

**“ENGINEERS DESIGN GUIDE  
FOR DEEPWATER FIBRE  
MOORINGS”**

**INTERIM DOCUMENTS**

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# JOINT INDUSTRY PROJECT

## ENGINEERS DESIGN GUIDE FOR DEEPWATER FIBRE MOORINGS

### FIBRE MOORING GUIDELINE - REV F

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Prepared by

**NOBLE DENTON EUROPE LTD.  
TENSION TECHNOLOGY INTERNATIONAL**

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#### Distribution

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Attn: see distribution list inside



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### Sponsoring Project Members

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28. Single Buoy Moorings, France
29. Smit Engineering B.V., Netherlands
30. Statoil, Norway



## Abbreviations for Documentation

The Documentation produced by the present Joint Industry Project is as follows:

<u>Initials</u>	<u>Document Name</u>	<u>Status</u>
FMG	Fibre Mooring Guideline	This Document
DPD	Design Practice Document	
EC	Engineering Commentary	
WE	Worked Examples	
APP	Appendices	



## Abbreviations Used in the Documents

The following list covers abbreviations for some of the technical terms and proper names which are commonly used in this document. The list also includes abbreviations which are frequently used in the textile fibre industry and which the designer of a fibre mooring system may need to be aware of.

<u>Abbreviation</u>	<u>Term</u>
ABS	American Bureau of Shipping (classification society)
API	American Petroleum Institute
BV	Bureau Veritas (classification society)
CALM	Catenary Anchor Leg Mooring
DNV	Det Norsk Veritas (classification society)
DP	Dynamic Positioning
HMPE	High Modulus (gel spun) Polyethylene
LCAP	Liquid Crystal Aromatic Polymer
NDE	Noble Denton Europe
OCIMF	Oil Companies International Marine Forum
PET	Polyester
PPMA	Aramid (Para Aramid)
SALM	Single Anchor Leg Mooring
TLP	Tension Leg Platform
TTI	Tension Technology International
WRC	Wire Rope Construction



## 1. INTRODUCTION

### 1.1 General

1.1.1 The Engineers Design Guide for Deepwater Fibre Moorings covers the deepwater mooring systems which incorporate synthetic fibre rope.

1.1.2 The Guide been developed as a Joint Industry Project supported by Oil Operators, Classification Societies, Offshore Design and Installation Contractors, Rope Producers and Fibre Manufacturers to provide a common reference which can be used with advantage by all those involved in the planning, design, analysis, approval, specification, commissioning, installation, testing, inspection and retirement of mooring systems that include fibre ropes.

1.1.3 The Design Guide consists of the following related documents:

- Fibre Mooring Guideline (this document)
- Design Practice Document
- Engineering Commentary
- Appendices

1.1.4 This document (the Fibre Mooring Guideline) describes the philosophy behind the Guide and indicates its scope.

1.1.5 The Design Practice Document provides practical guidance and instruction on the items that need to be considered and the way in which calculations should be made during the design and analysis process. It also provides guidance on matters such as specification, installation, inspection and discard.

1.1.6 The Engineering Commentary provides explanatory information to justify the comments made in the Design Practice Document.

1.1.7 The Appendices provide supporting information.

1.1.8 It is anticipated that the Engineers Design Guide for Deepwater Fibre Moorings will be used in conjunction with existing rules and regulations provided by such bodies as Classification Societies and Government Agencies.

1.1.9 The user is advised to take due account of any regulatory requirements that may apply.

### 1.2 The Fibre Mooring Guideline Document

1.2.1 The purpose of this overview GUIDELINE is to explain the scope and philosophy of the design approach which is contained in the Guide.

1.2.2 The GUIDELINE will also identify the factors which are likely to be the main concerns for any spread mooring system that makes use of synthetic fibre ropes.

1.2.3 It should be used in conjunction with the DESIGN PRACTICE DOCUMENT which provides detailed guidance on how to conduct the analysis and specification of such moorings.



**1.3 Relation to the Design Practice Document**

1.3.1 The "Design Practice Document" provides practical guidance and recommendations on the design and use of fibre rope assemblies in spread moorings. It is not in itself an exhaustive representation of all the information and data currently available for spread fibre moorings and, as this is a new and rapidly developing area of technology it will need to be supplemented periodically with additional information and revised to take account of technical developments.

**1.4 Other Recognised Standards**

1.4.1 It is assumed that the floating structure and the elements in the mooring system are built to recognised standards and will be maintained as required to continue to meet those standards.

**1.5 Fitness for Purpose**

1.5.1 Any deterioration of the moored structure, mooring elements or anchors should be taken into account by means of the design factor of safety when determining the fitness for purpose of the system.





## 2. APPLICABILITY AND LIMITATIONS

### 2.1 General

- 2.1.1 The Design Guide is principally concerned with structures which are moored to the seabed by a number of mooring lines consisting wholly or partly of synthetic fibre rope assemblies.
- 2.1.2 It is intended that the Design Guide be applicable to most temporarily or permanently moored floating vessels.
- 2.1.3 The vessel may be fitted with thrusters to reduce the loads transferred to the mooring system.
- 2.1.4 It is recognised that there may be designs and/or circumstances when certain provisions may not apply or where additional provisions would be required. Such instances should be reviewed on a case by case basis.
- 2.1.5 The mooring lines may (and probably will) include other elements such as wire rope, chain, standard connectors, buoys and sinker weights. Though the behaviour of these items is relatively well understood and covered in various authoritative documents their interaction with the fibre rope assemblies must be carefully considered.

### 2.2 Limitations

- 2.2.1 The following specific cases are not covered by the Design Guide although some parts of the document may be relevant for such systems:

- Mooring of vessels to adjacent surface structures by means of hawsers
- Mooring of buoys to the seabed using single line moorings
- Vertical tethers for Tension Leg Platforms



### 3. SITE AND ENVIRONMENTAL DATA

#### 3.1 General Site Data

3.1.1 Adequate site data must be available to allow the mooring and installation analysis to be undertaken.

#### 3.2 Environmental Data

3.2.1 Accurate environmental data will be required for the location to enable an adequate analysis of the mooring system to be undertaken.

3.2.2 If the mooring system deployment is to be of limited duration (for example, the summer season only) applicable seasonal data may be used.

#### 3.3 Geotechnical Data

3.3.1 Site specific geotechnical information must be obtained for the anchor locations.

#### 3.4 Floating Structure Data

3.4.1 Data for the vessel to be moored at the location will be required in order to allow aspects such as environmental loading to be calculated.

3.4.2 The vessel should have sufficient strength and stability for the loadings imposed.



## 4. MOORING ANALYSIS

### 4.1 Compatibility of Design Approach

- 4.1.1 The entire design should be undertaken using a consistent method to ensure that appropriate factors of safety against failure are maintained.

### 4.2 Design objectives

- 4.2.1 The following design requirements must be addressed:
- operational watchcircle requirements
  - system overload (the ultimate strength limit state)
  - tension-tension fatigue life and compression fatigue life (the fatigue limit state)
  - resistance to accidental damage conditions (damage limit state)

### 4.3 Loadings

- 4.3.1 Loadings can be derived from calculation or from model testing or a combination of these two methods.

### 4.4 Analysis Methods

- 4.4.1 The analysis method should consider the various relevant limit states and demonstrate that an acceptable solution has been achieved for the design life of the system.
- 4.4.2 The analysis of the mooring system behaviour can be determined by means of model tests, or calculation or both.
- 4.4.3 Quasi static and dynamic analysis methods should be used as appropriate.

### 4.5 Specification of Line Characteristics for Mooring Analysis

- 4.5.1 A clear specification of the physical properties of the fibre rope assemblies is needed when undertaking the design analysis to determine the response of the mooring system.

### 4.6 Factors of Safety

- 4.6.1 In line with current mooring analysis practice the present document provides Safety Factors based on:
- mooring line design loads resulting from a specified set of environmental conditions
  - the mooring element strength provided by testing or data furnished by the manufacturer
- 4.6.2 However certain fibre ropes can experience reductions in break strength and stiffness over their lives and these will require the use of additional safety factors

### 4.7 Partial Factors

- 4.7.1 Future developments in analysis may introduce the use of Partial Factors which allow explicit factors



to be used to account for:

- uncertainty in loads
- uncertainty in material and element strength
- consequence of failure

#### **4.8 Combined Riser - Mooring Analysis**

4.8.1 In the future it may become accepted practice for risers and moorings to be considered jointly in the analysis process. This may be done using the present document as long as it is suitably adjusted to account for the additional analysis requirements.



## 5. DESIGN LIMIT STATES

### 5.1 General

5.1.1 The design criteria can be considered in terms of the design limit states which are outlined below.

### 5.2 Displacement Limit State

5.2.1 The mooring system shall be adequately stiff to maintain the moored structure within the operational watch circle required for the activities of the platform.

### 5.3 Strength Limit State

5.3.1 The highest forces in the mooring lines determined from the mooring analysis should not exceed the actual line strength taking into account an appropriate factor of safety reflecting:

- material or constructional uncertainty
- load uncertainty
- failure consequence

### 5.4 Compression Buckling Limit State

5.4.1 Some fibre ropes lose strength in frequent repeat loadings that impose axial compression on parts of the fibre assembly. Limits for minimum axial loads and maximum bending will be required for these ropes.

### 5.5 Fatigue Limit State

5.5.1 An assessment of the fatigue loading of the mooring lines should be made and compared with data available on the fatigue resistance of the mooring line elements.

### 5.6 Effects of Creep and Creep Rupture on Fibre Mooring Systems

5.6.1 The effect of creep and creep rupture on a mooring system should be accounted for in the design.

### 5.7 Damage Due to External Abrasion, Particle Ingress and Fishbite

5.7.1 The rope should be able to survive the levels of fishbite damage to be expected for the location provided with adequate protection against external abrasion, particle ingress and fishbite.

### 5.8 Accidental Limit State

5.8.1 Provision should be made for accidental limit states such as the ability of the mooring system to survive damage to one or more mooring lines or a component of the station keeping system such as a buoy, thruster etc.



**5.9 Other Damaging Mechanisms**

- 5.9.1 The designers should be able to demonstrate that all realistic potential mechanisms that might cause failure in the mooring line elements have been investigated and that the likelihood of their not maintaining their fitness for purpose are acceptably low.

## **6. ROPE DESIGN AND SPECIFICATION**

### **6.1 Specification**

- 6.1.1 The rope vendor and the purchaser shall need to agree on a specification for the fibre rope assemblies to be delivered. The technical capability of the fibre rope assemblies to meet the mooring system requirements will depend critically on the as-delivered characteristics of the rope. The characteristics of the rope will be demonstrated by means of prototype testing.

## **7. ROPE MANUFACTURE AND CERTIFICATION**

### **7.1 General**

- 7.1.1 Ropes and rope assemblies shall be constructed to meet the performance standards required by the purchaser and within agreed tolerances.
- 7.1.2 Where prototypes have previously been made and tested the manufacturer should demonstrate that materials and construction are within agreed tolerances of the prototype. Where no prototypes have been made and tested the manufacturer shall document full material and constructional properties and perform such testing as required to demonstrate achievement of performance standards.

### **7.2 Acceptance of Fibre Rope Assemblies**

- 7.2.1 The Rope Manufacturer will provide appropriate quality assurance procedures. It is envisaged that purchasing, testing and Quality Assurance (QA) guidelines will be provided in the future by classifications and similar organisation

### **7.3 Other Items in the Mooring Lines**

- 7.3.1 All other mooring line components; such as wire; strand, chain; in-line buoys and anchors should be designed to perform adequately in the mooring system.

### **7.4 Storage and Shipping of Mooring Line System**

- 7.4.1 Adequate provisions shall be made by the manufacturer to prevent damage to the rope during storage and delivery. Fibre mooring lines should be stored to avoid overbending, crushing, overlapping and permanent set. Special provision should be made for custom built termination housing within any containers, reels or storage wells.



## 8. MOORING LINE INSTALLATION

### 8.1 General

- 8.1.1 Installation procedures shall be developed which are capable of installing the fibre mooring system without incurring damage to the fibre rope. If the system is pre-deployed prior to platform arrival the temporary deployment must avoid damage to the mooring components.
- 8.1.2 The same phases need to be considered whether the mooring system is permanent or temporary.

### 8.2 Installation of Fibre Mooring Assemblies

- 8.2.1 Adequate arrangements must be provided for handling the mooring rope assemblies during installation to ensure that they do not suffer damage.

## 9. OPERATION INSPECTION AND RETIREMENT

### 9.1 General

#### 9.1.1 Operation

- 9.1.2 Records should be kept of line tensions and line shortening (due to take up of creep) during the lifetime of the installation.

#### 9.1.3 Inspection

- 9.1.4 Pending the development of field-proven NDT techniques for fibre ropes and their termination's, reliable field discard criteria are to be established by planned removal and test of redundant moorings or mooring inserts on fibre rope moored platforms.
- 9.1.5 Depending on the design life of the mooring system prior to removal, it may be necessary to carry out inspection of the mooring lines in accordance with classification society rules.
- 9.1.6 In the case of mooring inserts, these are to be sited so as to experience representative loading on the lines in question.

**JOINT INDUSTRY PROJECT**  
**ENGINEERS DESIGN GUIDE FOR**  
**DEEPWATER FIBRE MOORINGS**

**Design Practice Document - Rev 4**  
Report No: L17768-Rev.3/NDE/RWPS dated 15th June.1998

Prepared by

**NOBLE DENTON EUROPE LTD.**  
and  
**TENSION TECHNOLOGY INTERNATIONAL**

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# Engineers Design Guide – Deepwater Fibre Moorings

## Design Practice Document

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**PREFACE**

**DESIGN PRACTICE DOCUMENT - REV 4**

**WORKING DRAFT FOR APPROVAL**

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**1. PURPOSE OF THIS DOCUMENT**

The Design Practice Document for Fibre Rope Mooring Systems deals with the practical design aspects of offshore mooring systems that incorporate fibre ropes.

It forms part of the Engineering Design Guide for Deepwater Fibre Rope Moorings developed through a Joint Industry Project supported by Oil companies, Classification Societies, Design Contractors, Rope Manufacturers, Installation Contractors and Fibre Producers. This document should be used in conjunction with the following associated documents:

- Fibre Mooring Guideline
- Engineering Commentary
- Working examples (see Appendix 1)
- Appendices

The present document is aimed at providing practical guidance and instructions on the issues that need to be considered and the way in which calculations should be made during the design and analysis of fibre rope mooring systems. It covers the subjects which are specifically related to the fibre rope moorings such as rope material properties, connecting equipment, design criteria, mooring analysis method, installation, certification and discard criteria.

This document has been developed to be complementary with API Recommended Practice 2SK, "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures", First Edition, June 1995 and references have been to API RP 2SK on many occasions.

The Design Practice Document for Fibre Rope Moorings is intended to be used as supplement to recognised standards and codes currently in use on design and analysis of offshore mooring systems.

