand prolonged cyclic loading with a controlled effect on the performance characteristics</td>
</tr>
<tr>
<td>design range</td>
<td>the biggest possible difference between the highest occurring tension and the lowest occurring tension which will not impair the 3-T endurance</td>
</tr>
<tr>
<td>dynamic stiffness</td>
<td>stiffness in response to harmonic or irregular tension variations. The dynamic stiffness changes with mean-tension and amplitude of loading, and it depends on previous loading and loading frequency. For prolonged cycling, the dynamic stiffness will increase, to approach the instant-elastic stiffness (at that working tension and tension amplitude). The dynamic stiffness is typically applicable for loading periods less than one minute in mooring analyses. It is used for low-frequency and wave-frequency tension variations and the instant-elastic stiffness can often be used conservatively.</td>
</tr>
<tr>
<td>elastic strain</td>
<td>strain which is proportional to the applied tension. Applicable to both the instant-elastic strain (immediate) and to the visco-elastic strain (delayed).</td>
</tr>
<tr>
<td>elongation</td>
<td>delayed increase in line length due to an increase in tension</td>
</tr>
<tr>
<td>endurance</td>
<td>ability to withstand prolonged loading with a controlled effect on the performance characteristics. Loading can be static, stochastically varying or cyclically varying.</td>
</tr>
<tr>
<td>extension</td>
<td>immediate increase in line length due to an increase in tension</td>
</tr>
<tr>
<td>fast stiffness</td>
<td>instant-elastic stiffness</td>
</tr>
<tr>
<td>fibre</td>
<td>bundle of filaments which is formed immediately after the individual filaments are formed in the production process</td>
</tr>
<tr>
<td>filament</td>
<td>individual synthetic fibre that is very long and made in a process that involves stretching</td>
</tr>
<tr>
<td>filter</td>
<td>barrier towards ingress of foreign matter, which is applied underneath the jacket</td>
</tr>
<tr>
<td>fit for designated service</td>
<td>capable of functioning safely and reliably with adequate performance under intended use and adequate condition management</td>
</tr>
<tr>
<td>fit for purpose</td>
<td>properly engineered, properly made and properly integrated in delivery condition, so that it can function safely and reliably with adequate performance in designated service</td>
</tr>
<tr>
<td>function</td>
<td>performance for purpose</td>
</tr>
<tr>
<td>Guidance note</td>
<td>advice or information which is additional to the recommendations of this document</td>
</tr>
<tr>
<td>holding curve</td>
<td>plot of strain versus time or of tension versus strain when tension is constant. Holding curves are the effects of the working strain and the polymer strain.</td>
</tr>
<tr>
<td>installation stretch</td>
<td>highest mooring line stretch which takes place during the installation process</td>
</tr>
<tr>
<td>installed stretch</td>
<td>mooring line stretch at equilibrium after completing the installation process</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>instant-elastic stiffness</td>
<td>stiffness resulting from instant-elastic strain only in response to very fast changes in tension. It is the dynamic stiffness around a working point.</td>
</tr>
<tr>
<td>instant-elastic strain</td>
<td>immediate strain which is proportional to the applied tension</td>
</tr>
<tr>
<td>jacket</td>
<td>sheathing on the free length which holds the core together and which can provide resistance to external damage</td>
</tr>
<tr>
<td>lifting line</td>
<td>line that is as an integral part of a lifting device</td>
</tr>
<tr>
<td>lifting pendant</td>
<td>single line for the intended use to extend the reach of a lifting device and which is loaded in tension only. It is not to be loaded in bending, but torsion might occur as a result of rotation of the lifted mass.</td>
</tr>
<tr>
<td>lifting sling</td>
<td>line intended for use as part of a standing lifting arrangement</td>
</tr>
<tr>
<td>line</td>
<td>offshore fibre rope that is finished for purpose with terminations and designated termination hardware</td>
</tr>
<tr>
<td>linear density</td>
<td>mass per length</td>
</tr>
<tr>
<td></td>
<td>Linear density as measured on a rope is not used in this recommended practice. In order to express the load-bearing cross section of the line, the nominal load-bearing linear density (NLLD) should be used, as expressed by the aggregate linear density of all load-bearing yarns. If needed for another reason than expressing the load-bearing cross section, linear density measurement on rope should be performed according to a norm such as CI 1500 or ISO 18692; however no emphasis is put on this type of linear density in this recommended practice.</td>
</tr>
<tr>
<td>loading curve</td>
<td>plot of tension versus stretch or of normalised tension versus strain</td>
</tr>
<tr>
<td></td>
<td>Examples of loading curves are the original loading curve, the subsequent loading curves for unloading and reloading, the original working curve and the subsequent working curves for unloading and reloading.</td>
</tr>
<tr>
<td>minimum breaking strength</td>
<td>indication of the suitable rating for connecting steel accessories, steel-wire rope or chain cables</td>
</tr>
<tr>
<td></td>
<td>In order to describe an offshore fibre rope the NLLD and generic load-bearing material should be stated on the label. Detailed information about the load-bearing material should be stated in the product documentation.</td>
</tr>
<tr>
<td>mooring leg</td>
<td>the series of mooring lines between anchor and floating unit</td>
</tr>
<tr>
<td>mooring line</td>
<td>rope or cable complete with terminations used alone or in series with other lines to maintain the position of a floating unit by transfer of tension to the anchor</td>
</tr>
<tr>
<td>nominal load-bearing linear density</td>
<td>total linear density of all the load-bearing yarns in the offshore fibre rope as stated by the yarn manufacturer for all the material used without considering the construction of the rope</td>
</tr>
<tr>
<td></td>
<td>There is no testing of rope required to determine nominal load-bearing linear density.</td>
</tr>
<tr>
<td>normalised stiffness</td>
<td>change in normalised tension divided by the change in strain</td>
</tr>
<tr>
<td></td>
<td>It has a unit of force per linear density, such as N/tex.</td>
</tr>
<tr>
<td>normalised tension</td>
<td>applied tension divided by the nominal load-bearing linear density</td>
</tr>
<tr>
<td></td>
<td>It has a unit of force per linear density, such as N/ktex.</td>
</tr>
<tr>
<td>offshore fibre rope</td>
<td>load-bearing rope for designated offshore service with strands that are made from synthetic load-bearing filament yarns, or jacketed bundle of load-bearing, parallel subropes or parallel yarns for designated offshore service</td>
</tr>
<tr>
<td>original loading curve</td>
<td>loading curve for when tension is applied the very first time</td>
</tr>
<tr>
<td></td>
<td>The original loading curve will depend on the rate of loading. It is general for all loading curves that quicker loading gives a steeper curve. It has been shown that the effect of variation in practical loading rates is small for the testing of polyester rope. Loading curves are typically obtained quickly enough to prohibit significant working strain and polymer strain from occurring in polyester.</td>
</tr>
<tr>
<td>original length</td>
<td>length of the offshore fibre rope as it has been produced</td>
</tr>
<tr>
<td></td>
<td>The original length is measured after a designated time at reference tension, either as the gauge length during testing, or as the original rope length during the process of manufacturing for delivery. A reference tension corresponding to 5 N/ktex, based on the nominal load-bearing linear density, with a minimum holding time of 17 minutes is recommended.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>original working curve</td>
<td>working curve for when tension is applied the very first time, slowly enough to permit visco-elastic strain to extend in proportion to the tension without delay. All strain contributions are active. The original working curve is the lower-bound original loading curve, for very slow loading. It is the working curve for loading of a new rope.</td>
</tr>
<tr>
<td>performance</td>
<td>quantitative expression of function</td>
</tr>
<tr>
<td>performance description</td>
<td>document that is provided by the supplier to describe how the product or system performs in designated service</td>
</tr>
<tr>
<td>performance characteristics</td>
<td>basis for evaluation of function</td>
</tr>
<tr>
<td>permanent strain</td>
<td>strain which remains in the rope after tension is removed</td>
</tr>
<tr>
<td>polymer strain</td>
<td>permanent visco-plastic strain</td>
</tr>
<tr>
<td></td>
<td>Polymer strain is permanent and remains in the rope, as contrasted to construction strain which contracts when the rope is relaxed and flexed.</td>
</tr>
<tr>
<td>preceding highest tension</td>
<td>highest peak tension that the rope has experienced since it was manufactured</td>
</tr>
<tr>
<td>preceding highest working tension</td>
<td>highest working tension that an offshore fibre rope has experienced since it was manufactured</td>
</tr>
<tr>
<td>qualification</td>
<td>making sure that a product or system meets acceptance criteria that are adequate for the designated service</td>
</tr>
<tr>
<td>quasi-static stiffness</td>
<td>working stiffness</td>
</tr>
<tr>
<td>reference tension</td>
<td>constant tension under which the original length is measured after a designated time. A reference tension corresponding to 5 N/kTex with a minimum holding time of 17 minutes is recommended.</td>
</tr>
<tr>
<td>retraction</td>
<td>immediate decrease in line length due to a decrease in tension. It is immediate.</td>
</tr>
<tr>
<td>rope</td>
<td>braided or helical assembly of strands made from yarns. The word is also used to refer to any type of offshore fibre rope in general text.</td>
</tr>
<tr>
<td>sheathing</td>
<td>protective jacket and soil barrier (if present)</td>
</tr>
<tr>
<td>slow stiffness</td>
<td>working stiffness</td>
</tr>
<tr>
<td>stiffness</td>
<td>ratio of change in tension to the corresponding stretch. The term spring rate is sometimes used for stiffness in other publications.</td>
</tr>
<tr>
<td>strain</td>
<td>stretch, ΔL, divided by the original length of the rope, L₀. Strain is the same as normalised stretch. The strain value can also be based on another reference length for the rope, Lᵢ.</td>
</tr>
<tr>
<td>strand</td>
<td>an assembly of yarns which are grouped together and form a rope (or a subrope) by either a helical or braided arrangement with other strands</td>
</tr>
<tr>
<td>stress rupture</td>
<td>breakage (of a synthetic fibre) due to prolonged application of tension which is lower than the break tension. The tension and the temperature affect the time to rupture. See the definition of 3-T.</td>
</tr>
<tr>
<td>stretch</td>
<td>change in rope length, ΔL, as a result from change in tension</td>
</tr>
<tr>
<td>subrope</td>
<td>several subropes are assembled in a parallel bundle to form the load-bearing core, such as in a tether for offshore mooring Subropes are not referred to as “rope” in this standard, but they are indeed ropes in their own right</td>
</tr>
<tr>
<td>system integrator</td>
<td>the role that is responsible for integration of the rope into a larger system such as a mooring system or deepwater deployment and recovery system. It is the responsibility of the System Integrator that the finalised system is fit for purpose, i.e. that it can provide its intended functions in the designated service</td>
</tr>
<tr>
<td>technology qualification</td>
<td>development of acceptance criteria that are adequate to show that the product will be fit for designated service. Reference is made to DNV-RP-A203.</td>
</tr>
</tbody>
</table>
tendon
vertical line that is used for the position keeping of a floating unit and which is pretensioned by the added buoyancy of the forced draught of the floating unit

termination
finished end of the offshore fibre rope that allows transfer of tension to connecting elements

termination hardware
component inserted in the rope eye to transfer the line loads from the fibre-rope segment to the connecting elements and the rest of the mooring line
The spool thimble made of steel is most commonly used.

tether
stationary line which is used to restrict movement
A tether can be made from a single rope; but it can also be a parallel assembly of load-bearing elements, either subropes or yarns.

tex
$10^{-3} \text{ g/m} (= 1 \text{ mg/m})$; the basic unit for linear density as weight per length of textile fibres

transport weight
weight of the fibre rope segment with a water content that is representative for outdoor conditions, after heavy rain and allowing excess water to drain off
The spliced eyes need to be self-draining, not to accumulate any water inside the PU coating, if present.

working curve
plot of working tension versus stretch, or of normalised working tension versus strain

working length
the length of the rope after stabilisation of working stretch

working point
point on a working curve that defines the working length of the rope at a given tension

working stiffness
the stiffness between two working points

working strain
total strain corresponding to stabilised visco-elastic strain

working tension
tension level that corresponds to the working stretch having stabilised

---

Table 1-9 Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>tendon</td>
<td>vertical line that is used for the position keeping of a floating unit and which is pretensioned by the added buoyancy of the forced draught of the floating unit</td>
</tr>
<tr>
<td>termination</td>
<td>finished end of the offshore fibre rope that allows transfer of tension to connecting elements</td>
</tr>
<tr>
<td>termination hardware</td>
<td>component inserted in the rope eye to transfer the line loads from the fibre-rope segment to the connecting elements and the rest of the mooring line</td>
</tr>
<tr>
<td>tether</td>
<td>stationary line which is used to restrict movement</td>
</tr>
<tr>
<td>tex</td>
<td>$10^{-3} \text{ g/m} (= 1 \text{ mg/m})$; the basic unit for linear density as weight per length of textile fibres</td>
</tr>
<tr>
<td>transport weight</td>
<td>weight of the fibre rope segment with a water content that is representative for outdoor conditions, after heavy rain and allowing excess water to drain off</td>
</tr>
<tr>
<td>working curve</td>
<td>plot of working tension versus stretch, or of normalised working tension versus strain</td>
</tr>
<tr>
<td>working length</td>
<td>the length of the rope after stabilisation of working stretch</td>
</tr>
<tr>
<td>working point</td>
<td>point on a working curve that defines the working length of the rope at a given tension</td>
</tr>
<tr>
<td>working stiffness</td>
<td>the stiffness between two working points</td>
</tr>
<tr>
<td>working strain</td>
<td>total strain corresponding to stabilised visco-elastic strain</td>
</tr>
<tr>
<td>working tension</td>
<td>tension level that corresponds to the working stretch having stabilised</td>
</tr>
</tbody>
</table>

Table 1-10 Abbreviations

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-T</td>
<td>the load-bearing capability of synthetic-yarn materials is referred to as 3-T endurance since it depends on the combination of the critical parameters 'tension', 'temperature' and 'time'</td>
</tr>
<tr>
<td></td>
<td>As the criticality of each parameter depends on the other two critical parameters, all three can be seen as a single, three-dimensional, critical parameter called 3-T. See DNV-RP-A203 for explanation of critical parameters.</td>
</tr>
<tr>
<td>DDLS</td>
<td>deepwater deployment and recovery system; see DNV-OS-E407</td>
</tr>
<tr>
<td>dtex</td>
<td>$10^{-1} \text{ tex} (= 10^{-4} \text{ g/m})$</td>
</tr>
<tr>
<td>HMPE</td>
<td>high-modulus polyethylene</td>
</tr>
<tr>
<td>ktex</td>
<td>$10^{3} \text{ tex} (= 1 \text{ g/m})$</td>
</tr>
<tr>
<td>MBS</td>
<td>minimum breaking strength</td>
</tr>
<tr>
<td>Mtex</td>
<td>$10^{6} \text{ tex} (= 1 \text{ kg/m})$</td>
</tr>
<tr>
<td>NLLD</td>
<td>nominal load-bearing linear density</td>
</tr>
<tr>
<td>S</td>
<td>normalised stiffness</td>
</tr>
<tr>
<td>S</td>
<td>the letter 'S' is used to denote the left-hand orientation of a rope or subrope strand</td>
</tr>
<tr>
<td></td>
<td>The same definition is also used for yarns.</td>
</tr>
<tr>
<td>tex</td>
<td>$10^{-3} \text{ g/m} (= 1 \text{ mg/m})$; the basic unit for linear density as weight per length of textile fibres</td>
</tr>
<tr>
<td>Z</td>
<td>the letter 'Z' is used to denote the right-hand orientation of a rope or subrope strand</td>
</tr>
<tr>
<td></td>
<td>The same definition is also used for yarns.</td>
</tr>
</tbody>
</table>
SECTION 2  DESIGN CONSIDERATIONS

2.1 Introduction
In order for a line to function effectively, its purpose and service context should govern the selection of the type of offshore fibre rope and its dimensioning.

The offshore fibre rope will almost certainly be a critically important strength member, on which the safety and reliability of offshore operations will depend. This is the case for mooring systems, as well as for lines used for installation of sub-sea infrastructure, or performing a lifting operation in air or underwater.

When selecting a particular rope design for the designated service, there are several factors to consider which all affect the functional and economic performance of the system which the line is part of. The performance-based selection and optimisation of the offshore fibre rope are important to the economy and efficiency of operations.

The tension versus stretch behaviour of the finished line is governed by that of the load-bearing material and by how much load-bearing material there is in the rope. The amount of load-bearing material should be expressed by the nominal load-bearing linear density. The nominal load-bearing linear density also governs how much tension the line can carry.

Some important design aspects are discussed in the following.

Note:
Recommendations provided in this document must not be regarded to exclude other, relevant methods.

2.2 Striking the balance
Figure 2-16 shows an offshore mooring system on a floating platform. Using an offshore mooring system as an example, tether dimensioning will be driven by two conflicting concerns:

a) Wanting to use as little load-bearing material as possible for economy and sometimes for lower stiffness
b) Wanting to use as much load-bearing material as possible for load-bearing capacity and sometimes for higher stiffness

Since the taut line – as shown in Figure 2-16 – is providing the elasticity of the mooring system by way of the stretch characteristics of the tethers; increasing the load-bearing linear density will increase the fatigue loading of connectors, steel-wire ropes and chain cables.

For a given yarn material, the rope with less load-bearing material will stretch more for the same change in tension. The rope with more load-bearing material will thus allow less motion around the equilibrium point.

For reasons related to manufacture and transport, reducing the amount of load-bearing material might reduce the number of segments required for a given water depths or reel size. Less load-bearing material will contribute to a lower price for the lines and easier handling.

Increasing the amount of load-bearing material in the cross section of the rope – the nominal load-bearing linear density - increases the 3-T endurance margins for given tension and temperature sequences because the normalised tension level is reduced in the rope (the concept of 3-T is discussed in the following). At the same time, increasing the amount of load-bearing material reduces the fatigue life of steel elements that are connected to the rope because the cyclic stress levels are increased in these components.

When dimensioning the offshore fibre rope, these key concerns should be weighed against each other, and several iterations made in order to arrive at the optimal mooring line. The fibre material can be chosen in order to optimise the line length and the tension versus stretch performance to finalise the dimensioning process.

A qualitative illustration of some of the dimensioning trade-offs are shown in Figure 2-1.
As can be seen from Figure 2-1 it is not a given that “stronger is safer” when the whole mooring system is considered. In other words, there is no help in a strong synthetic line if it causes fatigue failure in the connectors, steel-wire ropes or chain cables.

The tension versus stretch performance and the 3-T endurance are the key rope properties required for dimensioning of synthetic mooring lines. The key to optimum, cost-efficient dimensioning is the balancing of the tension versus stretch performance and the tension/time/temperature (3-T) margins.

The main function of a mooring system is to keep the position of a floating unit within acceptable limits; and on that basis the following work sequence is recommended for the dimensioning of mooring systems:

- First - using the basic tension versus stretch characteristics - determine the combination of load-bearing material and nominal load-bearing linear density that provides the desired station-keeping performance for the mooring system.
- Then, verify the capacity of the mooring lines in terms of long-term 3-T endurance margins.
- Then, verify the capacity of the mooring lines in terms of short-term 3-T endurance margins at rapid loading rate.

The rope will have sufficient strength over time when the 3-T endurance margins have been deemed to be sufficient for the applicable range of temperatures. The verification of capacity in direct, rapid overloading should be done towards the short-term 3-T endurance.

### 2.3 Minimum breaking strength

On basis of the above, this recommended practice discourages the use of MBS as a design parameter for synthetic ropes. The MBS is a stated value and not a property of a synthetic rope, so for offshore fibre ropes the Minimum Breaking Strength should be taken as an indication of the suitable rating for connecting steel accessories, steel-wire rope or chain cables.

Break tests serve as coarse verification of the strength of the fibre rope when tested under given conditions using test samples of limited length. The breaking strength that is obtained in testing is related to the tension-time-temperature (3-T) performance in that it will vary depending on the rate of loading in the final parts of the test, and the temperature of the load-bearing yarns.

When determining MBS by testing it is usually required that the lowest result needs to meet or exceed the...
MBS. For practical dimensioning purposes in cases where the lowest result fails to meet a stated MBS requirement it should be observed that increasing the nominal load-bearing linear density can have adverse effects such as increased fatigue exposure of steel components and a stiffer rope. Rope bulkiness is usually no advantage, and in a DDRS system the tendency to generate heat will increase.

If the lowest result is significantly lower than the other results, leading to suspicion that something was wrong with the sample, then it can be disregarded provided the manufacturer produces a technical report with detailed analysis and explanation of the cause of the low result, and demonstrates the measures to be implemented to prevent the same error to occur during production of the delivery. Sound judgement is encouraged.

2.4 Load-bearing materials

Several options exist with respect to load-bearing yarn material. For example, in the case of shallow-water mooring systems one would want a more compliant yarn material that facilitates station-keeping in taut configuration without restricting floater motions too much. In deep water a stiffer load-bearing yarn will be required to restrict floater motions sufficiently, should it not be possible to dimension the rope based on the required stiffness with the material that is currently being considered.

Guidance note:
ISO 18692 (which applies to polyester) states that the load-bearing rope should be manufactured from yarns of average normalised breaking strength (tenacity) not less than 0.78 N/tex.

The nominal load-bearing linear density should be used for normalisation of tension levels to compare different ropes in the process of rope selection and dimensioning. In order to describe an offshore fibre rope the NLLD and generic load-bearing material should be stated on the label. Detailed information about the load-bearing material should be stated in the product documentation.

2.5 Specifying and describing offshore fibre rope

This section discusses aspects that are important to clarify in connection with acquisition of synthetic lines and cables for designated offshore service.

2.5.1 Roles

Typically, the manufacturer is responsible for delivering the lines to a system integrator, who is responsible for the delivery of the system that the offshore fibre rope will be part of. This can be an offshore mooring system, a system for Deepwater deployment and recovery, or an arrangement of lifting slings.

Guidance note:
In the mooring industry, the system integrator role is commonly referred to as ‘mooring designer’ or ‘design company’.

2.5.2 Standard reference

Reference to an adequate standard is recommended when specifying and describing offshore fibre ropes. The reference standard will contain requirements to the system integrators for specifying, and for the manufacturers to describe the deliverables.

Using a reference standard with a scheme for independent verification of documentation will help avoid mismatch or ambiguities in specifying and describing offshore fibre ropes. DNVGL-OS-E303 is recommended to be adopted as the reference standard for the documentation requirements.

Should the requirements of a reference standard not be adequate for the case at hand, then supplementary requirements need to be developed using technology qualification principles as described in DNV-RP-A203.

2.5.3 Performance specification and designated service

The performance specification is a document issued by the system integrator or purchaser which defines what performance requirements the line needs to meet.

Offshore fibre ropes are products that can be tailored by the manufacturer to the service context that is
specified by the client.

**Guidance note:**
Offshore fibre ropes should not be considered as consumables. Economy of operations is achieved by careful engineering and dimensioning for the intended use. Notwithstanding this, the implementation of standardised dimensioning might be favourable for many reasons such as economy of scale and logistics, in particular for Mobile Moorings.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

### 2.5.4 Performance description

The performance description is a document which is issued by the manufacturer to describe the performance characteristics of the rope. It should address the key rope characteristics that are required for the designated service.

### 2.5.5 Key characteristics

Key characteristics that should be described (stated and explained) by the rope manufacturer are:

- 3-T design curve or set of 3-T design data for applicable temperatures
- design range which defines the applicability of the 3-T design curve or 3-T design data
- tension versus stretch performance characteristics
- torque and twist characteristics
- restrictions pertaining to operations, i.e. the service context
- restrictions pertaining to handling and installation
- requirements for the condition management programme.

**Guidance note:**
Further aspects pertaining to specifying and ordering offshore fibre ropes can be based on DNVGL-OS-E303, and relevant parts of OCIMF Guidelines for the purchasing and testing of SPM hawsers, ISO 18692, ABS or BV Guidance Notes or API RP2SM. This recommended practice is intended to be updated in order to provide recommendations for specifying and describing offshore fibre ropes.

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### 2.6 Condition management

A condition management programme should be agreed between Owner and system integrator. The condition management programme needs to be communicated to the supplier of the rope prior to placement of an order since it might affect material choice and engineering dimensioning of the rope. The designated service, including storage and handling, needs to be considered before the type of rope and the engineering dimensioning of it are concluded.

**Guidance note:**
For example, will the line be required to be torque-free, or should it have a defined torque/twist performance in order to better manage the condition of connecting steel-wire ropes through the service life?

What are the requirements to stopping off; will there be a need for integrated solutions on the rope?

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

The lines should not be subject to damage that affects load-bearing yarns, or subjected to excessive tension or temperature with respect to the 3-T endurance.

Recommendations pertaining to monitoring, inspection and maintenance are intended to be provided in revisions of DNV-RP-E304. Not excluding other aspects, the following aspects are important for condition management:

- 3-T endurance
- external damage and repair
- internal abrasion
- contamination
- determining the condition of used rope with sufficiently documented loading and service history
- determining the condition of used rope without knowledge about service history.
2.7 On the difference between steel elements and synthetic elements

In the system standard DNVGL-OS-E301 Position mooring, failure by excessive tension is referred to as ultimate limit state (ULS).

For a chain cable, whether or not it will fail by overloading depends largely on the magnitude of tension and not the time under tension or the temperature. If it has been loaded to 90% of the strength before, still the strength remains unchanged and the same ultimate capacity will be available on the next high loading.

The principal difference between the design curve for steel elements based on loading cycles and the design curve for synthetic elements based on time under tension is illustrated in Figure 2-2, as given by the units on the axes.

The combined effect of tension and temperature will cause failure of a synthetic rope after a corresponding time; and therefore a design-curve approach should be used in order to ensure sufficient endurance margin.

**Figure 2-2 Principal design curves for steel elements (left) and for synthetic elements (right)**

In a mooring system, the temperature element can be easily managed by ensuring the free-flooding of lines that are fully submersed; whereas in a Deepwater deployment and recovery system – which may have so-called heave-compensating capability – the temperature will be of critical importance in addition to the magnitudes of tension.

**Guidance note:**
For steel elements, the assessment of endurance under constant tension is not required for applications covered by this recommended practice. For steel elements the endurance under cyclic tension is important. Synthetic ropes are largely insensitive to cyclic loading as long as abrasion is managed and the design range is not exceeded.

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

2.8 3-T endurance

The time that a synthetic filament can carry tension without breaking depends on what the tension is and what it has been before, and what the temperature is and what it has been before.

The ability of a synthetic filament, fibre, yarn or rope to carry tension is given by its 3-T Endurance. The ‘T’s refers to tension, temperature and time. the load-bearing capacity depends on the combination and preceding history of these critical parameters.

For example, for the same tension, increasing the temperature will reduce the time before the filaments fail. For the same temperature, reducing the tension will increase the time before the filaments fail.
The concept of 3-T is discussed in the following. In short, it can be explained as tension-dependent time to failure, or as time-related strength. The break strength is a special case of this time-related strength where the time is very short. The tension-dependent time to failure - or the time-related strength - also depends on the temperature.

The 3-T load-bearing endurance should be managed by a design curve approach.

**Guidance note:**
As the criticality of each parameter depends on the other two critical parameters, all three can be seen as a single, three-dimensional, critical parameter called 3-T. See DNV-RP-A203 for explanation of critical parameters.

The utilisation of 3-T endurance should be addressed to keep sufficient margins to failure. The approach is not yet fully developed; however notes on the subject are provided in Chapter 3 of this recommended practice which discusses system analysis. More information applicable to the analysis of 3-T performance in the delivery phase is intended to be provided in revisions of this recommended practice. More information applicable to the analysis of 3-T performance in the operations phase is intended to be provided in revisions of DNV-RP-E304.

2.8.1 The design curve for 3-T endurance

An example of development of a design curve for 3-T endurance based on test data is provided in DNV Programme for Approval of Manufacturers 322, App.B.

For practical purposes involving polyester, which has a pronounced logarithmic relationship between the time to failure and tension at typical offshore service temperatures, it should not be needed to analyse the utilisation of 3-T endurance if all tensions are kept below 70% MBS (about 350 N/ktex) and the temperatures are kept below 20°C (in polyester), and where this is documented as part of the condition management programme. For tensions above 350 N/ktex or for temperatures above 20°C in polyester the 3-T endurance margin should generally be established.

**Guidance note:**
A similar relationship is likely to apply to other load-bearing yarns, but this has not been tested by DNV GL at this time.
Polyester yarn 3-T test data obtained at 20°C can be used to evaluate the effects of changes in temperature, and if detailed dimensioning based on 3-T endurance will be necessary for the case at hand.

Short-term or long-term 3-T endurance might not be dimensioning in most cases for moorings, and the dimensioning failure modes will depend on the case at hand.

The 3-T design curve should provide the time to 2.5% failure probability as a function of normalised tension level in N/ktex.

For aramid, LCP, polyamide (nylon), or polyester, the failure time should be taken as equal to the time to rupture. This failure mode is often referred to as stress rupture. For HMPE the failure time should be taken as the time upon entering into creep region III. This failure mode is often referred to as creep failure, where gross rupture of the yarn or the rope is yet to occur; however the strain is accelerating.

Before establishing the 3-T design curve, enough tension levels should be tested in order to demonstrate that extrapolation is applicable for lower tension levels. Independence of sequence needs also to be validated in order that 3-T design curves can be applied for assessment of utilisation (according to the Miner-Palmgren summation principle).