## 2. PROJECT MEMBERSHIP

The participating membership and representatives of the project are listed below:

Aker Marine a.s., Norway	H. Røraas
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Amerada Hess Limited, U.K.	Mike Taggart
American Bureau of Shipping, UK	F Rogers
American Group - Samson Division	Randy Longerich
Bluewater Engineering b.v., Netherlands	Richard Leeuwenburgh
BP Exploration, UK	W.D.M Morris / Roger Dyer
Bridon Fibres, UK	(c.f. Marlow)
Bureau Veritas, France	M Francois
Chevron	Steve Woehleke
Det Norske Veritas, Norway	B Sogstad
DSM High Performance Fibres B.V., Netherlands	E. van Gorp
Elf Enterprise Caledonia	Laurent Foulhoux
Exxon (EPRCo)	Tom Kwan
Hoechst Celanese Corp., USA	Tom Schmitt/Michael Stroud
Le Lis ,Netherlands	Eelko Bergsma
Lloyds Register of Shipping, UK	R.C MacDonald
Marlow Ropes	Andrew Street
Mærsk Supply Service, Denmark	Torben Hestbaek
Norsk Hydro, Norway	Finn Gunnar Nilson
Petrobras	Cesar Del Vecchio
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ScanRope a/s, Norway	Nils Martin Teien
Shell (A/S Norske Shell),Norway	Helge Skjaeveland / Ole Myklestad
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Smit Engineering B.V., Netherlands	T. Vergouw /W. Terpstra
Statoil, Norway	Bjorn Abrahamsen

### 3. CONFIDENTIALITY

This document is confidential to the project membership until the Working Draft is agreed and distributed.

Basic Terminology

Basic List of Terminology  
for  
Fibre Ropes and Fibre Rope Deepwater Mooring Systems

This is a brief list of some of the more important terms and abbreviations used in the Engineers Design Guide to Deepwater Fibre Moorings. A more comprehensive list is provided in Appendix 1.

The terms are listed alphabetically under each main heading.

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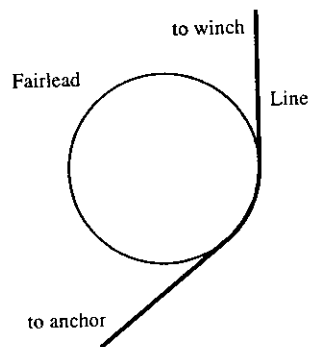
1. Mooring Systems and Equipment:	1
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**1. Mooring Systems and Equipment:**

<u>Term</u>	<u>Description</u>
<ul style="list-style-type: none"> <li>• <b>catenary mooring</b></li> </ul>	

A mooring in which the weight of the submerged line is significant and gives rise to a catenary profile. The line angle at the seabed is often close to horizontal meaning that very little vertical load exists at the anchors.

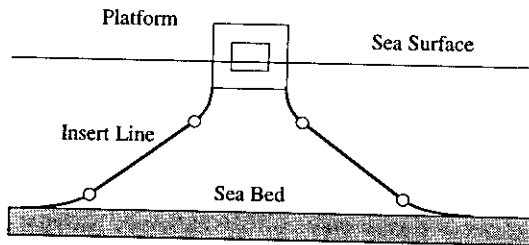
- **fairlead**



A sheave or guide used to divert the mooring line where it attached to the platform. It is usually submerged.

- Term**
- **insert line mooring system**

**Description**

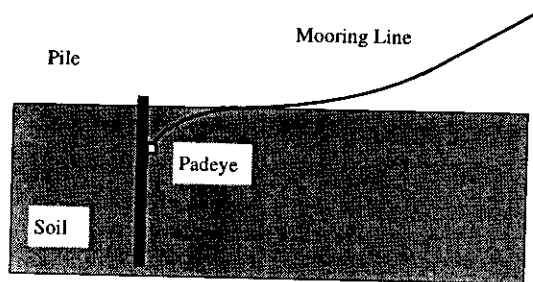


A mooring system in which a significant length of the free spanning mooring line in a system is replaced with an insert portion. Fibre rope inserts give low submerged weights for the mooring lines.

- **offset**
- **permanent mooring**
- **piled anchors**

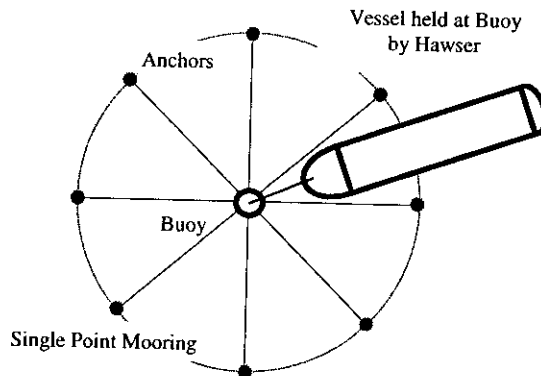
The horizontal distance moved by the platform under the influence of environmental loading

A mooring for a permanently located platform. (Typical design life between 2 and 30 years)



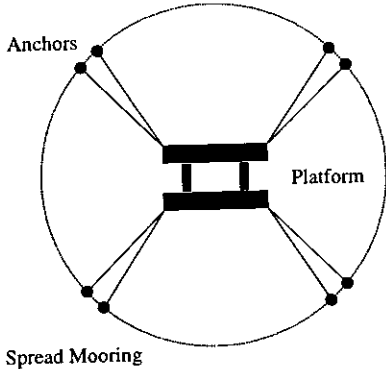
An anchor consisting of a vertical pile driven into the seabed.

- **single point mooring**

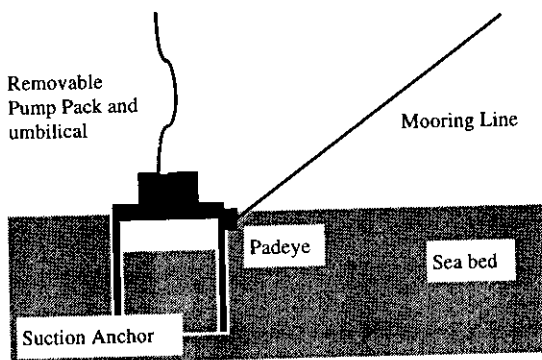


A mooring in which a buoy or turret is held in position by a spread of mooring lines but the connecting platform is free to rotate about the fixed point.

Basic Terminology

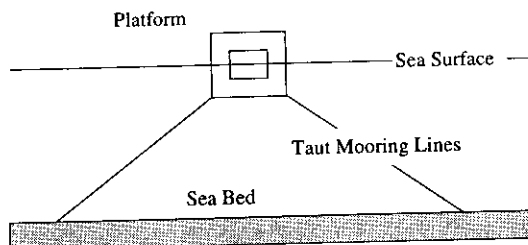
- | <u>Term</u>  | <u>Description</u>   |
|--|--|
| <ul style="list-style-type: none"> <li>• spread mooring</li> </ul> |  <p style="text-align: center;">Spread Mooring</p> <p>A mooring in which a spread of mooring lines is used to hold a platform horizontally in position without rotation.</p> |

- suction anchors



An anchor consisting of a vertical cylinder with a closed top and open bottom. It can be pulled into position by actively applied suction on the inside. Once in location it uses passive suction to withstand vertical loads.

- taut leg mooring

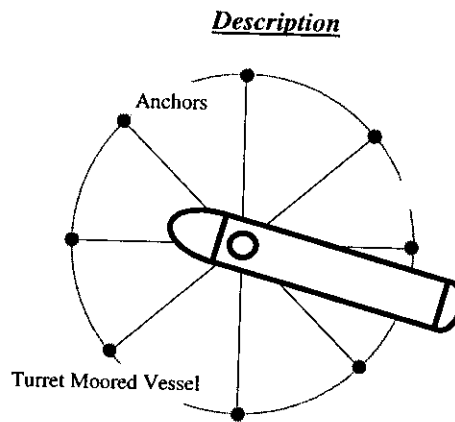


A mooring in which the lines are close to straight and possess little catenary sag. For such moorings there is a significant level of vertical load applied at the seabed anchors.

- temporary mooring

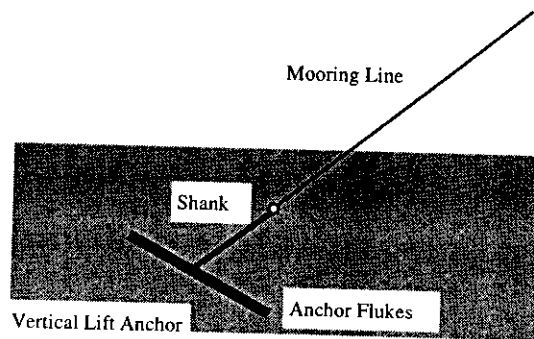
A platform mooring which will only exist for a temporary period such as during exploratory drilling.

- Term
- **turret mooring**



A type of single point mooring in which the vessel includes a turret which is held in position by a spread of mooring lines. The vessel is free to rotate about the turret.

- **vertical lift anchors**



Vertical lift anchors are modifications of conventional drag embedment anchors in which the line of loading is changed to be near perpendicular to the flukes after the anchor has been set in position.

- **vortex induced vibration**

Vibration induced by regular vortices such as water flowing perpendicular to a taut rope.



Basic Terminology

## 2. Fibre and Yarn Terms:

<u>Term</u>	<u>Description</u>
• <b>aramid (fibre, yarn)</b>	Commonly, the synthetic polymer, poly (p-phenylene terephthalamide), which is spun into high-modulus, high tenacity fibres from solution (e.g. Kevlar, Twaron).
• <b>fibre</b>	A "long fine unit of matter", used for textile purposes, including such technical textiles as rope. May be short (staple fibre) or of indefinite length (filament).
• <b>filament, continuous filament</b>	A fibre of indefinite (effectively infinite) length.
• <b>finish</b>	A substance applied to a fibre, yarn or rope to change surface properties, e.g. to reduce friction and improve abrasion resistance.
• <b>HMPE (fibre, yarn)</b>	Commonly, high modulus, high-tenacity fibres gel-spun from high molecular-weight polyethylene (e.g. Dyneema, Spectra).
• <b>linear density</b>	Mass/length, the usual way of expressing the "size" of a yarn.
• <b>marine finish</b>	A finish ( <i>q.v.</i> ), which will remain on the yarn in a marine environment.
• <b>nylon (fibre, yarn)</b>	Commonly, the synthetic polyamides, nylon 6 and nylon 66, which are made into fibres by melt-spinning
• <b>polyester (PET) (fibre, yarns)</b>	Commonly, the synthetic polymer, poly (ethylene terephthalate), which is made into fibres by melt spinning.
• <b>tex</b>	Unit of linear density (mass per unit length) for fibres and yarns, equal to g/km.
• <b>textile yarn</b>	A term used in the rope industry for yarns as made and supplied by fibre manufacturers.
• <b>yarn</b>	A linear assembly of fibres used for manufacturing fabrics and other products, such as ropes.

### 3. Rope Terms:

<u>Term</u>	<u>Description</u>
• <b>area (rope area)</b>	Area may be based on external rope dimensions, with or without jacket, or on yarn or fibre area in rope cross-section. Consistency in context is required.
• <b>bedding-in</b>	A tightening of the rope structure, which causes an increase in length, under applications of tension for a number of cycles after manufacture.
• <b>braid, braided</b>	A product of braiding <i>q.v.</i> Hollow braids are used as rope jackets.
• <b>braiding</b>	A process of interlacing yarns so that they cross one another in diagonal formation.
• <b>core (rope core)</b>	The main, central load-bearing part of a rope.
• <b>filler</b>	A substance used to fill the spaces between the components of a rope.
• <b>jacket (rope jacket)</b>	An outer covering put on a rope core to give protection, and, in parallel constructions to hold the components together. May be a braid, made from yarns, or a solid plastic tube.
• <b>parallel strand (rope)</b>	A rope composed of a number of parallel sub-ropes in a braided jacket. Usually the sub-ropes are of low-twist three-strand construction, but braided sub-ropes are also used.
• <b>parallel yarn (rope)</b>	A rope composed of a large number of parallel yarns, usually low-twist rope yarns, in a plastic jacket.
• <b>reference tension</b>	Low tension applied when measuring rope length.
• <b>rope weight</b>	Commonly used term for the linear density (mass per unit length) of a rope. Preferably given in kg/m.
• <b>rope yarn</b>	A yarn composed of a number of textile yarns twisted together by the ropemaker.
• <b>strand</b>	A number of rope yarns twisted together. The largest component of a rope or sub-rope.
• <b>sub-rope</b>	A number of strands twisted (or braided) into a rope form, commonly with low twist. Component of a parallel-strand rope.
• <b>wire-rope construction (fibre rope)</b>	A fibre rope with a construction similar to that of a steel-wire rope, consisting of a number of strands twisted in layers around a common axis. E.g. 6-round-1, 12/6/1, 18/12/6/1. The central strand may or may not be load-bearing.

Basic Terminology**4. Strength and Durability Terms:**

<u>Term</u>	<u>Description</u>
• <b>creep</b>	Continuing elongation with time under tension. May be recoverable (primary creep) or non-recoverable (secondary creep).
• <b>primary creep</b>	See <b>creep</b>
• <b>secondary creep</b>	See <b>creep</b>
• <b>creep rupture</b>	Breakage after a time under tension.
• <b>axial compression fatigue</b>	Failure after cyclic loading in which some rope components alternate between compression and tension.
• <b>hydrolysis</b>	Chemical degradation of fibre in the presence of water.
• <b>Certified Breaking Strength (CBS)</b>	The minimum rope strength guaranteed by the manufacturer.

**5. Stiffness Terms:**

(also see area and weight)

<u>Term</u>	<u>Description</u>
• <b>stiffness</b>	Force (tension) / strain. Equals <b>E.A</b> (modulus x area) and <b>K.L</b> (spring coefficient x length).
• <b>modulus (E)</b>	Stress (tension/area) divided by strain (elongation/length).
• <b>specific modulus</b>	Specific stress (tension/rope weight or yarn linear density) divided by strain (elongation/length).
• <b>post-installation stiffness</b>	Stiffness immediately after installation. (DPD 5.3.2.).
• <b>storm stiffness</b>	Stiffness in storm conditions. (DPD 5.3.2.).
• <b>intermediate stiffness</b>	Range of stiffnesses between minimum (post-installation) stiffness and maximum (storm) stiffness. Depends on prior history and applied cyclic loading.

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r2vc	mods by	jct/hwsh	22 Mar 97
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r4va	changes noted after TTI meeting	rwps	21 May 98
r4vb	various TTI + NDE	rwps	11 June 98

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## 1. INTRODUCTION

### 1.1 FIBRE ROPES FOR DEEPWATER MOORINGS

High strength and high modulus fibre materials offers particular advantages for deepwater moorings. This guide has been developed for the design of deepwater fibre moorings.

A good general description of conventional mooring configurations has been given in Section 1 of API RP\_2SK (1997) and in addition the API document presents a comprehensive guide to the design of conventional deepwater moorings. However it does not cover the subject of deepwater synthetic fibre mooring lines in any detail. The purpose of the present guide is to provide an extension to the API guide in order to cover the subject of deepwater fibre moorings.

This introduction gives a brief overview of the main features of fibre moorings. More details can be found in the

later Sections and their associated Engineering Commentary Sections.

### *1.1.1 LIMITATIONS OF STEEL MOORING SYSTEMS*

In deep water there may be advantages in using fibre moorings. With steel moorings, excessive line pretensions are required to maintain an acceptable horizontal angle at the fairlead and this reduces the payload of the platform. Also, installing steel moorings in deepwater calls for large and expensive handling equipment. Furthermore the catenary moorings take up a large area of the sea floor - typically a radius of 4 to 6 times the water depth for chain - which is a problem in congested sites. The weight effects of steel mooring systems can be mitigated by the use of sub-sea buoys but these have to be strong enough to withstand the hydrostatic pressure at the appropriate water depth. As a result they are heavy and expensive and have the additional disadvantage of being difficult to handle during installation.

According to Firth (1997) catenary mooring systems, using steel rope and chain, are used successfully up to 850 meters depth. However fibre ropes may be competitive at shallower depths and alternative steel rope and chain systems can be used at greater depth.

### *1.1.2 TAUT LEG AND INSERT MOORINGS USING FIBRE ROPE*

The two key features of high strength, synthetic fibre materials are their high strength-to-weight ratio and the changes in axial stiffnesses, which occur during use as a result of different load effects.

The low weight offers the possibility of moorings with very small catenary sag - the so-called **taut leg mooring system**. In such a system the anchors must resist vertical loads. The concept is illustrated in Figure 1.1.1. The taut leg mooring system relies for its compliance on the axial extensibility of the mooring line rather than the catenary profile and as has been noted this may vary considerably during the life of the rope. The mooring designer must be able to devise a mooring system in which the extreme range of axial stiffnesses inherent in fibre rope nevertheless results in an acceptable design.

A variant is the **insert line catenary mooring system** in which chain or steel wire is used at the seabed to provide a catenary, which provides both compliance and weight to stop the anchor seeing vertical loads. The insert line mooring concept is illustrated in Figure 1.1.2.

### *1.1.3 SUMMARY OF BENEFITS OF FIBRE ROPE MOORINGS*

A number of benefits of fibre rope in deepwater moorings are listed below.

#### **Reduced Offsets**

Taut Leg moorings can result in significantly smaller offsets which can result in the selection of simpler riser systems which are also easier to install.

#### **Less Equipment**

For ultra-deep water depth, mooring systems using fibre ropes can provide high restoring capacity without the need of using buoys and clump weights.

<b>Reduced Handling Weight</b>	Fibre ropes are lighter than steel ropes.
<b>Simpler Installation</b>	Lighter installation weights and simpler riser systems will result in reduced installation costs
<b>More Payload</b>	Fibre rope mooring systems apply smaller vertical loads to the moored vessel and thus <u>increase</u> the effective payload.
<b>Less Line Length</b>	Fibre rope mooring requires less line length especially for taut line systems. This reduces the amount of rope needed for a mooring with consequent savings in transport, storage, installation and inspection.
<b>Small Footprint</b>	The small foot print of the taut leg mooring concept is an advantage in areas where there is a considerable amount of subsea equipment deployed.

## 1.2 MAIN CHARACTERISTICS OF FIBRE ROPES

### 1.2.1 DIFFERENCES FROM WIRE ROPES

For the engineer, the most important difference between fibre ropes and wire ropes is the fact that, whereas for wire ropes there is a history of practical experience going back for over a hundred years, there is very little background of application of fibre ropes in demanding marine and other civil engineering applications. Both the fibre materials and the rope constructions and terminations are new technology. High-performance fibre ropes of the strength and type envisaged for deepwater moorings have only started to be made and tested in the last few years.

Technically, the main differences are:

- **Fibre ropes have low weight and so are lighter to handle and give negligible catenary forces in a mooring.**
- **Fibre ropes have higher strength at the same weight.**
- **Fibres have more complicated load-elongation properties than the simple elastic-plastic response of steel.**
- **A large fibre rope is made of millions of fine fibres, instead of a smaller number of thicker wires.**
- **Corrosion and metal fatigue are replaced as potential problems by other fatigue mechanisms.**

Although well-designed and manufactured ropes are rugged engineering products, it should be noted that their jackets are softer than steel and that fine fibres are easily broken if they are allowed to be individually stressed, though they act together in a well-constructed fibre rope. Misuse has led to failures, as in the past with steel constructions, but there is good evidence of durability greater than wire ropes under conditions expected in deepwater moorings.

### 1.2.2 FIBRE MATERIALS

The fibres currently being evaluated for use in permanent or temporary deepwater moorings are polyester (e.g. Diolen, Trevira, Seaguard), aramid (e.g. Kevlar, Twaron), and HMPE (e.g. Dyneema, Spectra). Detailed data and comments in this DPD will be limited to these fibres, for which comparative test data are available from the FIBRE TETHERS 2000 (1995) study.

Under some circumstances Nylon may be considered for use if a fibre similar in strength to polyester, but with lower stiffness, is required.

The LCAP fibre, Vectran, which was also included in FIBRE TETHERS 2000, is available for specialised applications where its properties are advantageous, but current production would not be sufficient for a large mooring. Several other high modulus fibres are under development, but are not currently available in sufficient quantities for use in moorings.

The bar charts in Figure 1.2.1 show typical values of yarn properties in comparison with steel. The mechanical properties will cover a range near these values, varying according to the fibre supplier and the grade. As discussed later, modulus values differ considerably depending on the conditions of measurement; the bar charts give only a rough indication of relative values. The mechanical properties for polyester are for industrial yarns; other polyester yarns with lower strength, lower modulus and higher extension are used for general textile applications.

### 1.2.3 ROPE CONSTRUCTIONS

There are many rope constructions. Those under current consideration for deepwater moorings are the so-called

- “wire-rope construction”
- “parallel strand”
- “parallel yarn”.

The main structural levels in a fibre rope, although not all present in every construction, are:

- **“textile yarns”, as made by the fibre producer and typically consisting of about 1000 individual filaments**
- **rope yarns, assembled from a number of textile yarns by the ropemaker**
- **strands made up from many rope yarns**
- **sub-ropes of several strands**
- **the complete core rope assembly**
- **rope, sub-rope and strand jackets**



### 1.2.4 FIBRE TERMINOLOGY

The fibre and rope industries take mass per unit length (commonly called "rope weight") as a basic defining quantity. This is because volume and area are uncertain quantities, which are dependent on how tightly the fibres are packed together.

Although there are variations based on other units, the essential definitions, which the engineer needs to keep in mind, are as follows.

For the mass (weight) of the product:

- fibres and yarns                      tex = gram per kilometre
- ropes                                      kilogram per meter (kg/m) = megatex (Mtex)

For mechanical properties:

specific values of strength, modulus, and stress are given by force divided by mass per unit length. This is also equal to stress/density

- Newton per tex (N/tex) = GPa/(g/cm<sup>3</sup>) or (kN/mm<sup>2</sup>) / (g/cm<sup>3</sup>)

Despite familiarity with conventional units of stress based on area, engineers could find it more convenient to work in these mass-based units.

### 1.2.5 ROPE SIZE AND STRENGTH

An engineer's first consideration is the strength and size of a rope. Current manufacturing capability provides for rope with break loads up to around 20,000 kN (≈ 2,000 tonne) in continuous lengths of up to 1,000 metres or more depending on the size of the rope. There are substantial differences between ropes made from different fibres, and from steel wire, but only smaller differences between the constructions. The bar charts in Figure 1.2.2 show comparisons for ropes with a break load of 10,000 kN (≈ 1,000 tonnes). For ropes of other break loads the mass per unit length and cross sectional area will, as a first approximation, scale directly with break load and diameter will scale as square root of break load.

### 1.2.6 ROPE ELONGATION AND STIFFNESS

Figure 1.2.3 shows the elongation properties of a rope-making polyester yarn as measured by Bosman (1996), compared with the ideal elastic-plastic response assumed for steel. The other fibres will show similar effects, in some cases less severely, in others more severely. The complications to note are the non-linearity and the lack of recovery to the initial state (inelasticity), the cyclic loop giving energy dissipation (hysteresis), the continuing elongation with time (creep). Due to the visco-elasticity of the material, the response would be somewhat different if the deformation was on a different time-scale. Another difference from steel is that fibres have

highly oriented structures and are therefore anisotropic and are weaker in the transverse direction and in shear than in the axial direction.

Rope construction brings in two other effects. Firstly, the values of strength and resistance to extension (stiffness), will be reduced by a conversion factor due to the angles of the fibres in the rope and effects of variability. Secondly, the rope is pulled into a tighter structure when load is initially applied. This gives additional elongation, known as bedding-in.

A simple approach is to separate the rope responses into upper and lower bounds as illustrated in Figure 1.2.4 in order to deal with different engineering design considerations. As shown in Figure 1.2.4 (b) and as discussed in DPD 5.3, the lower and upper bound stiffnesses can be used to treat post-installation, and storm loading respectively over appropriate tension ranges. The bar chart in Figure 1.2.5 is an approximate guide to comparative values of stiffness, for 10,000 kN ( $\approx$  1,000 tonne) break load ropes in different materials. To a first approximation, the stiffnesses will scale with break load.

Hysteresis leads to internal heating in any rope structure. Such heating is unlikely to present a problem in wetted ropes at the moderate cyclic strains typical of most FPS applications. Hysteresis can be calculated from the loss factor in load cycling, though more experimental data are needed for reliable estimates of heating.

There is little data available on creep in ropes, but a general indication of the effects of creep is given by yarn data from FIBRE TETHERS 2000 (1995). There are two practical effects. Continuing elongation under load may lead to a need to re-tension lines. In most fibres, creep reduces in rate with time and is approximately the same for equal increments of  $\log(\text{time})$ . Figure 1.2.6 shows comparative creep over 1 decade of  $\log(\text{time})$ .

Under high enough loads creep may eventually lead to rupture. Comparative values are given in Figure 1.2.7. Note that for HMPE, which is the fibre most susceptible to creep, the extent of creep and creep rupture is strongly dependent on the particular supplier and grade. Some newer HMPE fibres show reduced creep, and there is also evidence indicating that creep in rope is less than creep in yarns.

### 1.2.7 DURABILITY AND FATIGUE

In considering features which may limit the life of fibre ropes selected for deepwater mooring, factors which should be checked, but are not expected to be a problem, include hydrolysis, heating and internal abrasion. Comment on the possibility of creep rupture was given at the end of the previous section.

A major difference from wire ropes is the sensitivity of fibre ropes to axial compression fatigue. If any component of a rope goes into axial compression, sharp kinks will develop, either in fibres or yarns as a whole or in the internal structure of fibres, and lead to failure after a number of cycles. Figure 1.2.8 gives an indication of the comparative sensitivity of different fibres to axial compression fatigue as shown by yarn buckling tests. An excessive number of cycles in conditions which may give rise to axial compression should be avoided.

### 1.2.8 EXTERNAL ABRASION AND CUT RESISTANCE

If an unprotected fibre rope is subject to external abrasion, individual fibres on the surface can be broken and worn away with resulting weakening of the rope. In order to avoid the problems of external abrasion, the rope needs to be properly jacketed and to be handled with a reasonable degree of care.

In some locations it may be necessary to take steps to limit damage from fishbite

## 1.3 APPLICABILITY OF THIS DESIGN GUIDE

### 1.3.1 TAUT LEG AND INSERT LINE SYSTEMS

This Document has specifically been developed to be used for fibre rope moorings in the form of **taut leg** and **insert line** moorings. These mooring types are suitable for use in the two main configurations of deepwater moorings currently being developed:

- **Single point mooring** allows the moored vessel to weather vane
- **Spread mooring** provides restraint against yaw motion

The kinds of moored platforms that are suitable for mooring with fibre ropes includes: semi-submersibles, ship shaped floaters, spars and barges. Bottom based structures such as compliant towers may be suitable.

### 1.3.2 PERMANENT AND TEMPORARY MOORINGS

Fibre moorings are candidates for both permanent and temporary moorings and this Document may be used for both.

Permanent mooring systems are typically designed to operate at one location over a period that might range typically from 2 to 30 years. In addition there will normally be a requirement that risers etc. will not be disconnected throughout its life. As a result mooring lines used for such a system must provide high integrity over long periods. However once installed the lines will only receive occasional handling.

Temporary mooring systems are typically used for mobile rigs during exploratory drilling or tender support operation. In these circumstances it may be acceptable to disconnect the riser system in extreme weather conditions thus allowing the resulting watch circle to be increased. The mooring lines must however be able to withstand retrieval and deployment handling for each location move. The lines must be easily stored and handled and able to survive repeated deployment and retrieval.

## 1.4 CASES NOT COVERED BY THIS DESIGN GUIDE

### 1.4.1 SINGLE LINE MOORINGS

This Document is **not** designed for use with single line moorings where there is little control over the tension in the line and the possibility of seabed abrasion.

### 1.4.2 HAWSERS

This Design Practice Document is **not** designed for use with Berthing Hawsers, Towing Hawsers or Single Point Mooring Hawsers.

### 1.4.3 TENSION LEG PLATFORM TETHERS

This Document is **not** designed for use in the design of Tension Leg Platforms Tethers where there the loading regime of the tether is very different from conventionally moored vessels.

## 1.5 OTHER GENERAL CONSIDERATIONS

### 1.5.1 COMPATIBILITY OF MOORINGS AND RISERS

An integrated design approach of mooring and risers is advocated so that the excursion characteristics of the mooring system are consistent with the allowable excursions for the risers. Fibre rope mooring systems are likely to offer the benefit of smaller vessel offsets in deep waters when compared against comparable steel catenary mooring systems and this is beneficial to the riser system design.