It should further be noted that the 3-T performance of interest is that of the finalised offshore fibre rope. At the same time, the most efficient way of testing is undoubtedly on the yarns. Provided the relationship between yarn performance and rope performance is robustly understood then yarns should be chosen for the testing and the results translated to rope properties.

**Guidance note:**
Robust understanding implies showing by application of Technology Qualification principles as described in DNV-RP-A203.

2.8.2 Design range for fluctuating tensions

In comparison with metallic materials, synthetic yarns will be less sensitive to cyclic fatigue in that the endurance is governed by the highest tension and not by the variation in tension. However, there is generally a limit to that insensitivity and this limit is called the Design range.
The Design range expresses the largest difference between the absolute maximum tension and the absolute minimum tension that does not impair the design curve for 3-T endurance, as determined statically.

The 3-T load-bearing endurance is determined by testing with static loading; and it is thus required to establish the extent of tension fluctuation below this static level that can be tolerated whilst the statically determined design curve for 3-T endurance is still valid. With the static 3-T design curve in place, the Design range of the fibre rope needs to be determined by additional, cyclic tests.

It has been shown for polyester that tension variation below a constant tension level has a positive effect on the 3-T endurance for that tension level; however as cyclic unloading increases there is a limit to the beneficial effect of the unloading as this is “overtaken” by the adverse effect of cyclic loading of the filaments. This effect is illustrated in Figure 2-3.

![Figure 2-3](image)

**Figure 2-3  Cyclic unloading has both a beneficial and an adverse effect.**

Tension fluctuations equal to the Design Range should thus not affect the 3-T design curve for static loading. For this validation, a tension equal to the peak tension of the cycles is used.

For example, a design range of 250 N/mex means that the 3-T design curve (which has been obtained by static testing) is applicable to all loading scenarios where the difference between the highest and lowest occurring tension is within 250 N/mex.

Further notes on verification of 3-T design curve based on design-range test data is provided in DNV Programme for Approval of Manufacturers 322, App.C.

Testing to determine Design Range should be performed with varying tension range, and the effect investigated as illustrated in principle in Figure 2-4.
2.9 Temperature, internal heat build-up and external heat generation

The load-bearing endurance of a synthetic line depends on the temperature of the load-bearing yarn, and the preceding combinations of tension, time under tension, and temperature.

On this basis, offshore fibre ropes should be free-flooding in order to ensure cooling under dynamic loading underwater. Free-flooding is particularly important in the terminations where water will tend to be stationary.

For a rope which needs to serve under combined loading (possibly with so-called heave compensation) internal and external heat generation need to be actively managed. Material properties obtained at for example 20°C do not apply at for example 80°C. On the other hand, endurance data obtained for synthetic yarns at a higher temperature can usually be conservatively applied at a lower temperature.

The offshore fibre rope should be designed for the application in such a way that too much heat does not...
generate internally or externally. Heat build-up can occur internally due to phase difference and hysteresis effects within the load-bearing material, referred to as ‘tan $\Delta$’. More information can be found in paper On the Origin of Heat Build-up in Polyester Ropes [2]. Heat can also be generated by friction, which needs to be managed by the design and engineering processes, and by condition management activities.

**Guidance note:**
The methods to manage rope temperature will depend on the use and the service context. Recommendations can be included in revisions of this recommended practice.

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### 2.10 Tension versus stretch behaviour

#### 2.10.1 Introduction

The way that the length of an offshore fibre rope changes with applied tension is called its tension versus stretch behaviour. Stiffness for fibre rope is typically non-linear, though for some dimensioning purposes it can be treated as linear. Permanent strain is usually significant in fibre rope. Both stiffness and strain depend on the preceding loading of the offshore fibre rope.

Stiffness is not the same for all offshore fibre ropes, even for those of the same material type, such as polyester. Line behaviour can be tailored for an application through choice of load-bearing fibre material, dimensioning of nominal load-bearing linear density, and by varying the construction of the rope.

The term ‘rope’ refers to the so-called free length (between terminations), its construction and load-bearing linear density, and its load-bearing fibre material. The term ‘line’ includes the terminations and termination hardware as the rope is finished to be delivered.

**Guidance note:**
Fibre material refers to a producer’s fixed production description for the synthetic filament yarn. Another yarn of the same chemical material type, e.g. polyester, can have different properties imparted by the fibre spinning and drawing process, the associated temperature, and by the finish placed on the fibres. During the production process several filaments are combined into a fibre bundle, which is the starting point for turning the material into yarns for ropemaking.

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For improved explanations in text, this recommended practice uses the convention illustrated in Figure 2-5 for referring to how the length of a rope changes with either constant or changing tension.

![Figure 2-5](image)

**Figure 2-5** The convention used in this document to refer to rope stretch

The stretch over time due to changes in tension is important, in particular in systems where lines act in opposite directions such as in a mooring system or a lifting arrangement.

The offshore fibre rope tension versus stretch behaviour is discussed in the following, starting with the basic spring-dashpot model.

**Guidance note:**
Equally valid – or better – variant methods for describing non-linear tension versus stretch behaviour might exist or be developed.
On the basis of DNV GL's current understanding of the tension versus stretch behaviour of synthetic lines, this recommended practice does not aim to provide complete, ready-to-use methods. It aims at providing the best possible explanation of tension versus stretch behaviour as a help to industry in dealing with current shortcomings.

This recommended practice is intended to be revised. Information about on-going development work can be obtained by sending an e-mail enquiry to rules@dnvgl.com.

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2.10.2 Stretch and strain

Stretch $\Delta L$ is the change in rope length under tension and has the dimension of length. The magnitude of stretch measured in testing is proportional to the test specimen length. The magnitude of stretch experienced in service is proportional to the length of the line in service.

Reference tension is a low tension, recommended in this document to the tension that corresponds to a normalised tension of $5 \frac{N}{k_t}$, which is applied to measure a defined reference length before testing commences.

Reference length is measured between gauge marks after a minimum holding time of 17 minutes at reference tension. For new rope, the reference length should be stated as the Original Length before any higher tension is applied to the rope. If the rope is produced under a lower tension than the reference tension then this should be accounted for.

The basis for reference length should be agreed and stated, either as Original length $L_0$ at reference tension before further loading or as initial length at reference tension $L_i$ after a sequence of loading.

Splices and eyes are stiffer than the (long length of) rope. For this reason, the splices and eyes should be excluded from measurements unless specifically intended. Lines used in mooring systems and other typical uses are generally long enough that the effect on stiffness of splices and eyes is negligible for the tension versus stretch performance of the actual line compared to that of the (long length of) rope.

Strain $\varepsilon$ is the normalised expression of stretch. It is the amount of stretch under tension divided by the original length before applying tension above the reference tension.

$$\varepsilon = \frac{\Delta L}{L_o} \quad \text{or} \quad \varepsilon = \frac{\Delta L}{L_i}$$

where:

- $\varepsilon$ = strain
- $\Delta L$ = stretch
- $L_o$ = original length, at reference tension (length before tension is increased)
- $L_i$ = initial length, at reference tension (total length of rope, including stretch resulting from previous loadings)

When representing and discussing tension versus stretch characteristics for a type of rope, then the length independent term strain $\varepsilon$ should be used.

When, for example, polymer stretch is determined from a test, it should be divided by Original length and expressed as the basic rope-type property polymer strain $\varepsilon_p$.

$$\varepsilon_p = \frac{\Delta L_p}{L_0}$$

where:

- $\varepsilon_p$ = polymer strain
- $\Delta L_p$ = polymer stretch
2.10.3 Stiffness and normalised stiffness

Stiffness $K$ is the ratio of change in tension to the stretch which results from that change. The dimension of stiffness is force per length.

$$K = \frac{\Delta T}{\Delta L}$$

where:

- $K$ = stiffness
- $\Delta T$ = change in applied tension
- $\Delta L$ = stretch resulting from that applied tension

Normalised Stiffness $S$ is the change in normalised tension divided by the resulting change in strain. The normalised rope stiffness is calculated from the stiffness of a test specimen as follows.

$$S = \frac{\Delta T}{\Delta L} = \frac{\Delta T \cdot L_0}{\Delta L \cdot NLLD}$$

where

- $S$ = normalised stiffness
- $NLLD$ = nominal load-bearing linear density

When representing and discussing basic rope tension versus stretch performance characteristics, the term Normalised Stiffness $S$ should be used as it is independent of length and load-bearing linear density.

Conversely, the stiffness of any particular service rope is determined by

$$K = \frac{\Delta T}{\Delta L} = S \cdot \frac{NLLD}{L_0}$$

**Guidance note:**

It is common to use the minimum breaking strength of lines for delivery to normalise rope properties, but that is discouraged. The nominal load-bearing linear density should be used for normalisation since the tension efficiency decreases with increasing load-bearing area. The tension efficiency of test samples is further impaired by the practical aspects of terminating short lines.

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2.10.4 The basic spring-dashpot model

A simplified, analogue spring-dashpot model can be used to illustrate the viscoelastic tension versus stretch behaviour.
The basic spring-dashpot model is a simplification, to help explain the tension versus stretch behaviour of fibre rope with an analogue, physical illustration. It should be noted that the elements in this model are generally non-linear with respect to normalised tension versus strain and with respect to strain versus time.

Guidance note:
The explanations provided in this document are based on experience with the testing of polyester ropes. The principles are believed to be applicable to all fibre materials used in offshore fibre ropes.

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2.10.5 Individual performance characteristics

With reference to the spring-dashpot model, the stretch response to change in tension is the combined result of different types of strain. The individual performance characteristics for the types of strain are defined as:

— *instant-elastic strain*: elastic strain pertaining to the fast spring
— *visco-elastic strain*: the part of working strain pertaining to the slow spring
— *instant-plastic strain*: instant, permanent strain pertaining to the construction spring
— *visco-plastic strain*: polymer strain pertaining to the creep dashpot.

The tension versus stretch responses that result from these individual types of strain are discussed in the following.

These individual performance characteristics can be separated by an appropriate set of tests. The three-test approach described below was developed in order to separate these individual contributions to total strain.

2.10.6 Tension versus stretch characteristics

The tension versus stretch performance can be described by two types of curves in a diagram of normalised tension versus strain, or in a diagram of tension versus stretch:

— loading curves (for increasing or decreasing tension)
— holding curves (for constant tension).

In Figure 2-5, the curves marked Extension and Retraction are loading curves, whereas the curves marked Elongation and Contraction are holding curves.

2.10.7 Original loading curves

If a new rope is loaded for the first time, the plot of normalised tension versus strain may look something like in Figure 2-7.
Figure 2-7  Direct loading to break of new rope; rapid (left) and very slow (right)

The curve to the left is obtained when the rope is loaded quickly to failure in one pull. This blue curve is a loading curve, and it is in this particular case referred to as the original loading curve for the rope. The path of the original loading curve will depend on the loading rate. The slower the loading, the closer the blue curve will be to the red curve.

The curve to the right illustrates the original loading curve, as it is obtained with a loading rate that is so slow that the visco-elastic strain occurs simultaneously with the instant-elastic strain and the other strains. In this case, the slow spring in Figure 2-6 moves without restriction and according to the applied tension because there is no delay force in the slow dashpot. This red original loading curve to the right is called the original working curve and its path is given for a given rope.

In order to obtain the original working curve, two approaches can be taken:

— Increase the tension at a very slow rate.
— Increase the tension in steps of rapid loading and then hold the tension at each level until the working strain and polymer strain have been taken out.

In the latter case, the Original working curve is drawn through the points at the end of each constant-tension plateau, which are called preceding highest working points as discussed below. This is indicated in Figure 2-8 for six preceding highest working points.
The rate dependent original loading curve and the original working curve are special cases of loading curves. The original working curve is further a special case of a working curve. The general loading curves and working curves are discussed in the following.

### 2.10.8 Reversal of tension

After the rope has been loaded to a certain tension level for the first time and then this tension is held constant then the rope will continue to elongate until the length is corresponding to the original working curve for that tension level. As the tension is reduced (with or without holding constant tension first) the rope will follow a steeper path than for the first loading. These curves are generally referred to as (downwards) loading curves and the special case where loading is very slow is called (downwards) working curves. On the downwards working curves, the working strain has fully contracted and there is no force in the slow dashpot. Figure 2-9 illustrates how the downwards, rate-dependent loading curves and the downwards working curves relate to each other and to the original working curve.
Figure 2-9 Unloading according to general loading curve (blue) and general working curve (red)

If the tension is reversed again, then the rope will follow a general, rate-dependent (upwards) loading curve or a general (upwards) working curve (if the loading rate is sufficiently slow) as indicated in Figure 2-10.

Figure 2-10 Upwards loading curve (rapid) and working curve (very slow)

The black dot on the original working curve shown in Figure 2-9 indicates the preceding highest working point which defines the location of the associated working curves and corresponding loading curves. The working strain of the rope has never been fully elongated at any higher tension level which is called the preceding highest working tension.
Guidance note:
The preceding highest tension might have been higher than the preceding highest working tension for a short time, but not sufficiently to induce any significant working strain.

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Depending on the currently highest working point - the associated curves for unloading and reloading will be placed accordingly on the strain axis with respect to the original working curve. This is shown in Figure 2-11.

Figure 2-11  Different preceding highest working tension gives different location of loading curves

A larger range of unloading and reloading is shown to the right in Figure 2-11, for illustration.

Looking at the larger range of unloading and reloading, the direct unloading paths shown in Figure 2-11 can be replaced by stepwise unloading paths that enable drawing of the downwards working curve as shown in Figure 2-12.

The subsequent upwards, rate-dependent loading curve is also shown (blue) and the downwards and upwards working curves are indicated with dashed lines (red).
Figure 2-12 Downwards unloading path with constant-tension plateaus, and rapid reloading

The unloading path defines two working points (points on the working curve) at the end of each of the holding curves, as indicated with the two hollow dots.

In Figure 2-13, reversal of the tension is indicated at the first constant-tension plateau instead of unloading all the way down. The rate-dependent upwards loading curve and the upwards working curve are indicated.

Figure 2-13 Tension reversal at the first of the working points in Figure 2-12

After holding at the highest tension level, the length of the rope will be back at the preceding highest
working point which is indicated with the black dot.

At the working point indicated with the hollow dot, two alternative paths of loading are indicated, i.e. downwards (dashed) and upwards (solid).

At this working point, the working stretch has been stabilised and hence if the tension is rather reversed repeatedly around this working point then the instant-elastic stiffness will be obtained. This is indicated in Figure 2-14 with the thick black line. The amplitude shown is less than the difference between the tension levels at 1 and 2, for illustration.

![Diagram showing alternating tension reversals around working point 2](image)

**Figure 2-14 Alternating tension reversals (i.e. cyclic loading) around working point 2**

The same principle applies for dynamic cycling applied when the rope is on an upwards loading path.

If the cycling is starting or ongoing at the immediate attainment of a new constant tension level then it will take some cycles for working stretch to stabilise such that the stiffness stabilises. If the tension was increased prior to holding at mean tension then the rope will elongate; if tension was reduced then the rope will contract, until the working point is reached.