**Figures**

- Figure 1.1.1 Taut Leg Mooring Concept
- Figure 1.1.2 Insert Line Catenary Mooring Concept
- Figure 1.2.1 Typical yarn properties, data from manufacturers' literature or Morton and Hearle (1993).
- Figure 1.2.2 Typical dimensions of 10,000 kN ( $\approx$  1000 tonne) ropes.
- Figure 1.2.3 Typical Tension-Elongation Characteristics for Fibres Compared with Steel over Working Range
- Figure 1.2.4 (a) Illustration of Concept of Upper and Lower Stiffness Bounds for Fibre Ropes
- Figure 1.2.4 (b) Typical Stiffness Limits for 10,000 kN Breaking Strength Polyester Mooring Rope
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- Figure 1.2.6 Typical Estimates Of Creep (% Increase In Length) To Be Expected Under 30% Break Load.
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- Figure 1.2.8 Typical Sensitivities Of Yarns To Axial Compression Fatigue (from FIBRE TETHERS 2000 (1995))

**Tables**

None

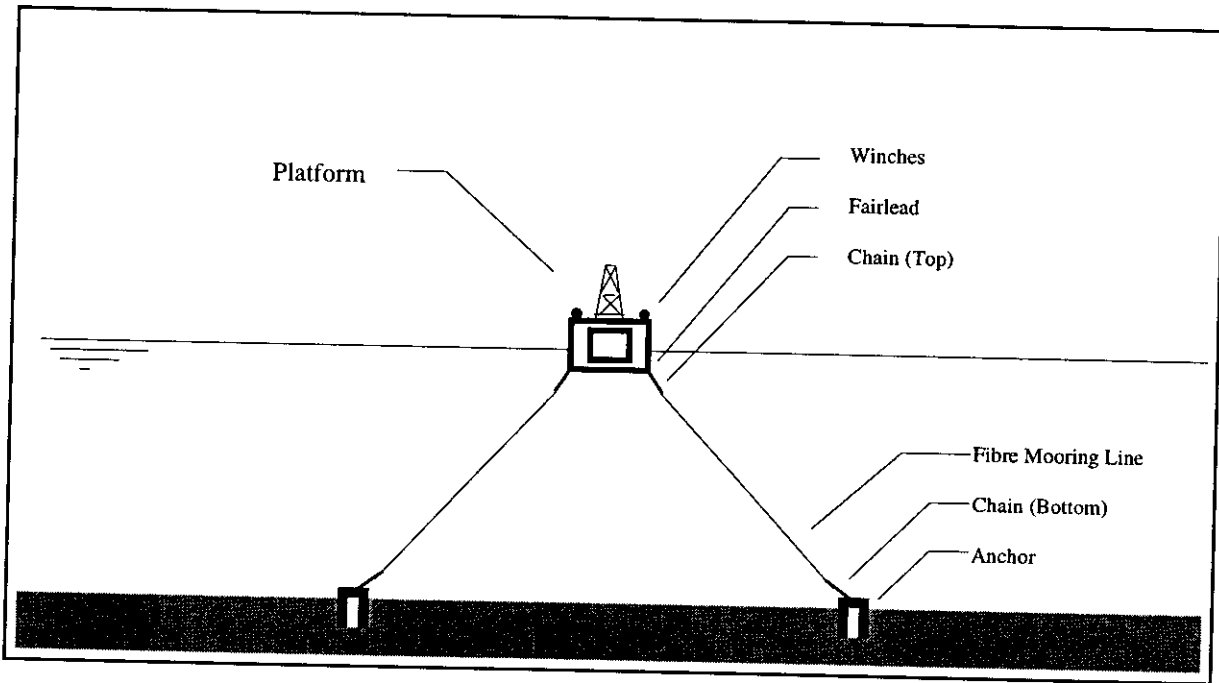
**Appendices Mentioned**

None

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**Figure 1.1.1**  
Taut Leg Mooring System



**Figure 1.1.2**  
Insert Line Catenary Mooring System

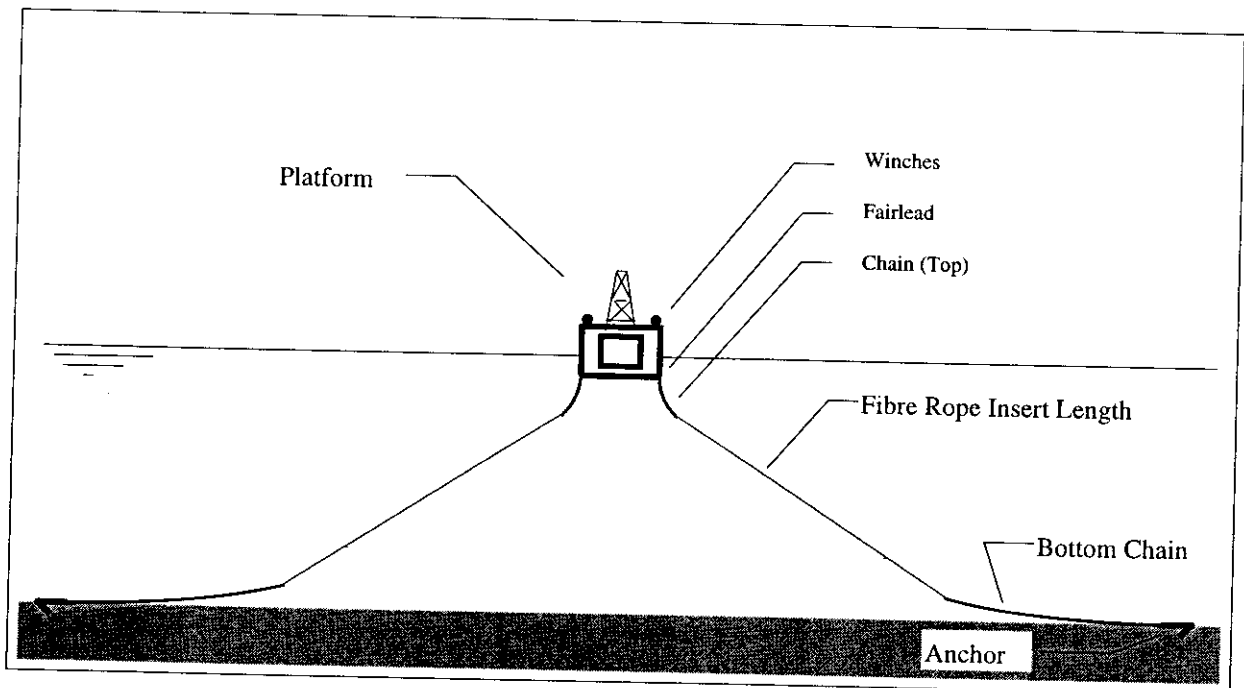
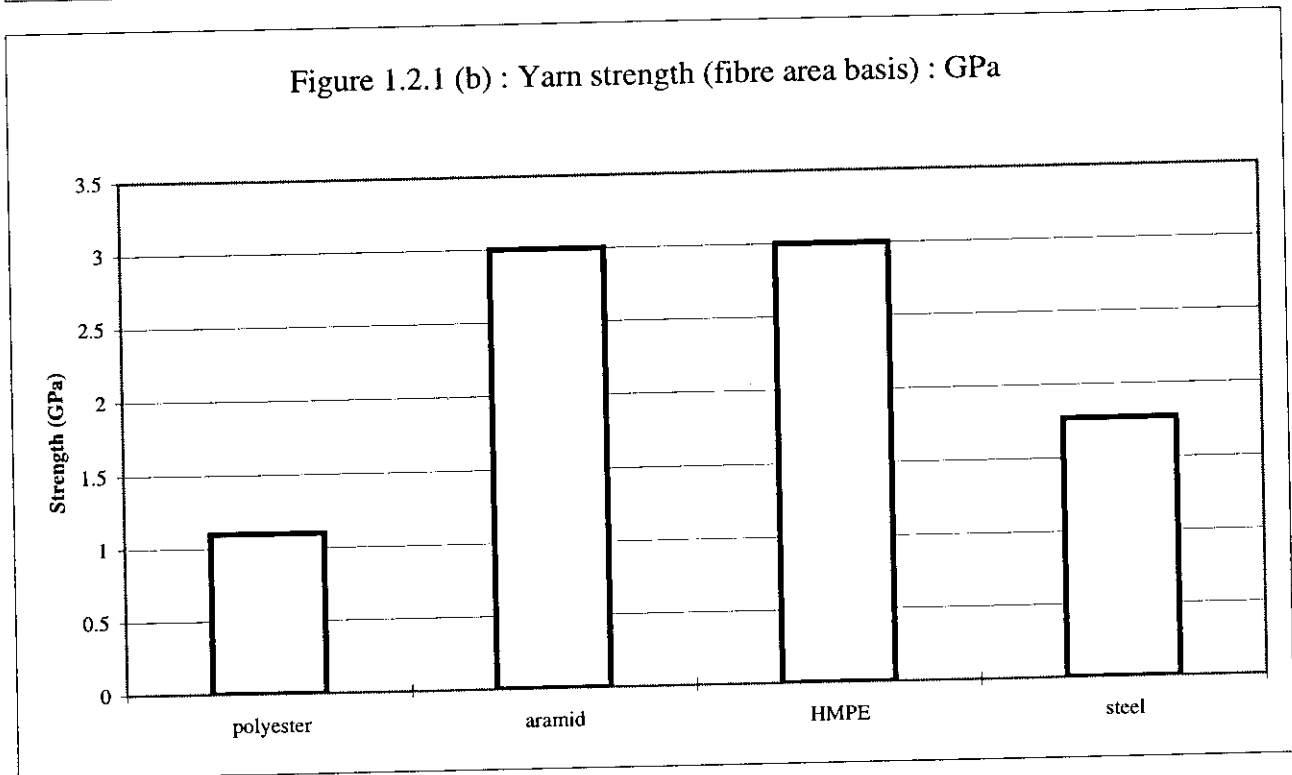
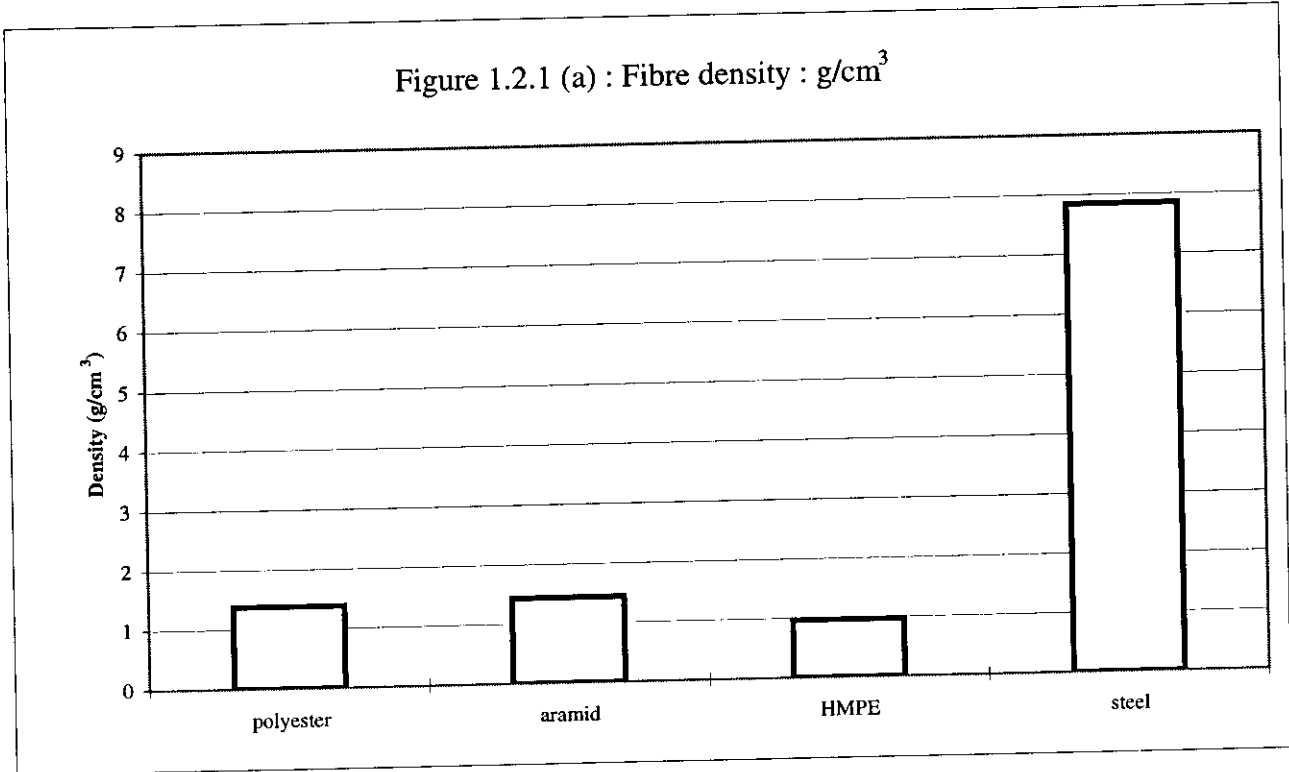
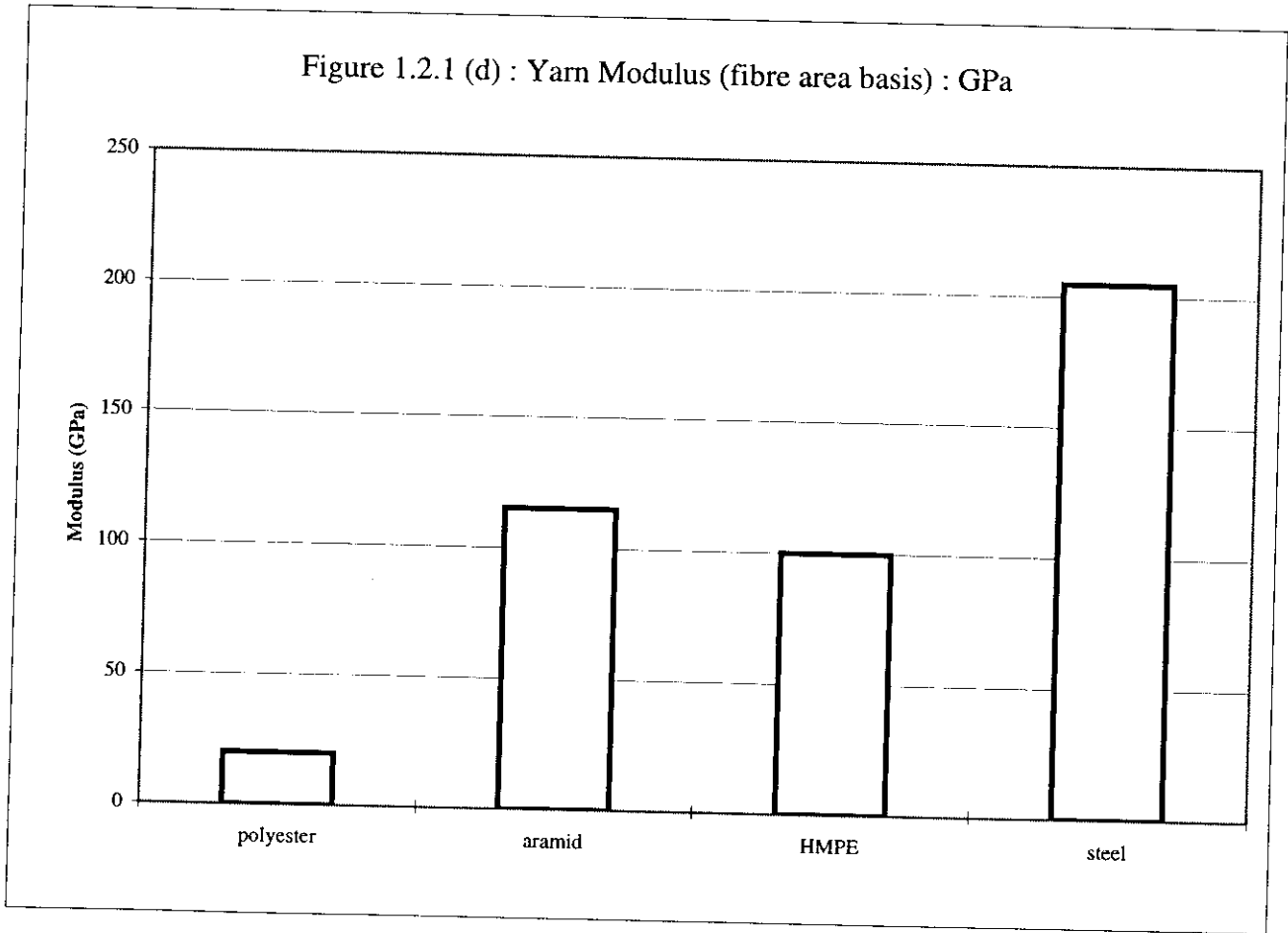
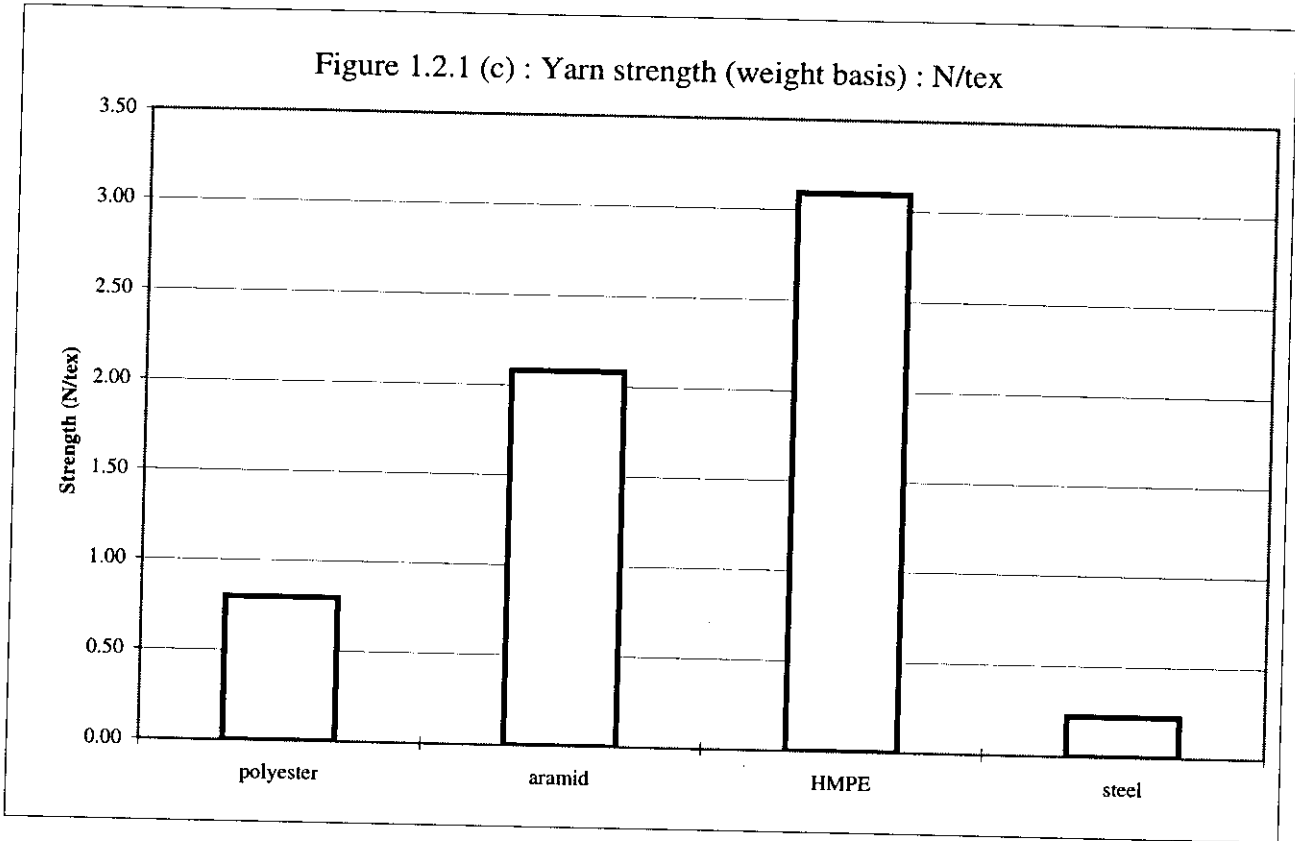
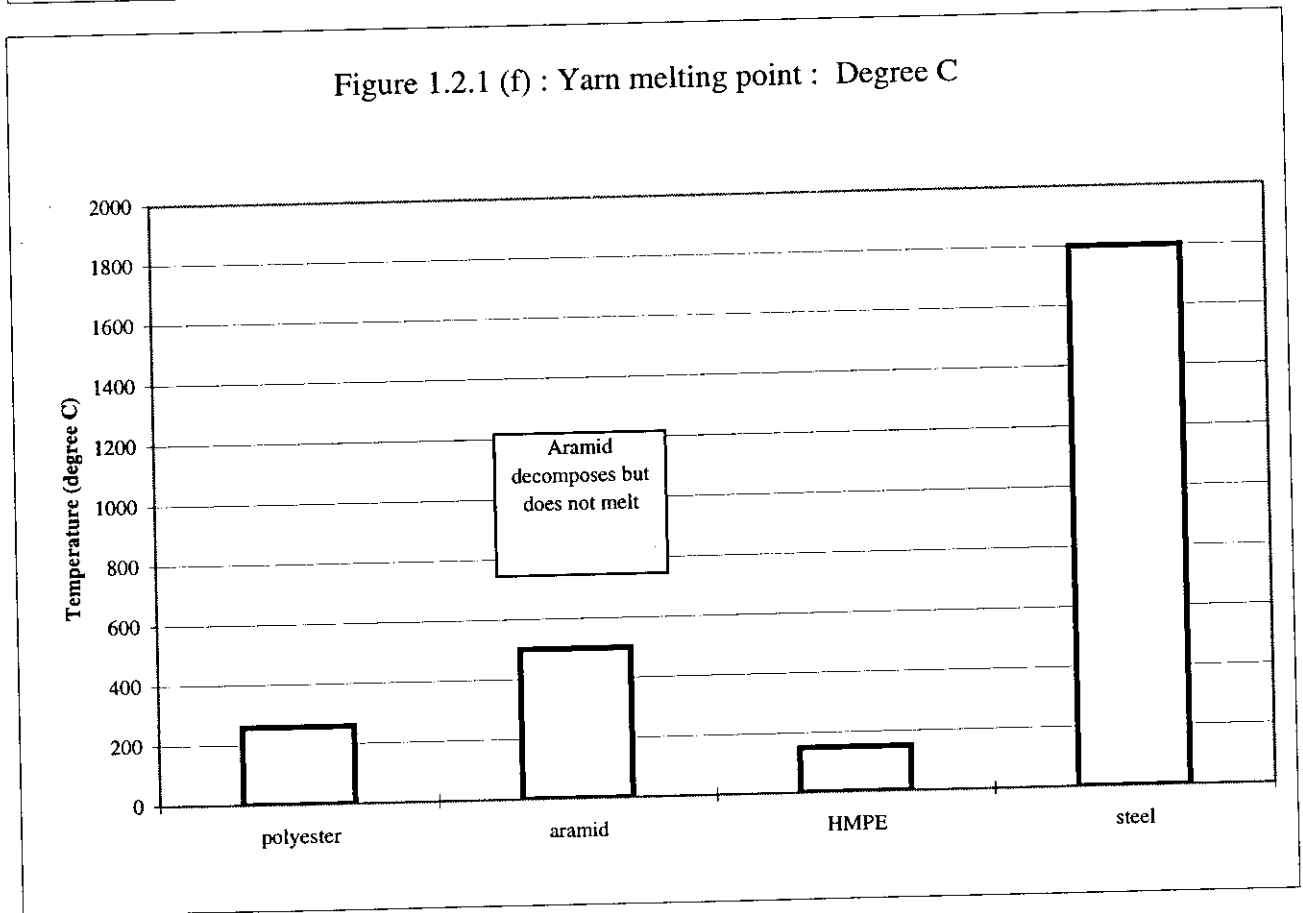
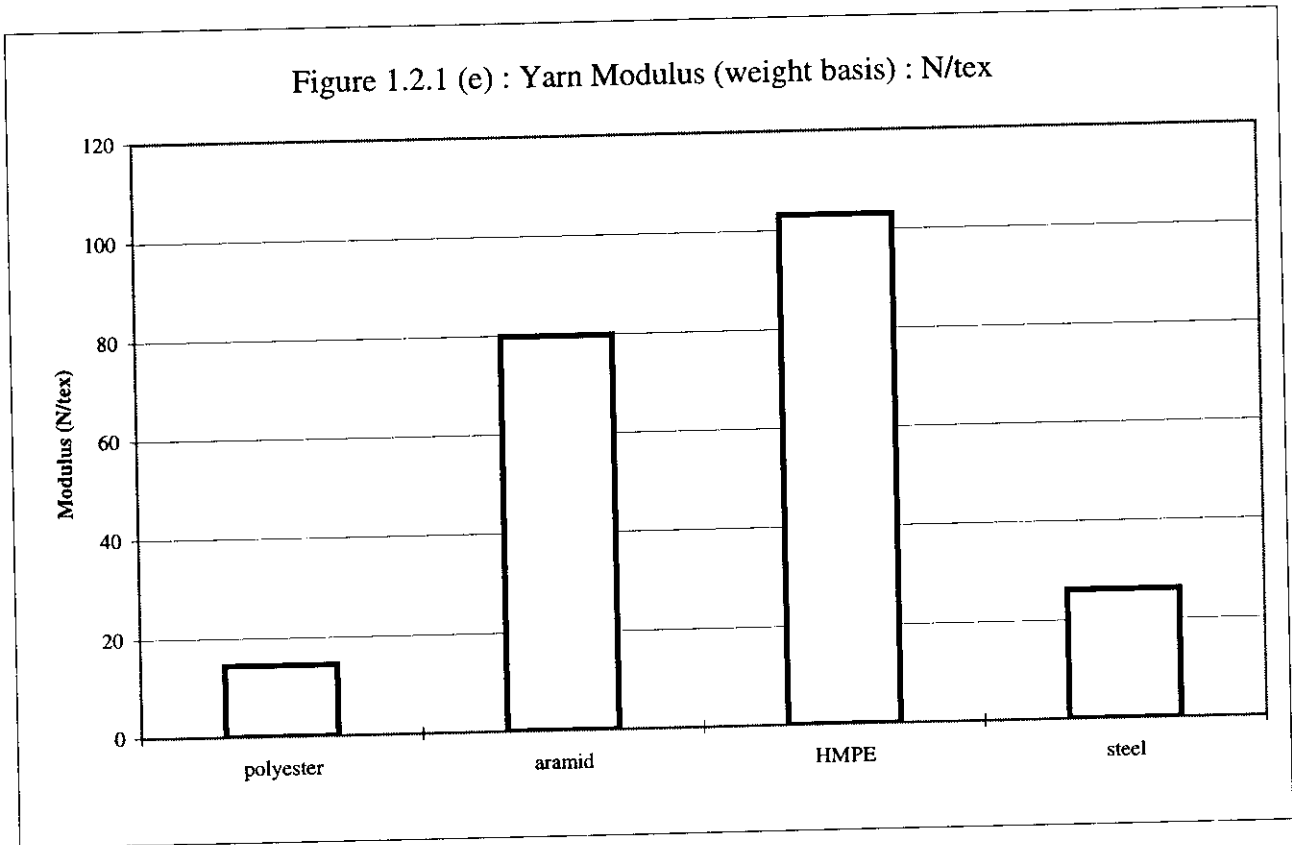


Figure 1.2.1  
Typical yarn properties, data from manufacturers literature or Morton and Hearle (1993)

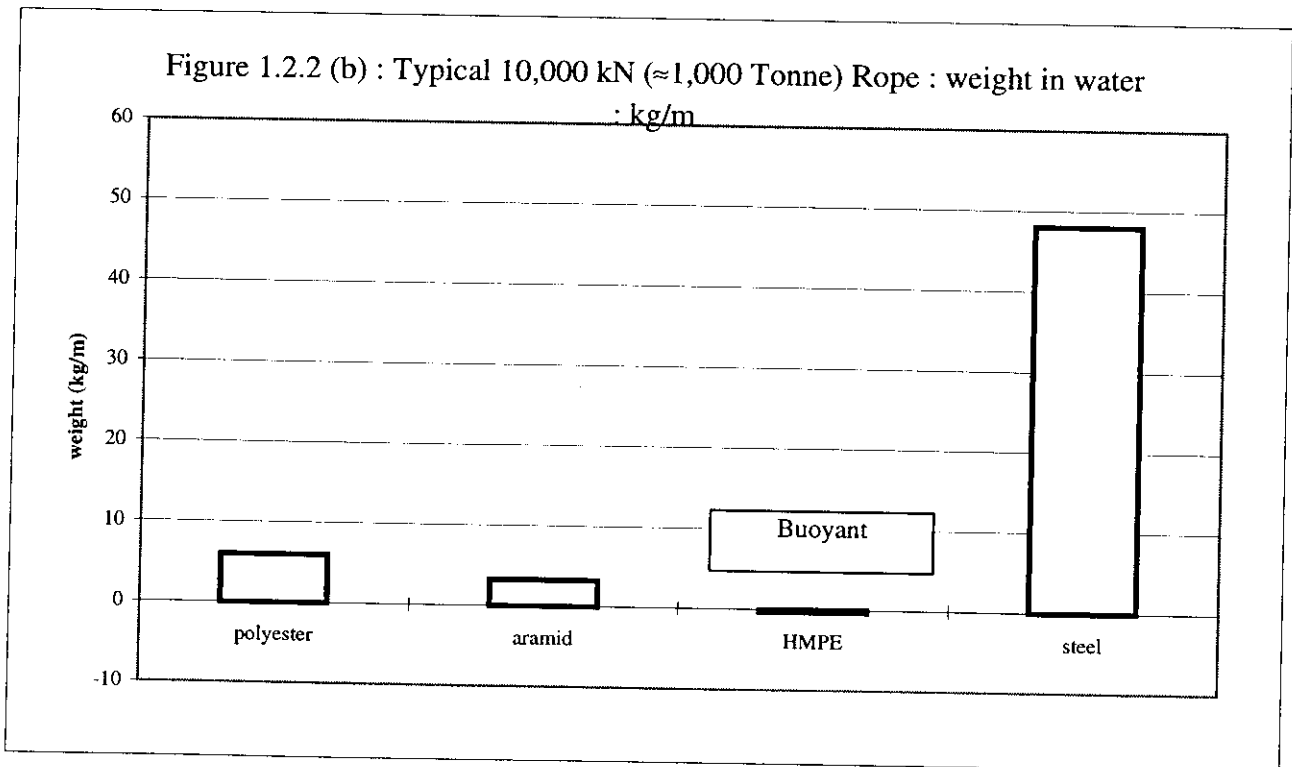
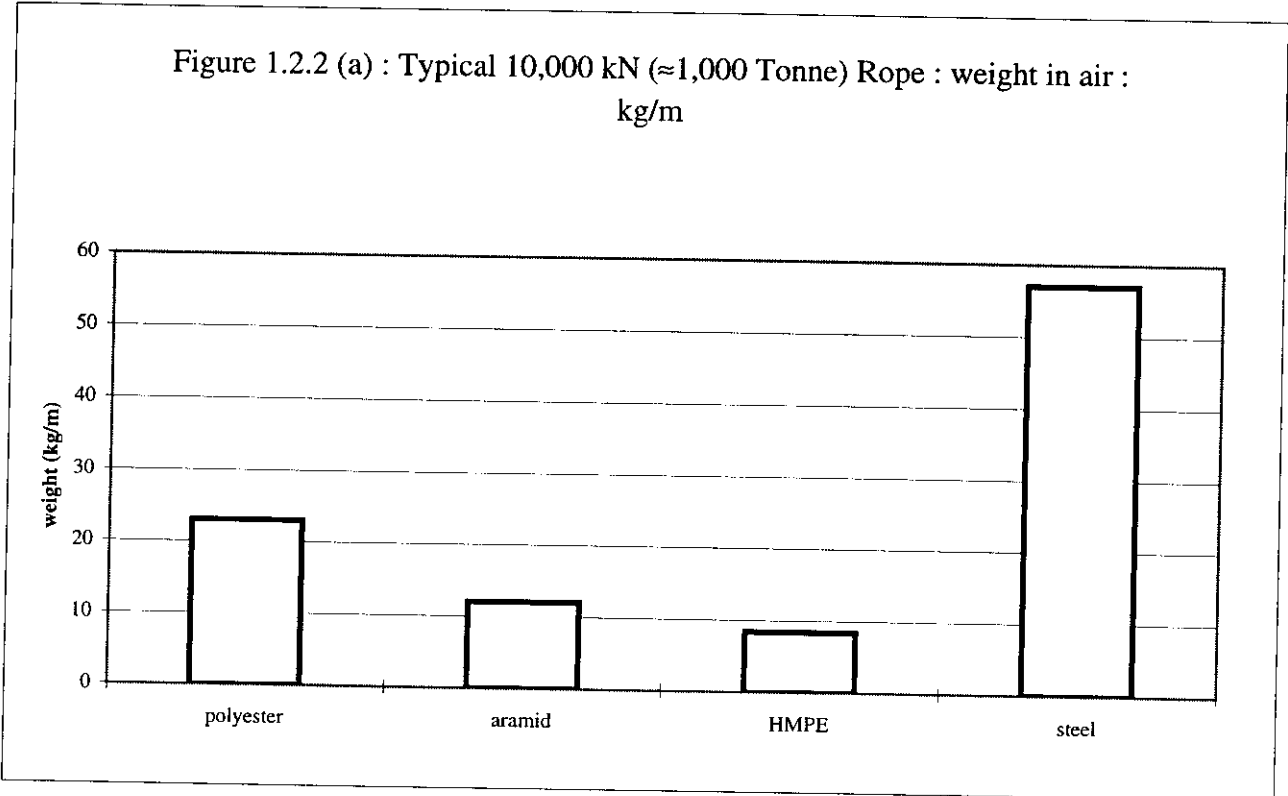