Instant-elastic stiffness is defined by (upper-bound) loading curves that are the result of only the instant-elastic strain (excluding working strain, construction strain and polymer strain).

The working curve path between two working points is called working stiffness.

The plot in Figure 2-15 summarises the above description of tension versus stretch behaviour, with stiffness examples indicated, as can be applied in analysis of mooring tethers.
Figure 2-15 Working stiffness and instant-elastic stiffness, both shown on a downwards working curve

For application to mooring systems, this recommended practice refers to the working stiffness for the changes in mean line-length between sea states, and instant-elastic stiffness for the dynamic stiffness after stabilisation of working strain.

The general dynamic stiffness will depend on the time at working tension, increasing towards the instant-elastic stiffness as working stretch is allowed to either elongate or contract.

Guidance note:
The general dynamic stiffness (particularly on the initial loading cycles) is important in lifting applications and therefore the distinction is made between dynamic stiffness in general and the special case called instant-elastic stiffness.
The instant-elastic stiffness has been shown to be independent of cyclic frequency for polyester. This finding is probably applicable for all synthetic yarn materials.

The values for the working stiffness are defined by the working points (including the preceding highest working point) that define the beginning point and the end point.

The values for the instant-elastic stiffness are defined by the working point and the tension or strain amplitude.

The working points are found on the working curve that is defined by the corresponding preceding highest working tension. The upwards working curves will additionally be defined by the working tension where direction of loading is reversed.

2.10.9 Rules of thumb for tension versus stretch behaviour
On basis of the above, the following rules-of-thumb have been established.

1) Rope working length depends on the highest working tension that has occurred, but it is independent of time and rate of loading.
2) Loading between two working tensions without reversal of direction, end rope working length depends on start rope working length and start working tension, and end working tension.
3) Loading between two working tensions with one reversal of direction, end rope working length depends on start rope working length and start working tension, reversal tension, and end working tension.
4) Loading between two working tensions with two reversals of direction, end rope working length is independent of the two reversals provided the reversals occur between the start and end working
tensions.

Guidance note:
The rope working length is the length of the rope after stabilisation of polymer stretch and working stretch.
Similar rules-of-thumb can also be developed for the general, time-dependent loading-curves, i.e. for the associated, momentary length of the rope.
The tension versus stretch behaviour measured on a given rope should not be assumed to apply to other types of rope, even if they appear to be made from the same generic type of load-bearing fibre, e.g. polyester and with the same construction category, e.g. 12-strand. When a different type of synthetic yarn is used or if the details of rope structure (e.g. strand twist) are different, then the tension versus stretch behaviour should be established by new testing.

It is, however, expected that when the fibre material is the same, then the tension versus stretch performance characteristics can be interpolated between different sizes and types of construction of ropes on basis of nominal load-bearing linear density. The applicability of such scaling needs to be validated; but such interpolation should at least be useful for initial, comparative analyses.

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2.11 Discussion of loading scenarios in offshore mooring

2.11.1 Introduction

This section discusses common loading scenarios that are experienced in mooring systems, with respect to the characteristic behaviour of synthetic lines.

Figure 2-16 shows a simplified deepwater taut leg mooring system. Only the windward and leeward mooring lines are considered here.

Guidance note:
Other lines would be analysed in the same manner, accounting for their horizontal and vertical vectors relative to the storm direction. The multiple mooring lines are at various vectors to the direction of the storm force and thus to the platform offset. Thus the resulting tension and stretch of each line should be separately determined.

A complete mooring system analysis would consider the properties of chain cables, connector links and steel-wire ropes, and the drag and catenary effects introduced by the water displacement and the weight of these elements. See Figure 4-2.

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The storm force is in line with those mooring lines, tensioning one line and slackening the other. The storm force moves the platform to a mean offset position. The storm also causes platform motion about this mean offset position.

Figure 2-16 Simplified deepwater taut leg mooring system

The tension and stretch in all of the mooring lines are determined at this new mean position. The new mean tension causes more working stretch in the windward lines and less working stretch in the
leeward lines. The platform-motion induced dynamic loading causes the mooring lines to exhibit dynamic stiffness. When working stretch has stabilised then the dynamic stiffness becomes the instant-elastic stiffness which is constant for the given working tension and tension amplitude.

In the leeward lines the working stretch will contract more slowly than in the windward lines, which might cause a mooring line to touch the sea floor. The unloading path on the leeward side will be steeper than the loading path on the windward side.

Guidance note:
‘Storm’ as used here includes hurricanes and loop currents.
For polyester, 3-T endurance will typically not be dimensioning if the tension never exceeds 70% MBS (350 N/ktex) and the temperature is below 20°C.
Cyclic tension endurance is not normally dimensioning for polyester mooring lines as long as the Design range is not exceeded or internal abrasion is not allowed to occur. But cyclic tension endurance might be dimensioning for shackles, chain cables, and other steel elements in the mooring system. See [2.2].

2.11.2 Installation stretch and installed stretch
During installation, the rope is typically loaded to an installation tension which is higher than the intended installed tension in order to minimise stretch during extreme events. It is typically held at that installation tension to test the mooring system and to set the anchors. After completing this process, the tension is reduced to the installed tension.

The mooring line stretch which takes place during this installation process is called installation stretch. The stretch after unloading to the installed tension is called installed stretch.

Figure 2-17 is a tension versus stretch diagram illustrating the steps for calculation of installation and installed stretch.

Figure 2-17  Installation stretch (black dot) and installed stretch (hollow dot)
If the time under installation tension will be limited in practice, then the installation stretch should be determined by using the Original loading curve up to the installation tension and then a corresponding holding time under tension which adds to the original loading curve the working stretch that takes place during the time under installation tension.
If the time under installation tension will not be limited in practice, then the installation stretch can be
determined from the original working curve up to the installation tension, directly. If the available time under installation tension is limited, but not of concern – for example if there is plenty of line length available for hook-up – then the installed stretch can be determined conservatively by using the original working curve also in this case.

The retraction and total length of mooring line immediately after unloading to installed tension can be determined using the appropriate downwards loading curve. The working strain contraction can be used to determine the line length over time at the installation tension. Alternatively, the downwards working curve can be used directly if mooring-line touch-down does not need to be checked.

Guidance note:
Whether it is best to use working curves or loading curves depends on available data, preference, and above all, on whether the time aspect is of importance to the analysis. Generally speaking, the working-curve approach will be easier to apply in mooring-system analyses provided time-dependency is not of interest, whereas the loading-curve approach is more suited towards dynamic lifting systems.

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2.11.3 Windward lines

On the windward side, the platform offset and mooring-line tension increases. In the mooring lines on the leeward side, mooring line tension and stretch decrease. During the storm, the platform can experience significant cyclic motions about the mean storm position.

Figure 2-18 illustrates the steps for conducting a storm analysis for the mooring lines which experience increased tension during a storm.

![Figure 2-18 Increasing tension and subsequent cyclic loading in windward lines](image)

If the mean mooring line tension is less than or equal to the preceding highest working tension, then the mean storm stretch can be calculated using the appropriate upwards loading curve and holding curve (for time-dependent analysis), or the corresponding upwards working curve.

If the mean mooring line tension is greater than the preceding highest working tension then additional permanent stretch takes place.

If the analyses to be performed are time-dependent, then the appropriate original loading curve should be used to the new, highest tension, and adding the visco-elastic and visco-plastic stretch corresponding to the holding time at the storm mean tension. If the analyses are not time-dependent then the Original working curve can be used to find the new highest working point as defined by the highest working tension.
Guidance note:
The mean mooring line length for the storm should be calculated for the tension in each mooring line, accounting for its horizontal angle with relation to storm direction and its vertical angle.

The platform-motion induced stretch amplitude in the mooring line should further be calculated with consideration to horizontal and vertical angles. The instant-elastic stiffness can be used to calculate the rope tension induced by platform motion in addition to the mean storm tension. This is the maximum mooring line tension induced by the storm.

It should be checked to see if this tension exceeds the preceding highest tension. If so, this value now becomes the (preceding) highest tension applied to this line and the analysis should be updated. The total stretch of the line which occurs during the storm event is used to determine the maximum mooring line length at the end of the storm event.

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2.11.4 Leeward lines

The platform storm offset decreases tension in the ropes on the leeward side of the storm. The platform-motion induced strain amplitude further decreases mooring line tension. Thus the minimum storm tension in these lines might be a concern to assure that the rope does not touch the sea floor. Also it is necessary to assure that potential axial compression fatigue will not occur in aramid lines.

Guidance note:
Axial compression fatigue is generally a rope design issue for aramid load-bearing filaments. Further, to avoid axial compression fatigue, the trough tension should not be allowed to drop below a qualified tension level. The susceptibility to axial compression fatigue is largely dependent on how the line is made, and thus the robustness can be qualified.

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Because mooring line tension is reduced on the slackened side of the system, some visco-elastic stretch will contract. As a result, the slackened line will become shorter under the same tension level, and some lift-up of the line will take place.

The mooring line tension on the slackened side of the mooring system will always be less than the preceding highest working tension. Thus construction stretch does not change on the slackened side of the mooring system.

Figure 2-19 illustrates the steps in determining the length in the most slackened mooring line. If this line does not touch the ocean floor, then the other slackened lines will not.

Based on the mean platform offset caused by the storm, calculate the mean mooring line length for the mooring line which is most slackened, using the appropriate unloading curve.

Figure 2-19  Decreasing tension and cyclic loading in leeward lines
After a few cycles, the dynamic stiffness for this slackened line will approach the instant-elastic stiffness associated with that storm mean tension and the platform-motion induced strain amplitude. Hence, use the instant-elastic stiffness to calculate the induced dynamic mooring line stretch. Subtract this stretch amplitude from mean mooring line length to determine the total line length in this slackened line. Using this value and the mean platform offset position, assure that the bottom of the slackened rope does not touch the ocean floor before any significant contraction occurs to lift up the line.

2.11.5 Fatigue calculations for steel components

Cyclic fatigue in polyester rope has been shown to not be a problem for loading kept within the design range; however the cyclic, platform-motion induced peak and trough tensions in mooring legs are of interest for fatigue calculations for the steel components.

Guidance note:
This is a significant driver for keeping the nominal load-bearing linear density of the fibre rope at a minimum.

The higher the nominal load-bearing linear density of the synthetic line the more fatigue loading is introduced in the connecting steel elements by the platform-motion induced strain amplitude. This effect is not insignificant and it cannot be countered by increasing the material grades of the steel hardware or line segments. On the contrary, more advanced steels might be more susceptible.

Reference is made to the illustration in Figure 2-1.

The cyclic tension fatigue in the most highly tensioned mooring leg should be calculated using the applicable values. Fatigue calculations should be carried out for each mooring leg for several different storm events and then the fatigue cycles for a number of such events over the projected life of the mooring system should be summarised.

---end---of---guidance---note---

2.11.6 Maximum mooring line length

The maximum mooring line length is of concern. Too much stretch during storms can result in excessive platform offset, also after the storm. To avoid this, it might be necessary to provide some means to shorten the mooring line, such as winching in, or removing a short segment of line.

Using the above principles, calculate on basis of the most severe storm loading the total line length from service. Use this value to assure that the bottom of the slackened line does not touch the ocean floor as discussed above.

Guidance note:
Offshore fibre ropes that have a soil ingress protection barrier will typically be qualified for lying still on the sea bed as part of the installation process. Hence, that qualification does not cover lines in service, and thus the leeward line should not be permitted to touch the sea bed.

---end---of---guidance---note---

2.12 Torque-matched lines

2.12.1 General

Two connecting lines are considered to be torque matched if the connection between the two will turn no more than 5 times when the line is loaded to 50% MBS and if each line has a length of 1,000 metres with the other ends fixed.

Braided rope structures are inherently torque neutral. Parallel-subrope lines are considered inherently torque neutral when 50% of otherwise identical subropes are S-lay and 50% of the subropes are Z-lay. For numbers of subropes that are not even, there can be one more subrope of either S or Z.

The appropriate combination of steel-wire rope and offshore fibre ropes should be determined based on testing of the actual torque and twist performance for both products. Interpolation should be used to generate look-up tables or diagrams for the relationship between torque, tension and rotation for both types of rope of the actual lengths to be used in service.

Mooring legs typically consist of a length of steel-wire rope or a chain cable, then one or more offshore fibre ropes, and then another length of steel-wire rope or chain cable towards the anchor. For different levels of tension, the results from each of the steel-wire ropes and the offshore fibre rope should be compared in order to arrive at the resulting rotational equilibrium for various tension levels which should be plotted in a manner as indicated in Figure 2-20 for the connection to each of the steel-wire rope segments.
When a mooring leg has steel-wire rope on each end of an offshore fibre rope, the analysis needs take into account the interaction at both ends.

**Guidance note:**
Provided the steel-wire rope segments are of identical design, the easiest way to handle this is probably to first treat the mooring line as consisting of two segments only, one offshore fibre rope and one steel-wire rope of length equal to the sum of the two segments.

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The rotation of each of the two connections towards the offshore fibre rope is determined according to the length difference between the segments of steel-wire rope. Steel-wire ropes are generally sensitive to twist; the offshore fibre rope is generally not. Thus it is the separate rotation of each of the connections that should be kept within the recommendation which is intended to protect the steel-wire ropes.
SECTION 3 TESTING

3.1 Introduction
In connection with delivery of offshore fibre ropes the performance characteristics of the product need to be well-established and documented to satisfy the use and service context for which the product is intended. This section covers testing to validate the performance characteristics of deliveries.

Offshore fibre ropes can be assembled in many ways. Many designs of synthetic lines consist of a parallel bundle of subropes. Some synthetic cable designs consist of parallel yarns. The subropes are typically identical, except for helical subropes where opposite lay is used to render the resulting line torque-neutral. When possible, tests should be performed on the subropes rather than the full rope because this is more accurate and more economical. Recommended methods of testing are described in the following.

Note:
Recommendations provided in this document must not be regarded to exclude other methods for fulfilment of requirements.

3.2 Reference measurements and expression of tension levels
Applied tension (kN) should be determined based on force per nominal load-bearing linear density ($N_{ktex}$) for the rope to be tested.

This document recommends using a reference tension for the testing equal to a normalised tension of $5 N_{ktex}$. The specimen must not be loaded higher than the reference tension prior to taking the measurement of rope original length. The original length should be measured after no less than 17 minutes at designated reference tension, keeping the tension constant.

Note:
The role that is responsible for performing the testing is not responsible for interpreting test procedures for sequences of loading, tension levels to be applied etc. This is the responsibility of the role that issues the testing specification, and all tension levels and length measurements need to be specified in the units that the test equipment is calibrated in and which are displayed by the equipment. Normalised values should not be used in the testing procedures. Hence, tension levels to be applied in testing need to be expressed in either kN or lbf and length needs to be expressed in either metres or feet.