**Figure 1.2.2**  
**Typical dimensions of 10,000 kN ( $\approx$ 1,000 Tonne) Ropes**  
 (Based on Jacketed Rope - Nominal Manufactures List Diameter)



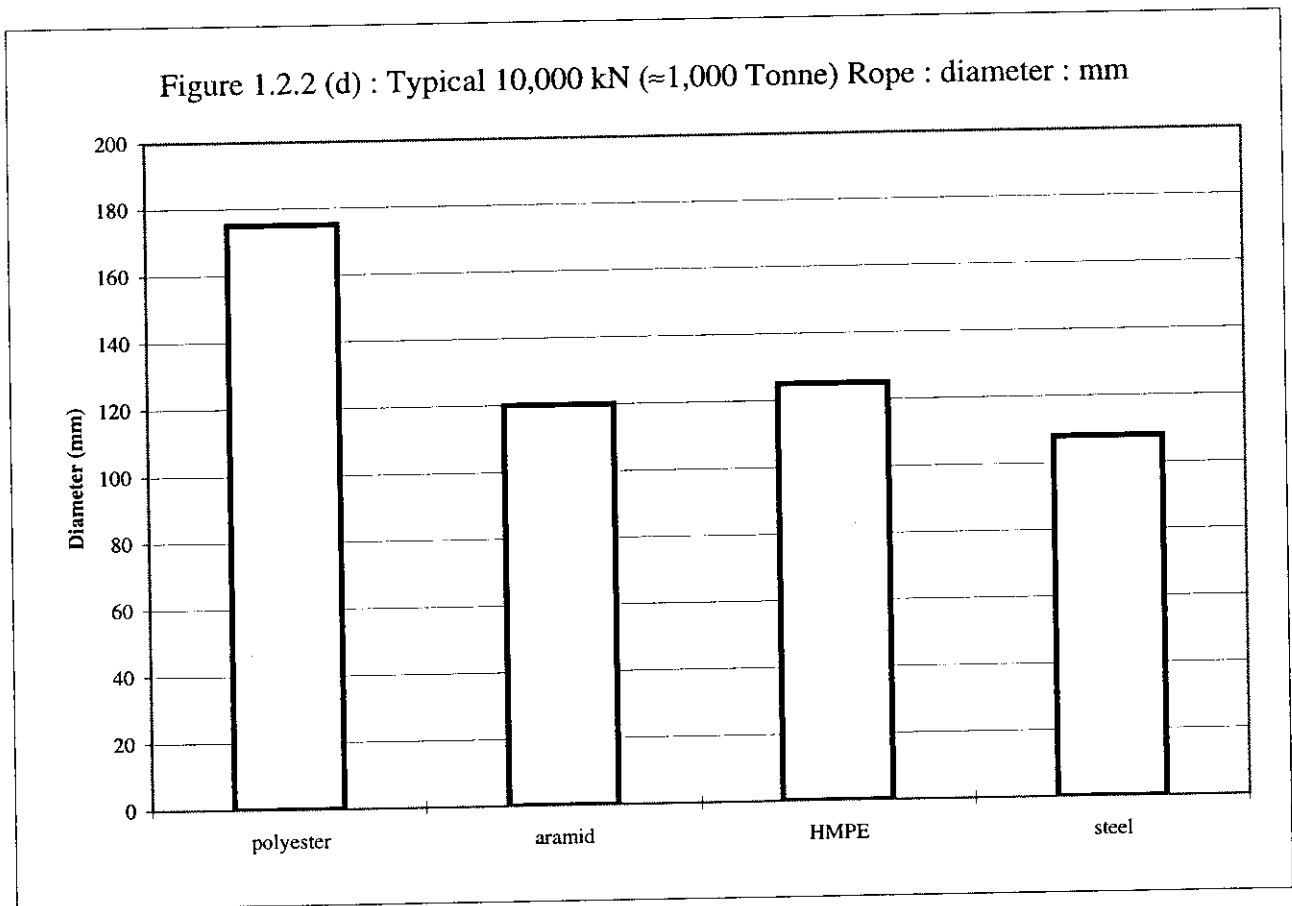
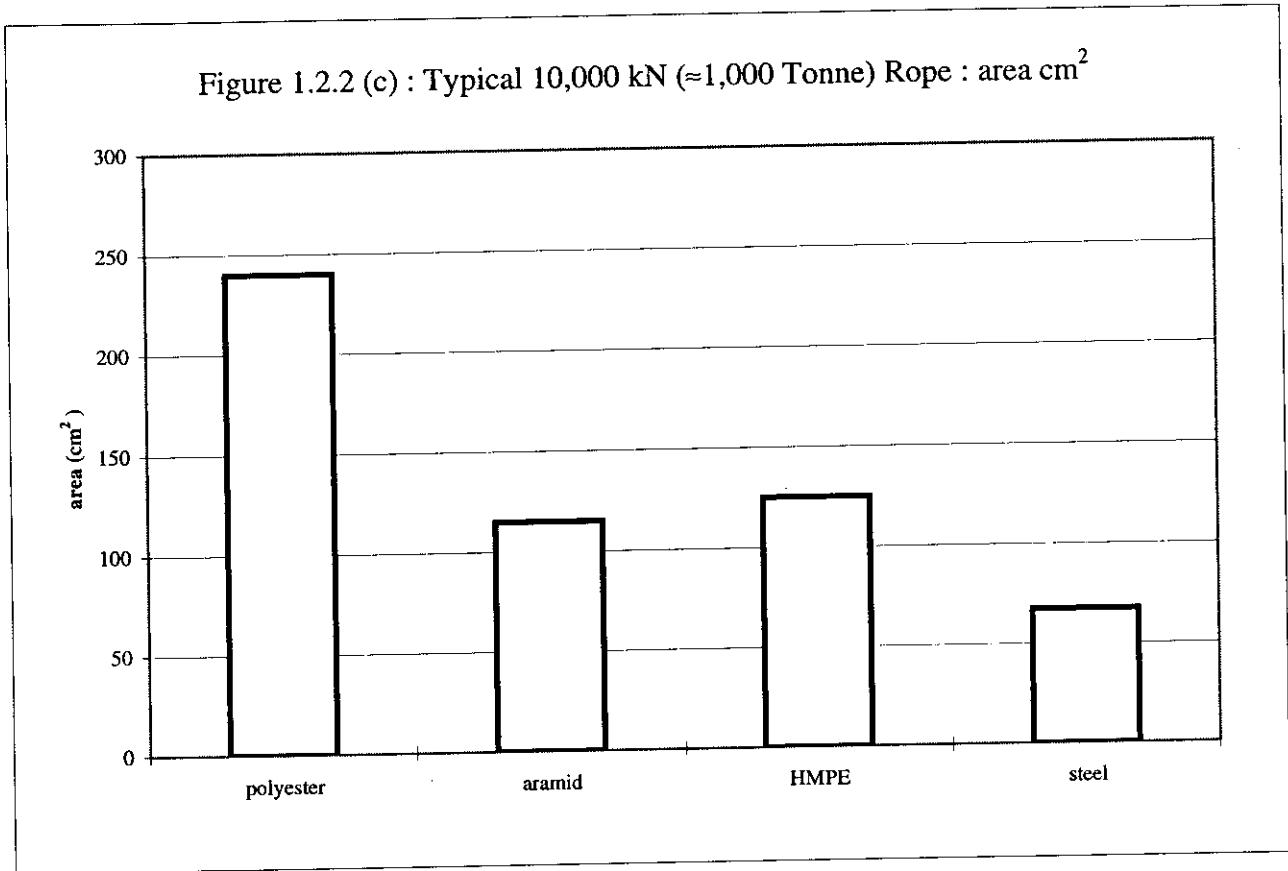


Figure 1.2.3

TYPICAL TENSION - ELONGATION CHARACTERISTICS  
 FOR FIBRES COMPARED WITH STEEL  
 OVER WORKING RANGE

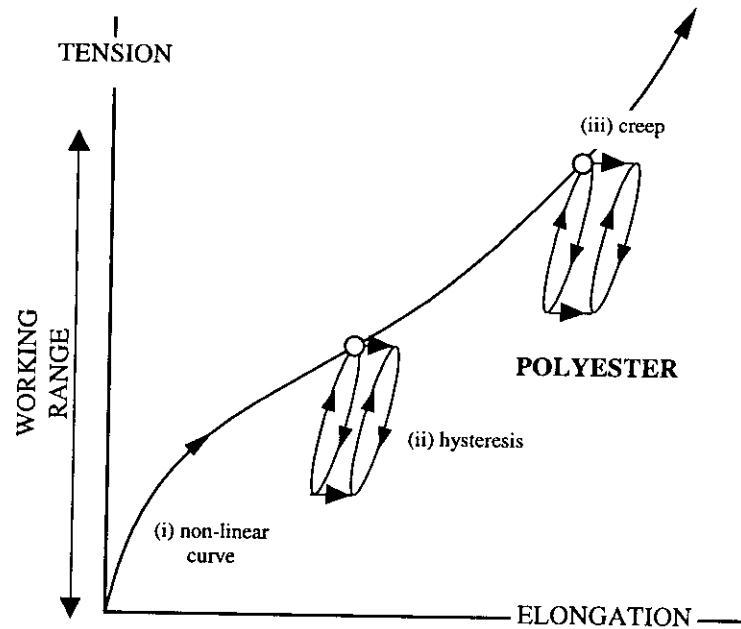


Fig 1.2.3(a): Typical Elastic Properties for Polyester Fibres (After Bosman, Akzo Nobel) Showing  
 (i) Initial non-linear load-extension.  
 (ii) Hysteresis loops.  
 (iii) Creep at constant tension within the working load range.

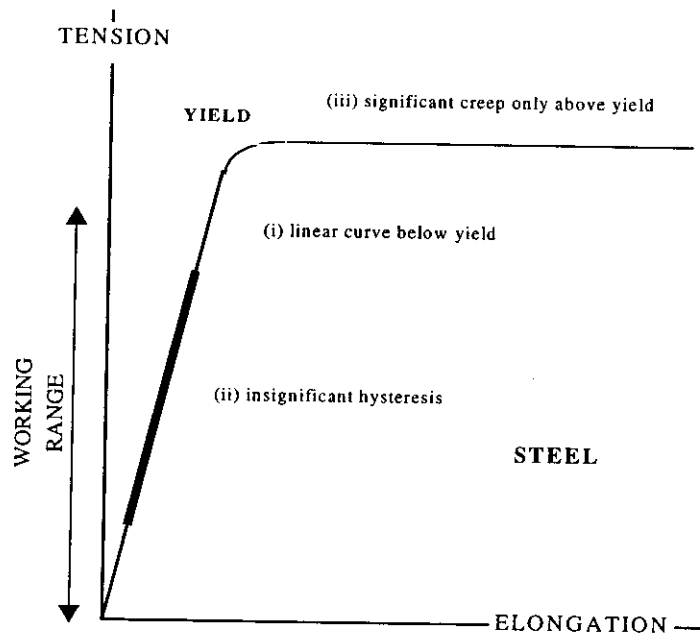


Fig 1.2.3(b): Typical Elastic Properties for Steel Wires Showing  
 (i) Highly linear load extension graph to yield point  
 (ii) Insignificant hysteresis loops up to yield point  
 (iii) Significant creep only above yield point

**Figure 1.2.4 (a)**  
Illustration of Concept of Upper and Lower Stiffness Bounds for Fibre Ropes

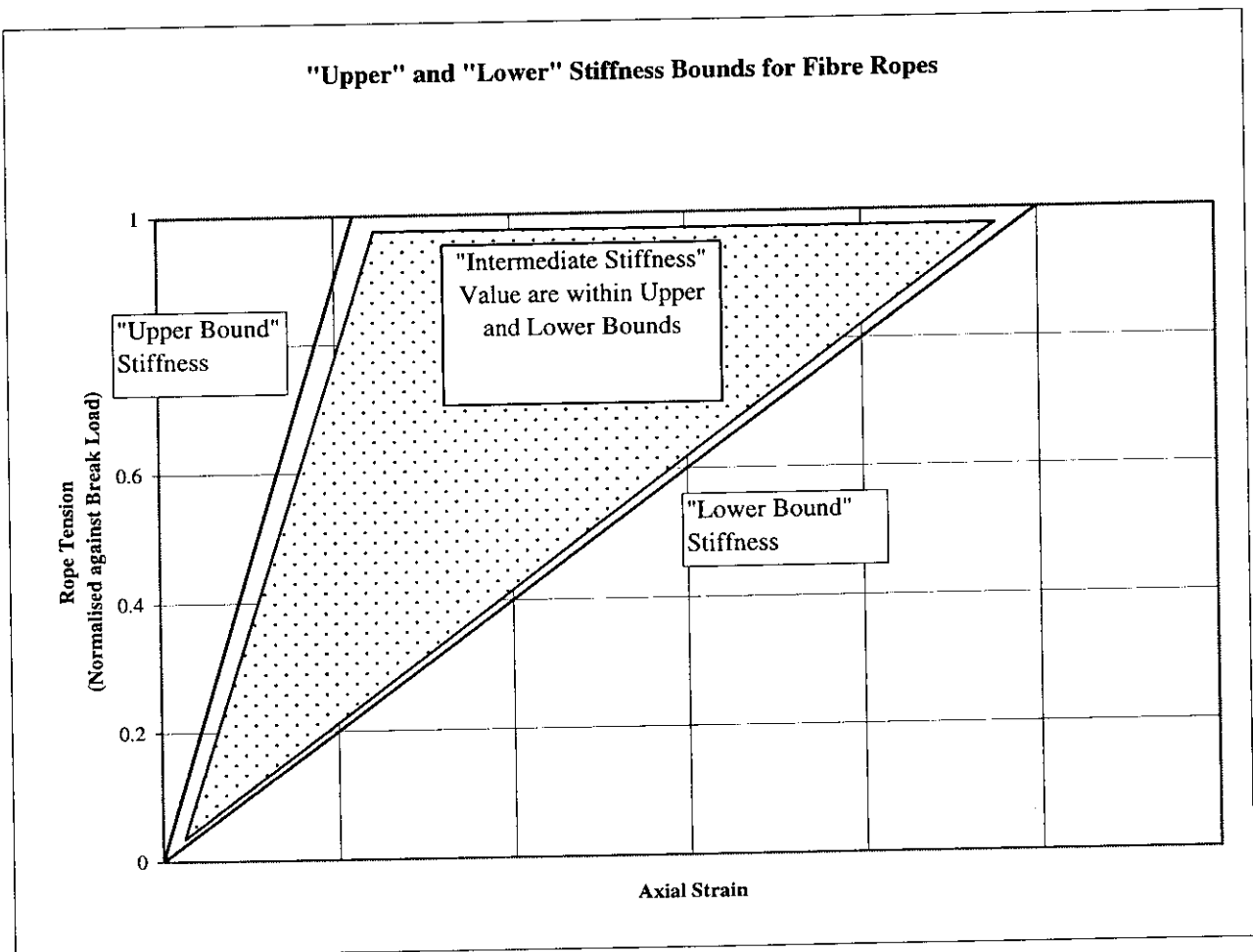


Figure 1.2.5  
Typical Stiffnesses for 10,000 kN Breaking Strength Ropes

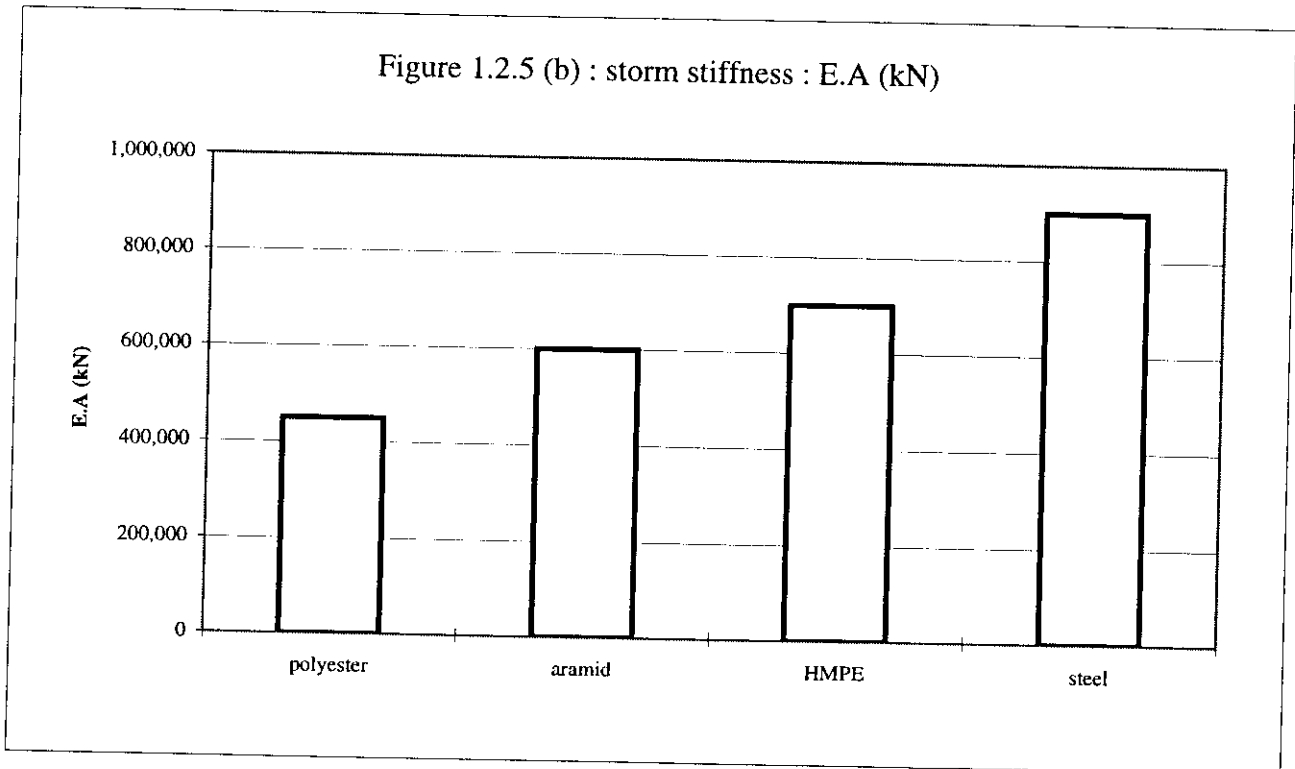
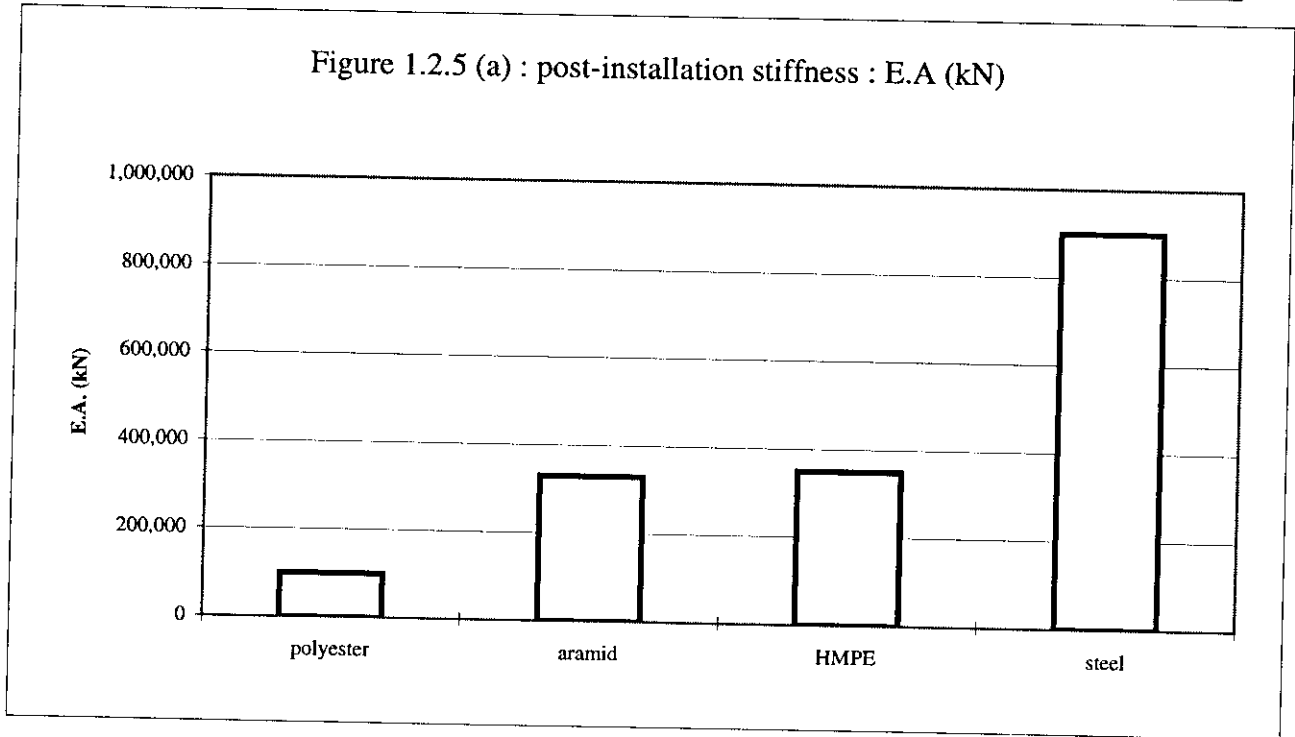


Figure 1.2.6  
Typical estimates of creep (% increase in length) to be expected under 30% break load,

Based on FIBRE TETHERS 2000 (1995) yarn data.  
Note that newer HMPE yarns are now available with less creep and that there are indications that creep in ropes is less than creep in yarns

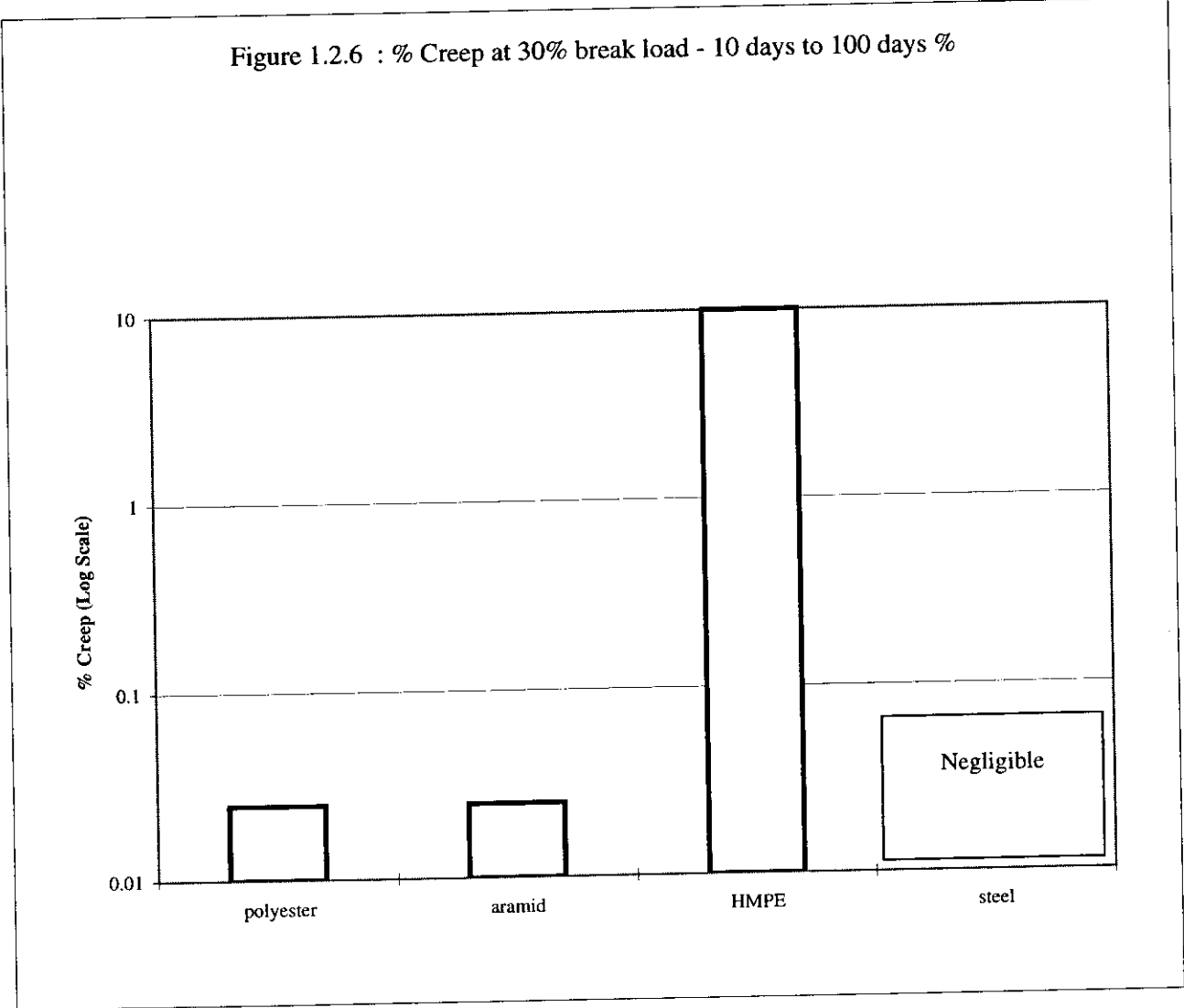


Figure 1.2.4(b)  
Typical Stiffness Limits for 10,000 kN Breaking Strength Polyester Mooring Ropes

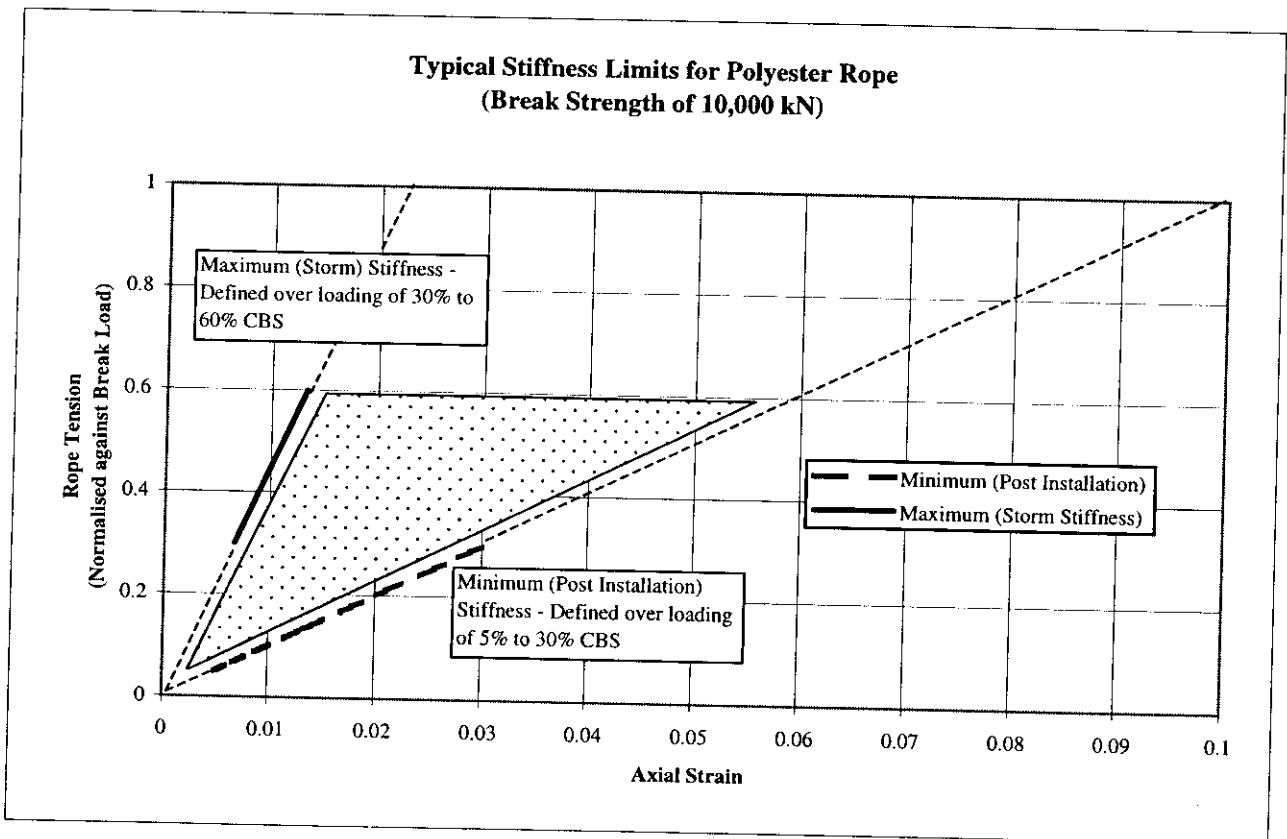




Figure 1.2.7  
Estimates of Creep Rupture time to fail at 30% of break load.