Guidance note:
If the rope is produced at a tension that is lower than the recommended reference tension, then it is recommended to measure the tension versus stretch behaviour also for the tensions below the reference tension prior to measurement of the original length.
The recommended reference tension (for all materials and types of rope) of $5 N_{ktex}$ corresponds to approximately 1% of the breaking strength of a typical polyester offshore mooring tether.

3.3 Test specimen conditioning
With the exception of specimens for 3-T testing, all test specimens should be pre-soaked by complete immersion in fresh water prior to testing. In case of polyamide load-bearing yarn, soaking time and handling should be in accordance with OCIMF Guidelines. Pre-soaking is recommended since the presence of water may be assumed for all offshore fibre ropes in service, unless testing in dry condition is important for the purpose of qualification. With the exception of polyamide (nylon) the time for soaking is not considered to affect results.

With the exception of specimens for tension versus stretch testing, all test specimens should be terminated in the same way as for delivery. It is recommended to perform tension versus stretch testing with socket terminations in order to lock off the rope construction to avoid nuisance strain readings.

Unless otherwise stated, all tests should be performed at an ambient temperature of approximately 20°C. The ambient temperature of testing should be noted, and recorded if important.

3.4 Data recording and measurement accuracy
Force, time, piston stroke and stretch should be logged at a sufficient rate when measurements are taken.
The following sampling rates are recommended:

- Loading above 70% MBS: 0.2 seconds between points
- Dynamic stiffness: 30 to 40 points per cycle
- Loading and unloading curves: 2 seconds between points
- Initial parts of holding curves: 1 to 10 seconds between points
- Final parts of holding curves: 1 minute to 1 hour between points.

Consideration should be given to the required accuracy, whilst avoiding excessive data files. For parallel-subrope lines the tension versus stretch measurements should be performed on subropes.

The techniques for testing and methods of measurement should be validated to generate the appropriate results. The gauge length for measurement of stretch needs to be commensurate with the accuracy of the length-measurement device. Advice is provided in CI 1500 - Appendix A on how to obtain adequate accuracy. Due care needs to be taken to avoid influence from the terminations on the mid-length strain measurements.

**Guidance note:**

Locking off the subrope structure with sockets prevents the occurrence of false construction stretch on the gauge length.

If tension versus stretch measurements are to be performed on the full, parallel-subrope tether, then the extensometer should be attached on the outer jacket with fixations that are gripping or squeezing the whole cross-section. It must be ensured that the jacket follow the changes in length of the load-bearing subrope bundle (the core). However, measurement on single subrope with socket terminations is the preferred method, and the accuracy when measuring on full-size tether should therefore be substantiated.

For subsequent break testing it is not necessary to re-soak the test specimen.

---end---of---guidance---note---

### 3.5 Scope of tests

The objective of the testing of products is to provide the evidence that the product (or system) to be delivered will be fit for purpose.

Which will be the right tests to perform, and how to perform those tests, and the number of samples for each test will depend on the requirements to documentation of performance for the designated service for the case at hand. Previous tests performed, as well as the variability associated with the type of test and the type of product will also need to be considered in order to decide the scope of testing.

**Guidance note:**

In the following description of test methods, a typical number of tests are indicated for what is usually performed for offshore mooring tethers that are made from subropes. For helical subrope constructions, both S and Z should be tested. The recommended number of tests is the combined number of tests of both S and Z specimens. The testing should be performed identically on each specimen such that variability can be assessed.

---end---of---guidance---note---

### 3.6 Testing of 3-T endurance

#### 3.6.1 Introduction

The objective of determining the 3-T performance is to obtain a measure of the time that the lines will sustain a high tension level (which is lower than the minimum breaking strength) before failure.

The 3-T endurance should be established by testing, whereby design curves for 3-T endurance are established for different temperatures. Two types of tests can be performed to determine the 3-T performance, depending on the type of yarn:

- stress rupture testing (polyester, polyamide, aramid and LCP)
- creep failure testing (HMPE).

These tests are in principle the same; only the failure criterion and the amount of elongation are different between the two as explained in the following.

As increasing temperature gives poorer 3-T performance, results obtained at a higher temperature can in most cases be applied conservatively for a lower temperature.
Guidance note:
For polyester mooring tethers, typically 5 subropes are tested at two different tension levels. It can also be possible to perform the 3-T testing on yarns and use a qualified translation between yarns and subropes, or to test 5 subropes at one tension level and use the slope from yarn tests to define the curve.

The recommendation for number of specimens for each tension level and temperature is made in order for the resulting 3-T design curve to be as good as possible for a reasonable number of tests. Fewer or more specimens can be tested, according to needs.

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3.6.2 Stress rupture testing

The objective of stress rupture testing is to establish the 3-T design curve that is applicable to the offshore fibre rope at a certain temperature, or lower.

Guidance note:
This 3-T design curve should be used to evaluate the margin to failure for elevated tension levels. It should also serve as basis for retirement or de-rating of an excessively loaded line, and the evaluation criteria should be stated in the condition management programme.

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3.6.2.1 Specimen preparation

If the testing is performed in air then the ropes should not be pre-soaked in order to keep the temperature stable during the test. It is preferable to perform the test in temperature-conditioned water, or air. The basic, recommended test temperature is 20 °C for mooring applications.

3.6.2.2 Basic test procedure:

1) Install the specimen in the test machine.
2) Perform 10 cycles 1 to 50% MBS to bed in the specimen.
3) Increase the tension to 70% MBS.
4) Allow the specimen to cool to make sure temperature is constant throughout the test sample.
5) Load the specimen to the designated tension and maintain tension constant. Record tension versus time.
6) Measure the time from attainment of designated tension until rupture occurs.

3.6.2.3 Failure criterion

For stress rupture testing, the failure criterion is designated by a drop-off in tension when a partial rupture, or complete breakage, occurs.
3.6.2.4 Test programme for stress rupture
An example test programme for stress rupture testing can be found in DNV Programme for Approval of Manufacturers 322.

3.6.2.5 Test programme for design range
An example test programme for design range testing can be found in DNV Programme for Approval of Manufacturers 322.

3.6.2.6 Data analysis
The Time To Rupture (TTR) test results are assumed to be log-normally distributed. An example of data analysis is provided in DNV Programme for Approval of Manufacturers 322, App.B.

Testing at two tension levels are indicated in Figure 3-1. Two levels are needed in order to establish the slope of the 3-T design curve. If the slope of the 3-T design curve is available from testing of yarns, then testing at one tension level can be sufficient. In that case a tension level should be chosen that gives times to failure in the range of 40 minutes to 3 days.

3.6.2.7 Finding the right tension level
It is recommended to choose the tension levels such that testing will not exceed 4 days at the lowest tension. At the highest tension level the time to rupture should be more than 40 seconds.

In order to avoid excessive durations it is recommended to increase the tension level slightly during testing should samples not fail within a reasonable time.

If such adjustment of test tension is made then the effective TTR for that test has to be calculated analytically based on the two tension levels and the corresponding times.

For the purpose of this recalculation it is important to increase the data logging rate before raising the tension level, and to keep the high rate for the beginning of the holding at the new tension level.
Figure 3-2  Increasing the tension level slightly when specimen does not fail

A step-wise approach can also be taken to the choice of tension levels, according to the same principle. The principle for adjusting TTR test results for slightly different load levels is described in the following, and the similar principle applies to calculating the effective TTR where more than one tension level have been applied to the same test sample.

3.6.2.8  Data processing from time to rupture testing at different tension levels

The time to rupture ($TTR$) at constant tension $F$ is dependent on $F$ according to:

$$ F = B - A \log_{10} TTR $$

where $A$ and $B$ are constants determined by tests.

1) When the load varies, the incremental utilisation $d$ from a period of constant tension is:

$$ d = \frac{t}{TTR} $$

where $TTR$ is determined for that load according to the above formula.

2) When the tension varies, failure occurs when the cumulative utilisation $D$ reaches unity (1); i.e. no failure if:

$$ D = \sum_{i} d_i < 1 $$

where $d_i$ are the incremental utilisation from the $i$ constant load periods.

3.6.2.9  Plotting data from tests with exposure at different tension

If the TTR curve is known (approximately) from previous constant-tension tests, the constants $A$ and $B$ can be taken as known. The result of a time to rupture (TTR) test with tension exposure at different levels can be incorporated as follows:
1) For each tension level, calculate the incremental utilization incurred in that step using the known TTR curve:

\[ d_i = \frac{t_i}{B - F_i} 10^{-\frac{F}{A}} \]

2) Choose the tension level \( j \) with the highest incremental utilisation \( d \) as the baseline tension level \( F_{base} \).

3) For the other tension levels \( (i \neq j) \), calculate the converted exposure time \( t_{ic} \) as the one that would have been required at the baseline tension level to obtain the incremental utilisation \( d_i \) that incurred at this other tension level:

\[ t_{ic} = d_i 10^{-\frac{B - F_{base}}{A}} \]

4) Calculated the sum of all the converted exposure times including the actual one at the baseline tension level:

\[ t_{base} = \sum_i t_i \]

The resulting data point \((\log_{10} t_{base}, F_{base})\) can be included in the TTR plot to show how well it fits the constant-tension data.

3.6.2.10 Updating the TTR curve

A slight error is produced if this data-point is used to update the TTR curve (calculate new \( A \) and \( B \)) because the time conversion used the old curve.

The result can be improved by iterating: redoing the calculation with the new \( A \) and \( B \) until they don't change from the previous iteration.

With several experiments having various tension exposures, the iterations should include all those data points.

3.6.3 Creep-failure testing

The constant-tension testing for establishment of the 3-T design curve for HMPE materials should be determined on a case-by-case basis. For an introduction, reference is made to technical paper Predicting the Creep Lifetime of HMPE Mooring Rope Applications /6/.

Guidance note:
It is intended to provide more information and recommendations in revisions of this recommended practice.

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Figure 3-3 illustrates the principal behaviour of HMPE yarns in a creep test.

![Figure 3-3 Illustration of results from creep testing of HMPE yarns](image-url)
3.6.3.1 Failure criterion
For creep failure testing, the failure criterion is designated by the increase in creep rate which defines the transition between stage II and stage III.

3.7 Testing of cyclic endurance of products

3.7.1 Introduction
The objectives of the cyclic endurance testing is to validate that cyclic loading corresponding to the design life of a six-strand steel-wire rope does not cause undue internal abrasion in the offshore fibre rope and that the 3-T utilisation of the load-bearing yarns has not been unacceptably high.

The residual performance of the rope should be adequate for the case at hand.

Following a cyclic endurance test it is of vital importance that the offshore fibre rope test specimen is not loaded to failure, since essentially all information of value about internal abrasion then will be lost.

Further, material from the cyclic endurance tested sample needs to be tested for 3-T utilisation after the cyclic loading exposure.

**Guidance note:**
For polyester mooring lines, typically one fibre rope segment is tested with termination hardware from the actual delivery.

---end---of---guidance---note---

3.7.2 Test method
The cyclic endurance testing should be carried out on the full, actual rope with termination hardware manufactured as part of the delivery.

**Guidance note:**
The diameter of thimble/H-link pin holes can be increased by machining to fit the loading pins of the test machine, keeping sure that the capacity is still sufficient.

---end---of---guidance---note---

The following test procedure is recommended:
— 6000 load cycles between 5% and 50% MBS (part 1)
— 14 000 load cycles between 5% and 44.1% MBS (part 2).

These load levels and cycle numbers are suggested since 50% of the intended design life is achieved rather quickly, with a total cycle number of 20 000.

The cycling speed of the test machine may be as fast as possible; however care should be taken with respect to heat build-up. The internal temperature of the rope should not be allowed to exceed what is recommended for the yarn material used.

The specimen should be equipped with an irrigation system to add sufficient fresh water to keep the sample moist and cooled during the test. Alternatively, testing may be performed submersed.

3.7.3 Examination and 3-T testing after the cyclic endurance test
— Photographic documentation of external and internal specimen condition
— Dimensions and external condition of splice and eye
— Condition of specimen interior
— 3-T performance tests
— Perform break testing of 5 selected subropes if enough subropes are available

**Guidance note:**
This is assuming parallel subrope mooring tethers. For fewer than 10 subropes the examination and testing programme will have to be established on a case-by-case basis. DNV-RP-E304 is intended to be updated in order to provide more testing recommendations for the condition assessment of used offshore fibre ropes. The cyclic endurance test is used to qualify fitness for designated service at end of design life.
On the basis of the 5-year design life of Mobile Moorings, it has not been common practice to perform the cyclic endurance test with subsequent 3-T testing of subropes for Mobile Mooring deliveries according to DNVGL-OS-E303.

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3.7.4 The following should be reported

- Plot of tension versus stretch based on piston stroke of first 10 cycles, cycle 20, 50, 100, 200, 500, 1000, etc. and last 5 cycles of part 1
- Plot of tension versus stretch based on piston stroke of first 10 cycles, cycle 20, 50, 100, 200, 500, 1000, etc. and last 5 cycles of part 2
- Photographic documentation from examinations
- 3-T performance test results for subropes of parallel-subrope tethers
- If performed: Break test results for subropes of parallel-subrope tethers
- Documentation as required for splice integrity for the full rope or tether
- Other reporting requirements as applicable.

3.7.5 Testing of maximum temperature due to hysteresis heating in mooring lines

If deemed necessary, the maximum temperature needs to be measured during cyclic endurance testing. The measuring method needs to ensure that it is the internal temperature of the synthetic fibres at critical location, and not that of the surrounding air or water, which is measured.

Guidance note:
If, during the cyclic endurance test of an offshore fibre rope, the measured temperature is considered to be higher than can be expected under actual load conditions, e.g. due to application of a broader than actual load range, then the loading regime should be modified during the temperature measurements to avoid over conservatism.

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3.8 Testing of splice integrity

The objective of the splice integrity test is to demonstrate that for the actual rope, the splices will not move after bedding down and eventually pull out after a sufficiently long time in service. In the case of parallel-subrope tethers, the test can be performed on subropes, otherwise the actual product needs to be tested.

Guidance note:
For offshore mooring tethers that are made from polyester subropes, typically 3 subropes are tested. The testing of subropes is more conservative since compressive forces from neighbouring subropes do not contribute to holding the splices. Consequently it may be more difficult to achieve splice locking in subrope compared to the actual line.

The specimen should be fitted on smooth steel pins in the test machine and cycled between 5% MBS and 50% MBS until the force versus stretch measurements demonstrate that the splices are self-locking.

When the tension versus stretch curve has a clearly asymptotic behaviour towards a certain length at peak tension, the splice can be deemed to be self-locking.
For the splice-integrity test to pass, the curve should show a clear convergence towards the asymptotic length.

A minimum of 1000 cycles should be applied, and the testing continued should the asymptotic behaviour not be proven after the initial 1000 cycles. It is often necessary to apply far more than 1000 cycles before the length of rope at peak tension ceases to increase.

It is important to apply enough cycles before this conclusion is drawn. The objective of this test is to show that the splices in the actual line will lock. For practical purposes this is considered to be sufficiently shown if subrope splices are showing this behaviour.

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3.9 Testing of resistance to external cutting

At present, the only defined requirement available in the industry is Statoil requirements to cut-resistant jackets on polyester mooring lines for permanent installations [7] which have been made available to the industry.

*Guidance note:*
DNVGL-OS-E303 defines service with contact towards external objects as ‘Special service’, which requires Technology Qualification according to the principles of DNV-RP-A203 in order to develop a set of adequate acceptance criteria to show that a delivery will be fit for purpose.

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3.10 Testing of tension versus stretch performance

3.10.1 Introduction

The tension versus stretch behaviour of an offshore fibre rope can generally be characterised by the loading curves and holding curves - stemming from the individual strain contributions - that are needed for the analysis that will be performed. The goal of the testing is to be able to predict the momentary length and stiffness of the rope for the loading scenario to be analysed.

An explanation of tension versus stretch behaviour is provided in Sec.2 with basis in the basic spring-dashpot model. Recommendations concerning test methods are provided in the following.

It is important that the test results are relevant for the actual service. The test programme should be defined such that the characteristics needed for system analysis are identified.

*Guidance note:*
For parallel-subrope tethers, it should generally be sufficient to run the tension versus stretch test procedures once to determine the tension versus stretch performance characteristics for each type of subrope. The properties measured on a subrope can be directly related by the number of subropes to the properties of the full tether. The same specimen should be used for as many measurements as possible. If testing is continued on a different specimen, then the previous sequence or its equivalent needs to be run to induce an adequate amount of creep and construction strain into the specimen before beginning the next sequence of the test programme. It is recommended to test 3 samples for each test sequence.

The recommendations provided herein are intended to be supplemented when new information becomes available to be published in revisions of this recommended practice.

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3.10.2 Selection and preparation of test specimens

Due to the effect of splices on the short length of rope in a test machine, tension versus stretch tests should be performed on samples with socketed terminations. The reason for this is the accuracy of measurement and economy of testing; however spliced terminations can be used as well provided measurements are sufficiently accurate.

*Guidance note:*
Use of spliced terminations on subrope samples of limited length has shown to give too high results for construction stretch from the extensometer on the mid-length. This is attributed to increased construction stretch as the splices move before they lock. The potted sockets lock off the rope construction such that the long length of rope can be represented by a short test specimen.

Samples for tension versus stretch testing should be taken from subropes in parallel-subrope tethers in order to achieve sufficient accuracy; otherwise the full rope should be tested. Three parallels should be tested for each test in order to get an appreciation of accuracy and repeatability.

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3.11 Testing for loading curves and holding curves

3.11.1 Original loading curve and original working curve

The rate-dependent Original loading curve can be determined by loading the rope from reference tension and (almost) to failure, as illustrated by the dashed blue line in Figure 2-8.

The Original working curve can be determined by loading in steps to several tension levels where the tension...
is held constant. The Original working curve is drawn through the working points as illustrated by the red curve in Figure 2-8.

For both these tests, it is possible to reverse the loading and perform other tests at lower tension as needed. Reference is made to the rules-of-thumb in [2.10.9].

3.11.2 Working curves
For each of the working points used to define the Original working curve, the associated downwards working curve can be obtained. Working curves are for very slow loading (where instant-elastic and visco-elastic strain happen concurrently); so the most effective method of testing will be to unload in increments and hold tension constant, as indicated in Figure 2-9 and Figure 2-12.

The upwards working curves will be defined by two points:

— the preceding highest working point
— the working point where the tension is reversed.

Test sequences can be defined for the case at hand using the rules-of-thumb in [2.10.9].

3.11.3 Working stiffness
The working stiffness can be determined between chosen working points (including preceding highest working points) depending on the path of loading being analysed. The working points to be determined in the testing should be chosen with the analyses that will be performed in mind.

3.11.4 Instant-elastic stiffness
On each of the working points determined through a testing sequence, the instant-elastic stiffness can be determined by applying rapid cycling. Various amplitudes can be tested and it will for polyester typically take only 10 to 20 cycles before the dynamic stiffness becomes practically constant, and equal to the instant-elastic stiffness for the tested working tension and tension amplitude. For mooring applications also irregular tension variations with realistic wave frequency and low frequency contents can be applied.

3.11.5 Calculating dynamic stiffness from data file
The slope of the secant line between the peak and trough tensions can be used to determine dynamic stiffness of harmonic loading cycles. This is illustrated in Figure 3-6. Alternatively, linear regression can be applied on a sufficient number of sampled points for both harmonic and for irregular loading.
For harmonic cycles the dynamic stiffness can be calculated using the average rope length during the cycle as basis. With input in kN for tension and % for strain from the data file, the formula for normalised dynamic stiffness then becomes:

\[
S = \frac{(200 + PS + TS) \cdot (PT - TT)}{2 \cdot (PS - TS) \cdot NLLD} \left[ \frac{N}{tex} \right]
\]

where:

\( PT \) = peak tension
\( TT \) = trough tension
\( PS \) = peak strain
\( TS \) = trough strain
\( NLLD \) = nominal load-bearing linear density [ktex]

Strain can be based on average rope length or original rope length. The selected alternative must be noticed, and accounted for when converting to axial stiffness for use in a calculation.

### 3.11.6 Calculating working stiffness from data file

Except for under dynamic loading, the tension versus stretch behaviour of synthetic rope is non-linear. However, when mooring analyses are performed it is customary to make simplifications in order that stretch from one sea state to the next can be analysed using linear representation. The effective linear stiffness between two points on a curve, or from a point on one curve to a point on another curve, is therefore useful for practical analysis purposes.

For analysis of system behaviour under changes in mean tension, the effective loading stiffness can be calculated using the beginning point and end point. This is illustrated in Figure 3-7.
The effective loading stiffness can be calculated using the rope length at the beginning point as basis. With input in kN for tension and % for strain from the data file, the formula for effective, linear normalised stiffness then becomes:

\[ S = \frac{(100 + BS) \cdot (ET - BT)}{(ES - BS) \cdot NLLD} \left[ \frac{N}{tex} \right] \]

where:

- \( ET \) = end tension
- \( BT \) = beginning tension
- \( ES \) = end strain
- \( BS \) = beginning strain
- \( NLLD \) = nominal load-bearing linear density [ktex]

**Guidance note:**
These input values are read out from the data logging file.
Here, the normalised stiffness is shown where the nominal load-bearing linear density is used as basis.

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### 3.12 Testing for individual strain contributions

#### 3.12.1 The three-test approach

Three specific tests have been developed previously to be performed on the same rope specimen in order to isolate the instant-elastic strain, the visco-plastic strain, the construction strain and the polymer strain as function of tension level or time, or both /6/. The tests are illustrated in Figure 3-6, Figure 3-7 and Figure 3-8.
Guidance note:
Variants of these tests can also be used to determine the characteristic curves discussed above.

Note that the tension levels refer to % MBS in order to be general for the various material types; however it is recommended to define the actual tension levels for testing as normalised tension in \( \frac{N}{\text{ktex}} \) in order to facilitate comparison of types of rope.

Guidance note:
For the purpose of setting up test tension levels, MBS can be approximated to 500 \( \frac{N}{\text{ktex}} \) for polyester subropes. For other materials, these values will be different and thus it is convenient to present the recommended test sequences in terms of approximate % MBS. Hence, when testing polyester rope, then a tension level of 250 \( \frac{N}{\text{ktex}} \), with basis in the nominal load-bearing linear density can be used for the recommended tension level of 50% MBS.

3.12.2 Test for original loading curve, loading curves, polymer strain and working strain

Figure 3-8 is a schematic of Test Sequence 1. This test sequence must be done with a new rope specimen which has not previously been loaded. If the specimen was previously loaded above reference tension, the loading curves and holding curve measurements will be flawed.

![Test Sequence 1 schematic](image)

**Figure 3-8 Test Sequence 1 for Original loading curve, Loading and Unloading Curve, and Creep Strain Rate**

The rope specimen is first loaded to reference tension to record Original Length \( L_0 \). It is then rapidly loaded up to the target tension to record normalised tension versus strain for the Original loading curve. It is held at the target tension for a sufficient time, typically 1 hour, to record strain versus time for polymer and working strain rates.

The rope specimen is then unloaded rapidly to reference tension. It is held at reference tension for a sufficient time, typically 1 hour, to record strain versus time. The length at the end of this step is recorded as \( L_i \). Finally, it is again loaded rapidly to the target tension to again record normalised tension versus strain to obtain the loading and unloading curves.

The Original loading curve is determined from a plot of normalised tension versus strain during the first loading to target tension. Composite strain rate (the sum of polymer strain rate and working strain rate) is determined from the strain versus time plot (holding curve) at the target tension. Loading and unloading curves are determined from a plot of normalised tension versus strain during the second loading.
3.12.3 Test for construction strain

Figure 3-9 is a schematic of Test Sequence 2. If this test is done on a new rope, then that rope should first be held at high tension for sufficient time to induce substantial polymer strain, i.e. 1 hour at target tension.

![Figure 3-9 Test Sequence 2 for Construction Strain](image)

After inducing polymer strain, as in Test Sequence 1, the rope must be completely relaxed and flexed in order to release construction strain. After relaxing and flexing, the rope length is again measured at reference tension to record initial length $L_i$. This length is the base against which construction strain will be calculated.

The rope is then rapidly loaded to a low tension level approximately 10% MBS with immediate, rapid unloading. The rope is held at reference tension for 17 minutes to relax working strain induced during the loading cycle. The length of the specimen after this hold at reference tension, $L_{c1}$ is recorded.

This test is then repeated at successively higher tension levels, for example at approximately 20% MBS, 30% MBS, etc.

The actual tension levels should be defined in $N/k_t e x$, which will differ depending on the type of material. Each of these steps is carried in the same way with rapid loading and immediate, rapid unloading. At the end of each of these steps the respective length, $L_{c2}$, $L_{c3}$, etc, is recorded.

The construction strain is then calculated from these $L_c$ data and their corresponding tension levels.

3.12.4 Test for working strain and instant-elastic stiffness

Figure 3-10 is a schematic of test sequence 3. This test sequence should be done on the same specimen as was used in test sequence 1 or 2.
In order to preserve construction strain, the specimen should remain in the test machine and should not be flexed before test sequence 3. If this test sequence is to be done on a new rope, the specimen should be held at a high tension for 1 hour to induce substantial creep and construction strain before beginning the first step.

The specimen should first be held at reference tension for 1 hour to relieve any working strain which has been induced in the rope during previous loadings. If the test is conducted after test sequences 1 or 2, this hold can be an extension of the last hold at reference tension in that sequence.

The specimen is loaded to an approximate mean tension of 11% MBS. It is held at that tension for 17 minutes, whilst recording time versus tension, to induce substantial working strain. It is then cycled ten times about this mean tension over a first tension amplitude of approximately 2.5% MBS whilst recording tension versus strain. After these first cycles, the specimen is then cycled ten times over a second tension amplitude of 5%, again recording normalised tension versus strain. Then, a tension amplitude of 10% MBS is applied.

Guidance note:
This ~11% MBS tension level is recommended on the first step because it allows cycling to 10% MBS tension amplitude without falling below reference tension.

The above steps are then repeated at a 20% MBS mean tension. Tension is held at that tension for 17 minutes. It is then cycled ten times to over a first tension amplitude of 2.5% MBS. The specimen is then cycled ten times over a second tension amplitude of 5% MBS. And then the specimen is cycled ten times over a third tension amplitude of 10% MBS.

This test is repeated at successively higher mean tensions, e.g. approximately 30% MBS, 40% MBS, etc., with the same tension amplitudes as used before.

Guidance note:
Although this test is conducted with controlled tension amplitudes, the results can be presented and plotted as instant-elastic stiffness versus strain amplitude. An empirical equation for instant-elastic stiffness as a function of strain amplitude can then be derived.

Expressing the rope instant-elastic stiffness as a function of strain amplitude is useful for storm-event mooring tension and offset analyses.

Data analysis for determination of the individual performance characteristics from the above described test
sequences 1, 2 and 3 is explained in more detail in a technical paper /4/.

3.13 Testing of torque and twist performance

3.13.1 Introduction

One of the important performance characteristics of a line is how it responds to imposed torque, and how it responds to applied tension in terms of torque and twist over its length, and the tendency to local aggregation of twist.

Knowledge about the torque and twist characteristics is vital in both mooring systems and in systems for deepwater deployment and recovery, as well as in lifting pendants and TLP tendons.

These tests and the below analysis technique are also recommended for combinations of offshore fibre ropes as well as to combinations of steel-wire ropes.

Guidance note:

For this test characterisation test the basic recommendation has been to test one full rope. For offshore mooring tethers made from subropes it can be considered to test subropes and summarise the torque response.

The basic recommendation is to test one sample in connection with deliveries. There should be no need to perform this test on inherently torque neutral rope.

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3.13.2 Diagrams of torque versus tension

In order to determine the torque response of an offshore fibre rope to changes in applied tension, a diagram of the torque versus tension needs to be established. This diagram should further be established for various angles of rotation between the end terminations. An example is shown in Figure 3-11.

The test is performed as loading – unloading tests with the specimen terminations locked at these fixed angles. The various values of fixed rotation in the test machine should be selected to correspond to for example 5°, 10°, 15°, 20° and so on for a rope length of 1000 m.

![Figure 3-11 Illustration of plots of torque versus tension for different angular rotation of 1000 m length of rope](image)

3.13.3 Requirements to test setup

In order to perform this type of test, a test machine is needed that can accommodate socketed end
terminations and load the specimen to 50% MBS. It should further be capable of testing the rope with the required changes in fixed angular rotation between the end terminations.

### 3.14 Testing of break strength

Break testing is performed in order to verify the integrity of the termination areas including the termination hardware and the rope-to-hardware interface, and to verify the MBS of the offshore fibre rope for reference purposes. Break testing further provides a crude appreciation of the balance between the main load-bearing elements within the rope, such as between subropes.

The specimens should not have been previously loaded to more than 70% MBS.

Recommended test procedure:

- 10 cycles between reference tension and 50% MBS
- loading to failure.

The following should be reported for each specimen:

- tension versus stretch curve for cycles 1, 2 and 10 to 50% MBS
- breaking tension and tension versus piston stroke curve for the loading to break
- the rate of loading reported in \( \text{KN}/\text{min} \) for the region above 70% MBS
- number of broken subropes in full-rope specimen, or number of broken strands in single rope specimen
- location of failure
- photographic documentation as appropriate.

The 10 cycles to 50% MBS are recommended in order to bed in and set the splices of the test sample before loading to break.

The specimen should fail on the free length or at the toe of the splice. The basic recommendation is to perform three break tests in connection with deliveries. For offshore mooring tethers that are made from polyester subropes, typically 3 full ropes are tested.

**Guidance note:**

Offshore fibre ropes should be tested to break using termination hardware that is produced as part of the delivery. Should hardware from the actual delivery not be available at the time of testing then the offshore fibre rope can be tested with terminations that provide the same contact interface as would the original hardware. The integrity of the termination hardware then needs to be verified by other means.

For testing of complete specimens of offshore fibre rope, the diameter of thimble/H-link pin holes may be increased by machining to fit the loading pins of the test machine. A force-control test machine is not required.

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### 3.15 Testing of soil ingress resistance

#### 3.15.1 Introduction

The objective of the basic Soil ingress resistance test is to qualify that un-loaded offshore mooring tether has adequate resistance to ingress of sea-bed particles.

When there is relative movement within the rope then particles can cause abrasion of the filaments and decrease the effective cross-section and load-bearing capacity. Presence of particles might impair the friction properties of the marine finish, which might impede the internal realignment as the rope is being stretched, and thus also reduce the load-bearing capacity of the rope.

Testing of soil ingress resistance is usually required if a mooring tether is intended for pre-installation to the sea bed prior to final hook-up. Following such validation – which is closely tied to the handling and installation procedure for the rope – the rope can be in contact with the sea bed.

The basic test as described here is valid for unloaded rope since the test is performed on a cut-off sample of the rope free length, which is not subject to any loads during soil exposure. If a rope is intended to be exposed to cyclic loading whilst it is exposed to seabed particles, then validation testing needs to be performed that includes such cyclic loading. This will be a more advanced test.
Cyclic loading produces a pumping effect in the rope, whereby a radial flow of water in and out of the rope is taking place. Such flow might transport particles into the rope if particles are suspended in the water. The basic test is focused on the free length of the rope. However, it needs to be ensured that also the termination areas have adequate soil ingress resistance. The rope eye regions are usually sealed with impermeable polyurethane coating. Here, the flow of water from the pumping effect in dynamic loading will be concentrated to the ventilation holes. Reduction of permeability in some areas will increase the tendency to take in soil in other areas due to increased flow of water.

It should be shown by way of the rope design that the protection of the eye region is equal to or better than the protection of the rope free length. The continuous protection of the eyes – underneath the PU coating needs to be demonstrated and it further needs to be demonstrated that the PU will not form cracks when loaded. The presence of cracks will concentrate water flow and potentially cause soil ingress even if the main length of rope is well enough protected.

3.15.2 Specimen selection
For the basic test – not including any dynamic loading – a cut-off from the free length is used in the soil exposure test. The specimen can be prepared according to the description in ISO 18692.

Note that if the rope is intended to be loaded prior to placing it on the sea bed, then the rope from which the cut-off is taken needs to be loaded to at least the same tension level, and held for a minimum of 17 minutes prior to unloading it and cutting off the soil test specimen. This should be done to make sure that the condition of the filter barrier in the test is the same as the worst case for the field exposure.

Guidance note:
If the rope is subjected to the installation tension prior to sea-bed storage then the test sample needs to be tensioned to the same tension level and held for sufficient time before the soil ingress resistance test.

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3.15.3 Preparation
The soil ingress resistance test is performed in order to make sure that soil particles will not penetrate into the load-bearing rope. The exposure is done in a pressure tank which contains emulsified soil particles in the water. The soil grading chart given in ISO 18692 gives an indication of the particle distribution which should be found in the soil being used for testing. The particle distribution of the soil in the area where the ropes are to be installed should be analysed to make sure the soil used for the test is adequately representative, as it is the fine particles that are the most likely to penetrate the filter.

When the test is being prepared then the soil is stirred into the water so that it becomes completely emulsified. The amount of soft soil in the bottom of the through should correspond to half the diameter of the rope such that the lower half is below the mud line. Then, the soil which is emulsified in the water needs to be allowed to settle on the rope. In this way, the finest possible particles are available to be pressed into the rope when the tank is pressurised. A suitable depth of this “sediment” has been found to be around 3 mm.

The pressure used for the test should reflect the pressure at the seabed where installation shall take place.

3.15.4 The basic test
Before the pressurisation and exposure testing, the sample should be pre-soaked overnight in fresh water to remove all entrapped air and completely soak the specimen, to avoid any undue water flow when pressure is applied. The sample needs to be placed in the emulsified mud in the pressurisation tank and the soil whipped into emulsion as described above.

After allowing the soil to settle until the next day, the pressurisation tank is carefully topped up with fresh water and the pressure is applied and then maintained overnight.

After this period, the pressure needs to be removed and the specimen lightly cleaned with water by soft spraying. The specimen needs to be left to dry at max 50°C prior to opening. The specimen can be slightly damp when opened.

In order to evaluate the soil-barrier efficiency, the braided jacket needs to be removed in one area and the
underlying filter layers needs to be visually examined. For indication of particle size deposits on the filters they should be examined in a stereo microscope.

3.15.5 Advanced test
Provided appropriate test design is carried out, advanced testing can be performed that includes the cyclic loading.

3.15.6 Evaluation of the test result
The specimen rope core needs to be visually examined. The surface colour of the subropes from the exposed rope should be the same as that of new, unexposed subropes. Stereo Microscope can be used in order to document the absence of particles on load-bearing yarns. Scanning Electron Microscope should be used with caution, to illustrate.

The white surface of the load-bearing subropes should not be discoloured by soil in order for the sample to pass the test. This can be determined visually by comparing the colour of the subropes of the exposed rope with the colour of new subrope.

3.15.7 Comments on the qualification of soil ingress resistance
The objective of the soil ingress testing as described above is to qualify adequate resistance to soil ingress for the designated service implied by the handling and installation of synthetic lines before mooring system hook-up. Other approaches to qualification should also be considered as required. Reference is made to other work in the industry such as described in /8/ for information that might be useful in this respect.

The qualification of the resistance to soil ingress needs to be performed according to the principles of DNV-RP-A203 whereby the failure modes and critical parameters need to be understood for the case at hand. Notwithstanding this, the basic qualification test as described above is generally considered to be conservative provided the rope does not flutter on the sea bed as induced by current or from the action of buoys that for some reason might be placed on the rope.

3.16 Testing of yarn abrasion resistance

3.16.1 Introduction
Yarn-on-yarn abrasion resistance is an important qualitative indicator of rope durability in wet cyclic tension if yarn-on-yarn abrasive motion is occurring in the rope.

Marine Grade Yarn is defined by Cordage Institute as yarn that has been demonstrated through testing to meet stated acceptance criteria. Marine Grade performance can be achieved in a number of ways, most commonly by the addition of a marine overlay finish to the surface of the yarn.

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3.16.2 Yarn-on-yarn abrasion test method
The yarn-on-yarn abrasion test should be performed in accordance with CI 1503.

The yarn needs to use the same finish and be applied in the same way as that used for all regular production of the applicable marine grade yarn type.

3.16.3 Polyamide yarn
Wet yarn-on-yarn abrasion performance criteria for polyamide (nylon) are provided in CI 2009N.
3.16.4 Polyester yarn
Wet yarn-on-yarn abrasion performance criteria for polyester are provided in CI 2009P.

3.17 Transport weight
For lines that are stored on reels with exposure to weather, the weight for transport might include the weight of water contained in the ropes and terminations.

The (wet) transport weight of offshore fibre ropes can be estimated according to the following procedure:

A length of rope equal to 3 metre Original length can be cut off, and the ends sealed. Each of the sealed ends should be equipped with a drain hole, allowing air to escape. The entire length of rope should be soaked in fresh water overnight.

Then, the rope should be removed from the water, and excess water allowed to run off for 6 hours before the sample is weighed.

The transport weight of the delivery rope is then calculated on basis of the 3-m sample.

The additional weight of the termination areas should be determined by calculation or sound judgement.

Unless more thorough measures are implemented, tarpaulins should not be trusted to prevent water ingress into lines stored on reels.

3.18 Linear density
This recommended practice does not use linear density as measured on ropes; however methods for this measurement on ropes may be found in CI 1500 and ISO 18692.

**Guidance note:**
DNVGL-OS-E303 does not require linear density measurement of offshore fibre rope.

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The nominal load-bearing linear density - which is used for normalisation in the analysis of offshore fibre rope - is the sum of load-bearing yarn linear density as stated by yarn manufacturer.

No testing of rope is needed in order to establish it. The effects of rope construction and rope stretch are not included in the nominal load-bearing linear density in order to keep it simple.

3.19 Testing of termination hardware

3.19.1 Introduction
Materials' testing of the termination hardware is performed in order to determine the material strength and ductility of the hardware. The forces exerted by the fibre rope terminations onto the termination hardware are high, and therefore only tough and ductile materials should be used.

3.19.2 Cast and forged thimbles
The materials should satisfy a Charpy V-notch impact toughness of 50 J at -20°C.

The mechanical tests should be taken from sacrificial items from the actual delivery.

One sacrificial item should be taken for each test unit.

For each test unit, 1-off tensile tests and 3-off Charpy V-notch tests should be performed.

The test specimens should be taken from critical section, as indicated in Figure 3-12. The test pieces for mechanical testing should be taken at 1/3 thickness from the surface in the critical section.
This is an illustration example; hence the appropriate critical section(s) should be identified for each termination hardware design, material and production method.

**Guidance note:**
The critical section is indicated on basis of the casting module (for castings) and the location of highest bend stresses from the soft eye acting on the thimble flanges.

---end---of---guidance---note---

It should be considered to take material from test blocks instead of from several sacrificial items provided it is validated by testing that test block properties are representative of the delivery. This may be useful in particular if test units consist of very few delivery items. At least one sacrificial item should always be tested.

**Guidance note:**
A test unit is defined as items from the same heat of steel and same heat-treatment batch. If an alternative test programme is applied then this should be substantiated.

---end---of---guidance---note---

All items need to be 100% visually inspected and be free from burrs, rough edges, cracks, dents, cuts, and other injurious imperfections. Particular attention needs to be paid to rope interface.

All surfaces that are in direct contact with the rope eye should be magnetic-particle tested (MT) or Liquid Penetrant Tested (DPI) in accordance with a recognised standard.

### 3.19.3 Manufacturing from rolled plate
The material in plates (and tubes) should comply with the requirements to mechanical properties of grades NV D as given in DNV-OS-B101.

Fabrication and non-destructive testing should be in accordance with DNV-OS-C401. Welds need to be considered as special category.

### 3.19.4 Other termination elements
Shackles and H-links should comply with DNVGL-OS-E302. Sockets should comply with DNVGL-OS-E304.

The material in custom-made termination elements should comply with DNVGL-OS-E302 and/or DNVGL-OS-C401, as appropriate.

### 3.19.5 Other materials
Other materials, such as polymers and fibre composites can be used provided the solutions have been duly qualified based on DNV-RP-A203.

**Guidance note:**
Recommendations can be provided in revisions of this recommended practice.

---end---of---guidance---note---

### 3.19.6 Testing as part of the line
In addition to the mechanical tests on the thimble material, the thimble should also be tested as part of the line:

— to verify the fit between the soft eye and the thimble at high tension in the break test
— to verify the capacity of the thimble in the break test
— to verify the fatigue endurance in the cyclic endurance test.

Due consideration should be given to corrosion expected to occur over service lifetime, methods for inspection, possible replacement etc.
SECTION 4 SYSTEM ANALYSIS

4.1 Introduction
This section is intended to provide recommendations pertaining to the analysis of the behaviour of offshore fibre ropes as part of an integrated system.

This first issue of this recommended practice discusses some aspects that are relevant for the analysis of offshore mooring systems. Complete methods are not intended to be provided in this first issue.

Note:
Recommendations provided in this document should not be regarded to exclude other methods for fulfilment of Requirements.

The representation of tension versus stretch performance in software tools might be a challenge for System Integrators since current software tools might not describe the tension versus stretch of synthetic lines adequately. Design practices will therefore rely on simplifications to adapt to existing software, and much iteration in the design processes.

It is the hope that the explanations provided in this recommended practice will help System Integrators in adapting design practices until the tension versus stretch of synthetic lines can be fully represented in computer software.

Guidance note:
This recommended practice is intended to be updated to provide more recommendations when results from on-going development work are available to be published. Recommendations for lifting lines in Deepwater deployment and recovery systems and offshore fibre ropes in other applications are intended to be included. Information about on-going development work can be obtained by sending an e-mail enquiry to rules@dnvgl.com.

4.2 Offshore mooring systems

4.2.1 Tasks to be performed

The design analysis of a synthetic line for a deep-water platform mooring system involves the following tasks.

— Determine the length of rope necessary for installation and so that the upper end of the rope does not rise too high in the water as tension increases and stretch takes place
— Determine the necessary length of top chain for length adjustment. Sufficient take-up capability must be provided to accommodate rope stretch
— Determine the necessary length of anchor chain so that the rope does not contact the sea floor
— Determine the maximum offset of the platform during extreme storm event conditions
— Determine the highest working tension and stretch and minimum tension in mooring lines during extreme storm event conditions
— Determine the fatigue loading parameters mean tension and cyclic tension range in connecting mooring line components
— Determine that the most slackened line will not touch the sea floor and that potential axial compression fatigue will not occur in aramid ropes by maintaining a qualified minimum tension

When candidate rope designs are evaluated, they should be compared on basis of actual tension versus stretch test data. Test results from different ropes should be compared using the Nominal Load-bearing Linear Density as basis.

4.2.2 Analysis procedure

Mooring analyses are normally performed with software where all mooring lines are modelled with their properties; weight, buoyancy, length, elasticity and hydrodynamic properties. Normally linear elasticity is assumed, but some programs can also handle non-linear elastic stiffness. The different mooring line components are modelled with their elastic properties.

The normal procedure for mooring analyses is as follows:

1) Calculate mean environmental forces. (The environmental forces on the floating unit are caused by action from wind, waves and current.)
2) Calculate the equilibrium structure position where mean environmental forces are balanced by mean line tensions.

3) Calculate dynamic motions and line tensions. The floating unit will have responses in two different frequency ranges, at wave frequencies and at low frequencies which correspond to the natural periods of horizontal plane motions. There are different options for solving the dynamic responses:

   a) **Frequency domain analysis**: The equations of motion are linearized and are solved under the assumption of linear superposition of responses at different frequencies. The wave frequency and low frequency responses are handled separately, and could in principle use different stiffness properties of the line, but how to combine the tension response in the different frequency ranges is then not well defined.

   b) **Time domain analysis**: Time series of wind and wave forces are generated and the equations of motion are solved by numerical integration. There is no separation of wave-frequency and low-frequency motions, and the same line model must be used for both. In time domain it is possible to apply complex line models like the spring-dashpot model if the parameterization of the model is known.

   c) **Combined analysis**: The wave-frequency motions are solved in frequency domain and the low-frequency motions are solved in time domain. With regards to modelling of the lines the same comments as given above for the frequency-domain analysis apply.

With a fibre rope model based on working curves the following procedure can be followed:

— Perform a static analysis with mean environmental forces, using the appropriate non-linear working curve for each line
— If the mean tension in any of the lines is higher than the preceding highest working tension then the working curve for these lines needs to be updated
— Identify tensions at top of the synthetic lines and update input files with an axial stiffness depending on the mean tension, and a stress-free length of the line that corresponds to this stiffness
— Perform static and dynamic analysis with the updated mooring line description, where dynamic analysis is performed according to any of the methods 3a, 3b or 3c above

Mean tensions from the two static calculations are close to equal.

*Figure 4-1* shows the use of a stress-free rope length to give the same strain at mean tension for the analysis of both dynamic (instant-elastic) stiffness and working stiffness.
4.3 Discussion of system analysis

4.3.1 Introduction

The platform mooring system comprises a number of individual mooring legs arranged radially around the platform. Consideration must be given to the individual mooring legs horizontal force vectors in relation to the direction of platform offset caused by external forces. Consideration must also be given to the individual mooring leg vertical force vectors as applied to the platform.

**Guidance note:**
There are many ways that mooring system analysis can be performed; so this recommended practice aims more at explaining the tension versus stretch characteristics of synthetic ropes in the context of analysis than at providing guidance on detailed system analysis as such.

For practical design analysis of mooring systems it will often be sufficient to perform the analysis in steps defined by sea-states of typically 3-hour duration. The analysis of rope length can thus be based on working curves. The working curves, including the original working curve, represent the length of the rope when working strain and polymer strain have stabilised. The working curves can be used when the time element is not important, such as in most aspects of mooring analysis.

On the other hand, the time element is very important in lifting applications, and the original and loading behaviour should be emphasised in the analyses.

And for analysis of the highest tension and associated length of rope in windward lines, rapid loading should be included. An accurate appreciation of the total strain should be included in the check for maximum length of the rope. For the lowest tension and associated length of rope in leeward lines, the actual unloading curve should be used, and the time-dependent contraction of visco-elastic strain possibly excluded from the check for avoidance of sea-bed touchdown.

---end---of---guidance---note---

4.3.2 Individual mooring leg response

An individual mooring leg typically comprises several sections of synthetic line in series with sections of chain or wire rope. The stretch characteristics of all of these components should appropriately be summed, accounting for their respective stiffness to achieve the individual mooring leg stretch curve.

If the mooring leg includes components of substantial weight, or includes substantial buoys or floats, the geometry or catenary of the mooring leg should be accounted for in the mooring leg stretch curve.

If the geometric stiffness of for example heavy bottom chain is included, the physical representation with the spring-dashpot model can be expanded as shown in Figure 4-2.

**Guidance note:**
This is usually accounted for in commonly available mooring analysis software.

---end---of---guidance---note---

Figure 4-2  Illustration of the mechanical model for polyester ropes with bottom chain

4.3.3 System response diagrams

A simplified mooring system comprised only of two, horizontally opposed mooring lines is discussed first.

The system response diagram is a plot of the horizontal force applied to the platform and the resulting platform offset. Figure 4-3 shows the platform mooring system response diagram for this simple two-opposed-line mooring system. Only the synthetic lines are considered here.
The system response diagram is produced by superimposing the effective working curves for the windward and leeward lines. These effective working curves are arranged such that they intersect at the installed mooring line tension. This intersection represents the neutral position, the platform position without any externally applied force.

**Guidance note:**
Although the terms storm, windward, and leeward are used in this narrative, these principles apply to any situation in which the platform is offset, for example due to current or the pull of a tugboat.

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The windward and leeward lines pull against each other and at the intersection point of the two working curves the working stiffness of the windward and leeward lines cancel each other out. When a storm force is applied from the windward side and pushes the platform in the leeward direction, then the mean tension in the windward line increases whilst the mean tension in the leeward line decreases.

The resultant system response diagram for the effective platform restoring force is constructed by subtracting the effective working curve of the leeward line from that of the windward line.

**Figure 4-4** illustrates what happens when the windward mooring line is loaded above its preceding highest working tension. The windward effective working curve follows the original working curve up to the next highest tension. Then when the mean tension is reduced, it follows an offset downwards working curve. This working curve starts in the newly established preceding highest working point for that line corresponding to the new (preceding) highest working tension.

The platform will find a new equilibrium position where the downwards working curve for the windward line intersects the upwards working curve for the leeward line. This new equilibrium point will be somewhat offset from the installed equilibrium position, and the mean tension will be somewhat lower, see **Figure 4-4**.
Figure 4-4 System response diagram after loading that has exceeded the installation tension in one line

Additional visco-elastic stretch and instant-plastic stretch (and visco-plastic stretch) takes place in the windward line when the tension is high. Note that the preceding highest working tension for the leeward line does not change and that its working stretch is reduced according to the downwards working curve from the installed equilibrium point. As a result of the additional plastic stretch, the windward line is longer and the system response diagram is now asymmetrical.

Guidance note:
In the above figures the platform response curves are drawn for increasing excursion only. Combined hysteresis (if any) of the upwards working curve of the leeward line and the downwards working curve of the windward line is not shown.

The above response diagrams have been assumed to be drawn on the basis of non-time-dependent working curves, and thus they are assumed to represent very slow response to changes in sea states. The same principles apply to the establishment of time-dependent response diagrams on basis of time-dependent loading curves.

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4.3.4 Use of spare lines
When a synthetic mooring line is replaced with a new one, then this will affect the system response initially. It is, however, recommended to not compensate for the longer length of the lines in use as the stretch of the new line soon will catch up with the line that was removed.

4.4 Deepwater deployment and recovery systems
The tension versus stretch analysis of lifting lines in Deepwater Deployment and Recovery Systems is intended to be covered in revisions of this recommended practice.

4.5 Notes on the verification of 3-T endurance

4.5.1 Introduction
Design criteria analogous to those presented in DNVGL-OS-E301 for traditional dimensioning - based on characteristic strength - can be applied for verification of 3-T endurance.
Following the dimensioning of synthetic mooring lines on basis of the tension versus stretch characteristics, then a subsequent check of the margins against line failure needs to be performed with respect to short-term and long-term 3-T endurance such that the synthetic lines will have sufficient load-bearing capability in all loading scenarios.

Notes on this subject are provided in App.A, where the set of stress rupture data that is presented in DNV Programme for Approval of Manufacturers 322, App.B is used as basis.

**Guidance note:**
This document recommends to dimension a system on basis of tension versus stretch characteristics, and then to verify the short-term 3-T endurance (akin to break strength) and long-term 3-T endurance (static fatigue) of the lines. This recommendation is based on the way synthetic fibres actually perform under tension. These notes are provided as a first outline since a ready-to-use industry method for 3-T dimensioning is yet to be developed, and it is intended to provide more recommendations in revisions of this recommended practice.

For practical appreciation of 3-T margins for mooring lines and lifting equipment (not lifting lines), it should be observed that it has been shown for polyester that the 3-T endurance in practice will remain unaffected as long as the peak tension levels do not exceed 70% MBS for temperatures that do not exceed 20°C.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
APPENDIX A  CASE-SPECIFIC CALIBRATION OF 3-T DESIGN FACTOR

The time to rupture at load level S is expressed through the relationship \( T = K \cdot \exp(\varepsilon) \cdot \exp(-mS) \), in which \( \varepsilon \) reflects the variability in the time to rupture about the median value. The mean value of \( \varepsilon \) is taken as 0 and the standard deviation is taken as \( \sigma_\varepsilon = 0.32 \), which is based on available test data. The distribution of \( \varepsilon \) is assumed to be a normal distribution. \( \sigma_\varepsilon \) may be interpreted as the standard deviation in the natural logarithm of the time to failure. The characteristic time to rupture is taken as the 2.5% quantile in the distribution of \( T \), hence \( T_C = K \cdot \exp(-1.96 \cdot \sigma_\varepsilon) \cdot \exp(-mS) \). The slope parameter \( m \) is initially taken as \( m = 0.0525 \text{ (N/ tex)}^{-1} \), which is based on test results; however, a range of representative values have been investigated.

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The ratio between time spent at a sustained load level S and the time to rupture at this level can be considered a cumulative utilisation, and rupture then occurs when this utilisation has become large enough.

The loading leading to cumulative utilisation is assumed to consist of some history of sustained load S over a certain design life \( T_L \). The loads of this history of sustained loads are assumed to follow a Weibull distribution in which the scale parameter \( S_0 \) represents the overall level of the loading and may be encumbered with uncertainty. The uncertainty in \( S_0 \) is dealt with later. The shape parameter \( \beta \) governs the width of the Weibull distribution and is also dealt with later.

The stochastic cumulative utilisation is predicted by a Miner’s sum approach on integral form, hence

\[
D = \int_0^{\infty} T_L \cdot \frac{dF_S}{ds} \cdot ds = \frac{T_L \cdot \beta}{K \cdot \exp(\varepsilon) \cdot S_0^\beta} \int_0^{\infty} s^{\beta-1} \cdot \exp(-s^\beta) \cdot ds
\]

The characteristic cumulative utilisation is based on the characteristic time to rupture and on the expected value of the scale parameter \( S_0 \), hence

\[
D_c = \frac{T_L \cdot \beta}{K \cdot \exp(-1.96 \cdot \sigma_\varepsilon) \cdot E[S_0]^\beta} \int_0^{\infty} s^{\beta-1} \cdot \exp(-s^\beta) \cdot ds
\]

The integral

\[
h(s_0, m, \beta) = \int_0^{\infty} s^{\beta-1} \cdot \exp(-s^\beta) \cdot ds
\]

can be solved numerically.

Based on the inequality valid in the safe region, i.e. \( D < 1.0 \), and on the deterministic design equation, i.e. \( \gamma \cdot D_C = 1.0 \), in which \( \gamma \) is a design factor for 3-T, a limit state function is defined as

\[
g = 1 - \frac{D}{\gamma \cdot D_C} = 1 - \frac{X_{mod} \cdot \exp(-1.96 \cdot \sigma_\varepsilon) \cdot \exp(\varepsilon) \cdot h(S_0, m, \beta)}{h(E[S_0], m, \beta)}
\]

in which \( X_{mod} \) is a random model uncertainty factor representing the uncertainty in utilisation predictions by a Miner’s sum approach. The mean value is taken equal to 1.0, as the Miner’s sum approach is assumed to be unbiased, and the coefficient of variation is taken equal to 30%. The distribution is assumed to be a
normal distribution.

The distribution of \( S_0 \), which represents the uncertainty in the tension level, is taken as a normal distribution with mean value \( E[S_0] = 0.2 \ N/\text{tex} \) and coefficient of variation \( \text{COV}_{S_0} \). In the following, the value of \( \text{COV}_{S_0} \) is taken as 15%. The sensitivity to the choice of mean value will be dealt with later.

As described above, the distribution of \( \varepsilon \) is taken as a normal distribution with mean value 0 and standard deviation \( \sigma_\varepsilon = 0.32 \).

The requirement in order to ensure sufficient structural reliability is a requirement for the annual failure probability. The target annual failure probability is assumed to be \( 10^{-5} \), which is a commonly used value for manned offshore structures. For the present problem, where failure is associated with the accumulation of utilisation over time, the annual failure probability will increase from one year to the next during the design life. The requirement for the annual failure probability needs to be met in all years during the design life. This implies that when the requirement is fulfilled for the last year during the design life, it will be fulfilled for all years.

When the design life is \( T_L \), the failure probability in the last year during the design life comes about as the difference between the failure probability in \( T_L \) years and the failure probability in \( T_L - 1 \) years,

\[
P_F = P_{F,T_L} - P_{F,T_L-1}
\]

where \( P_{F,T_L} \) is calculated based on the limit state function

\[
g = 1 - \frac{X_{mod}}{\gamma} \cdot \frac{\exp(-1.96 \cdot \sigma_\varepsilon)}{\exp(\varepsilon)} \cdot \frac{h(S_0, m, \beta)}{h(E[S_0], m, \beta)}
\]

and where \( P_{F,T_L} \) is calculated based on the limit state function

\[
g = 1 - \frac{T_L - 1}{T_L} \cdot \frac{X_{mod}}{\gamma} \cdot \frac{\exp(-1.96 \cdot \sigma_\varepsilon)}{\exp(\varepsilon)} \cdot \frac{h(S_0, m, \beta)}{h(E[S_0], m, \beta)}
\]

This is based on the assumption that the Weibull distribution of the sustained load is representative not only over the design lifetime, but also over each individual year during the design lifetime.

A second-order reliability method (SORM) as described in /9/ is used to calculate the failure probability as \( P_f = P_{F,T_L} - P_{F,T_L-1} \). A design lifetime \( T_L = 20 \) years is assumed. The design factor \( \gamma \) for 3-T is calibrated as the one that leads to an annual failure probability \( P_F \) equal to the target of \( 10^{-5} \) in the last year of the design life.

The results are shown in Table A-1 for various values of the shape parameter \( \beta \) in the Weibull distribution of the sustained load level \( S \).

**Table A-1  Calibrated requirement for design factor \( \gamma \) for 3-T**

<table>
<thead>
<tr>
<th>( E[S_0] = 0.2 \ N/\text{tex} )</th>
<th>( M = 0.0525 \ (N/\text{tex})^{-1} )</th>
<th>( \sigma_\varepsilon = 0.32 ) (standard deviation of natural logarithm of time to failure)</th>
<th>( T_L = 20 ) years</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>( \gamma )</td>
<td>( \beta )</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>1.0</td>
<td>2.645</td>
<td>2.0</td>
<td>2.640</td>
</tr>
<tr>
<td>1.5</td>
<td>2.661</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>2.640</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It appears that to meet a target annual failure probability of \( 10^{-5} \), a 3-T design factor requirement of approximately 2.65 results for the range of shape parameter values beta investigated. The sensitivity to \( \beta \) within this range appears to be insignificant.

A sensitivity study has been carried out, based on the results for \( \beta = 2.0 \) as a base case. A change in \( E[S_0] \) from 0.2 to 0.4 \( N/\text{tex} \) indicates no sensitivity in the resulting requirement for the 3-T design factor \( \gamma \) and the
same is the case for a change in the slope parameter $m$ from 0.0525 to 0.700 $(t_{10y})^{-1}$. A change in the design life $T_L$ from 20 to 30 years implies a slight reduction in the calibrated 3-T design factor requirement from 2.64 to 2.56.

Other sensitivity studies may be apt, first of all to check the sensitivity to assumptions made regarding the uncertainty in the general load level ($S_0$) and regarding model uncertainty associated with predictions of utilisation by a Miner’s sum approach.

It is intended to quantify these uncertainties more accurately and to provide recommendations in revisions of this recommended practice.
APPENDIX B  OVERVIEW OF DNV GL DOCUMENTS

An overview of DNV GL documents that are relevant for offshore fibre ropes is shown in Figure B-1.

Figure B-1  Overview of DNV GL documents relevant for offshore fibre ropes