Based on FIBRE TETHERS 2000 (1995) yarn data.  
Note that newer HMPE yarns are now available with less creep and that there are indications that creep in ropes is less than creep in yarns

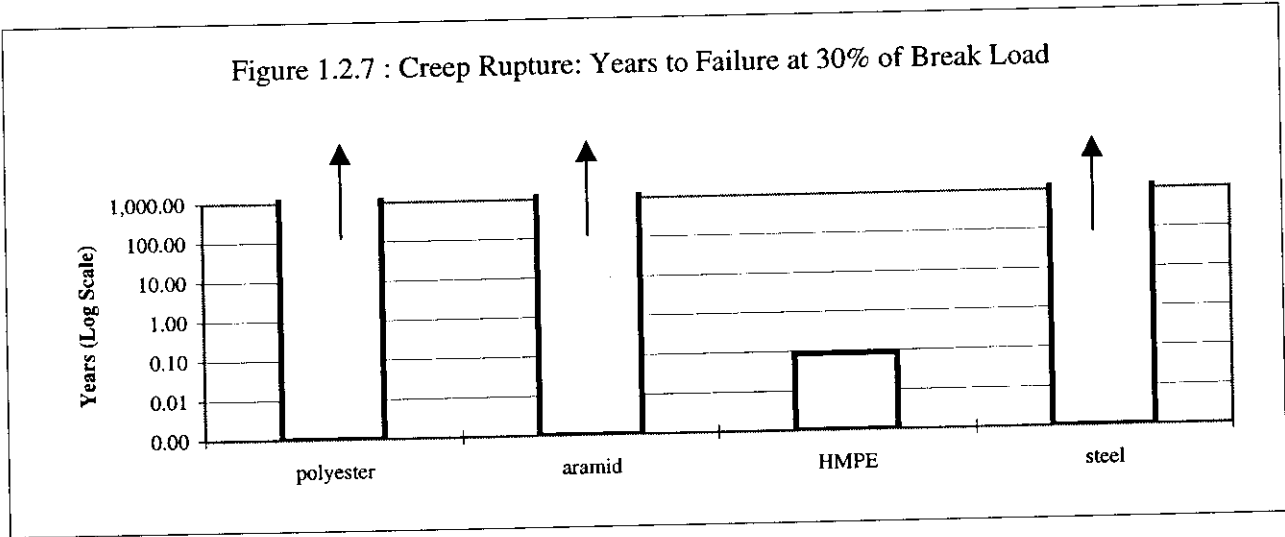
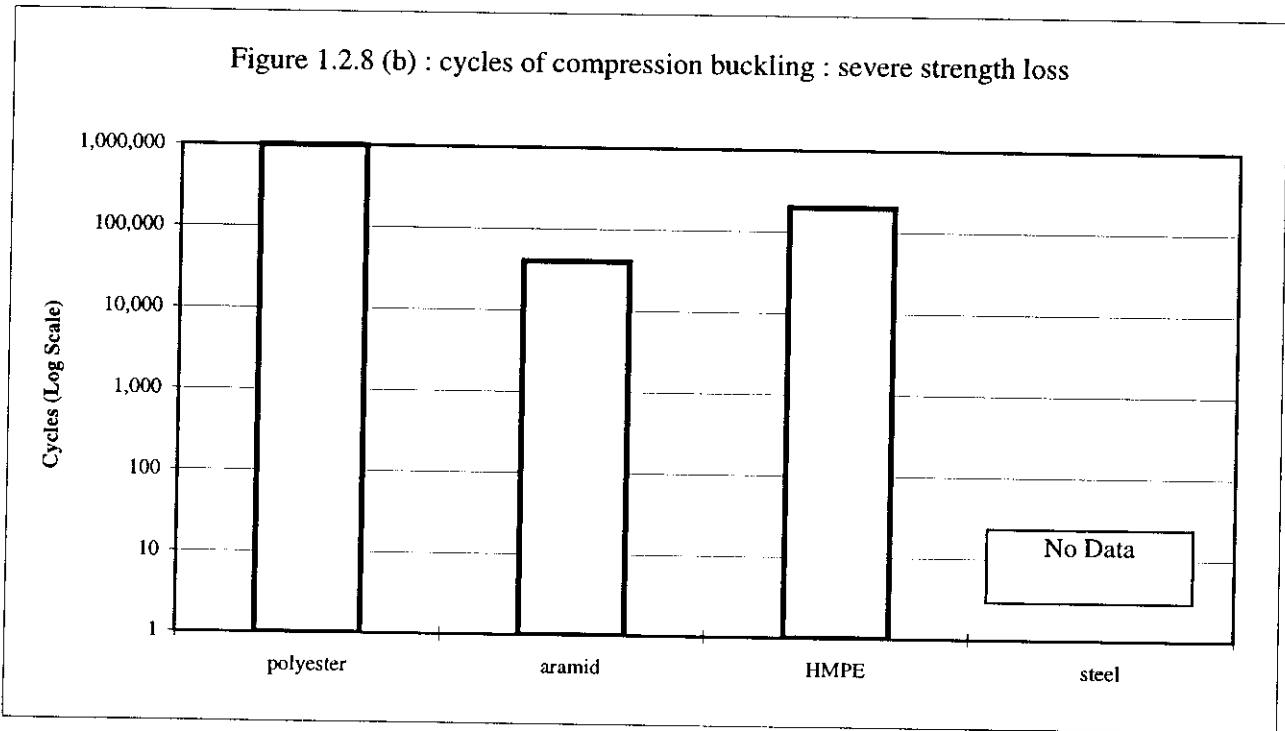
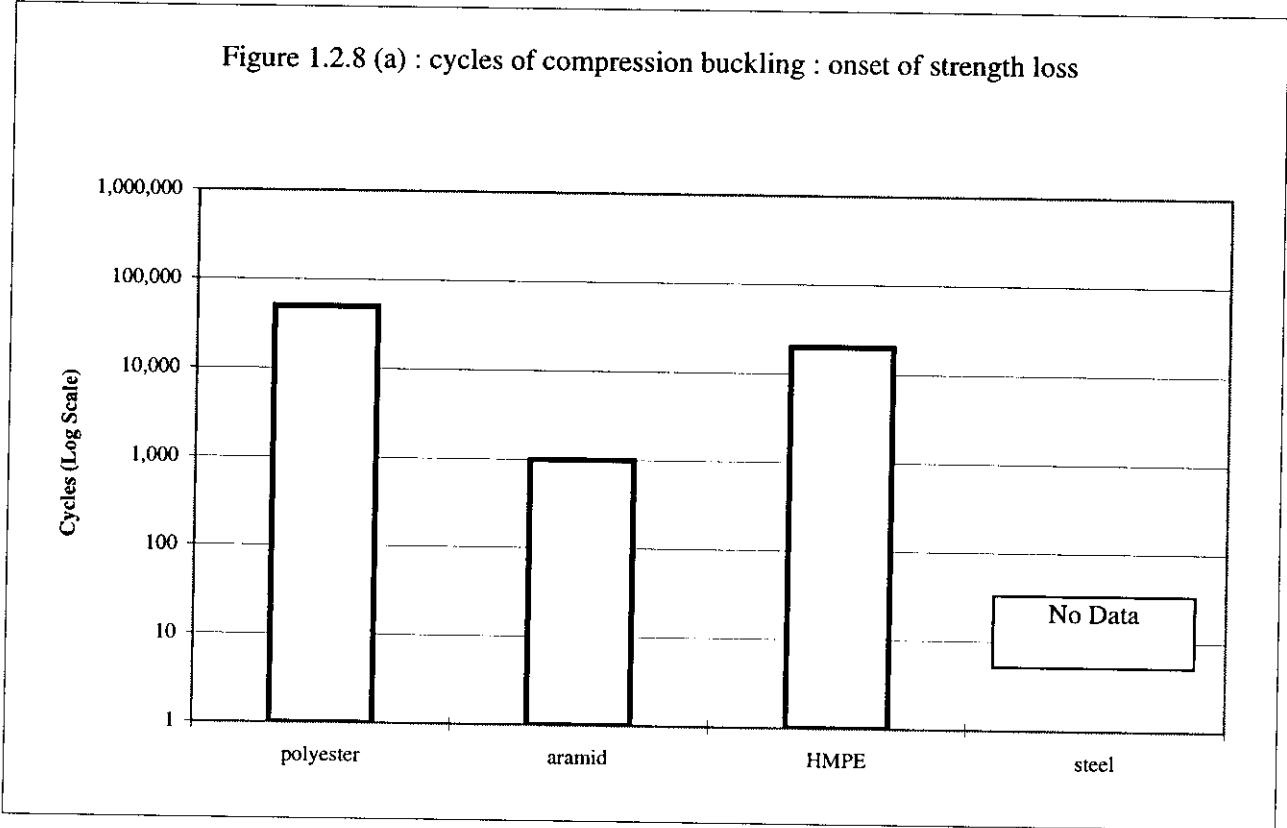


Figure 1.2.8  
Typical sensitivities of yarns to axial compression fatigue  
(from Fibre Tethers 2000 (1995))



r1va	DRAFT with mods agreed at meeting on	jwsh	6 September 1996 17.Sept.96
r1vb	edited	rwps	1 Oct 96
r2va	edited	jwsh	6 Mar 97 (was sect 3; now sect 2)
r2vax	"	"	16 Mar
r2vb	mods	jwsh/rwps/jct	22 Mar
r3va	new rev after SC#4 plus jwsh 'B' comments + sundry others to date	rwps et al	20 Oct 97
r4va	edits	spo/rwps	26 Feb 98
r4va	text corrections	rwps	5.May.98
r4va	changes noted after TTI meeting	rwps	21 May 98
r4vb	tti/nde	rwps	11 June 98

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## 2. ROPE MATERIALS

### 2.1 INTRODUCTION

The principal materials used in fibre ropes are the yarns supplied by fibremakers, which are used in the main load-bearing core of the rope. The rope core may also contain lubricants and fillers, and other materials. Outer protective Jackets may be made from yarns or from other materials, usually plastics.

Since not all fibre rope assembly properties can yet be accurately predicted from yarn properties, the mooring designer should select and specify fibre moorings on the basis of properties of the complete fibre rope assembly as set out in DPD-5 and DPD-9 respectively.

Primary responsibility for selection of materials lies with the rope assembly manufacturer.

The details on yarn materials provided in the following section are intended to assist the mooring designer in discussing the selection of rope yarn with the rope assembly manufacturer.

## 2.2 LOAD BEARING CORE YARNS

### 2.2.1 YARN TYPES

The yarns currently being evaluated for use in deepwater moorings are:

- polyester (polyethylene terephthalate)
- aramid (aromatic polyamide)
- HMPE (high modulus polyethylene)

Detailed comment in the DPD is limited to these materials. Polyester provides ropes of lower axial stiffness and strength than aramid and HMPE ropes of the same size.

Nylon is recommended by Cloos and Bosman (1997) when a lower modulus fibre, with a strength similar to polyester, is required. This is particularly applicable to situations with large displacements and shallow depths, but care should be taken to minimise the incidence of internal abrasion in wet nylon ropes.

A number of other high performance fibres are available for specialised applications or are under development. Further information is given in EC-2.2.

Indicative values of yarn properties were given in DPD-1.2. The effective properties of the material when made into a rope will be significantly different and this is considered in DPD-5. Further information on these and other yarns is given in EC-2 and in the detailed Tables of fibre properties in Appendix 2.

### 2.2.2 YARN SELECTION

Appropriate core yarns will be selected by the ropemaker to meet the fibre rope assembly properties selected and specified in DPD-5 and DPD-9 respectively.

### 2.2.3 EXISTING STANDARDS, GUIDELINES AND SPECIFICATIONS

No commonly accepted standards, guidelines and specifications exist for man-made-fibre ropes for deepwater fibre moorings in the above materials. In specifying fibre mooring rope assemblies in DPD-9, it is recommended that the philosophy of first building and testing a carefully specified prototype rope as prescribed in the OCIMF (1987) hawser guidelines be followed.

### 2.2.4 YARN QUALITY

It is essential that first-grade yarns of a type intended for use in marine ropes should be used. Quality control procedures, as specified in DPD-11, should ensure that the yarn used in the rope manufacture is the yarn specified or used in prototype rope testing.

## 2.3 ROPE JACKETS AND COVERS ON SPLICES

### *2.3.1 GENERAL REQUIREMENTS*

Outer protective materials should be selected to have adequate resistance to hydrolysis, fishbite, friction and shear and retain adequate flexibility at minimum exposure temperatures. These characteristics are described in more detail in DPD-3.3.

### *2.3.2 BRAIDED JACKETS*

The yarns used in braided jackets and protection for spliced terminations will be of the types listed in DPD-2.2, but will not necessarily be of the same material as the core yarns. Primary responsibility for selection of the yarns to meet the rope specification will be with the rope manufacturer.

Splice covering materials should have low friction and high wear resistance. They should have adequate resistance to hydrolysis and adequate flexibility at minimum exposure temperatures throughout design life.

### *2.3.3 PLASTIC JACKETS*

Materials suitable for plastic jackets can be applied by many different techniques, the most common are by extrusion, dip or spraying.

Plastic jackets are usually of the thermoplastic or elastomer type and can be applied in the form of 100% solids, or water or solvent based solutions. Material properties are very diverse and the rope designer can choose from a complete range of hardness from soft to very hard. Some typical plastic grades used for jackets are discussed further in the EC.

## 2.4 FINISH AND FILLERS

Yarns used by the ropemaker to meet the fibre rope assembly properties selected and specified in DPD-5 and DPD-9 respectively should be provided with a durable marine finish. Additional lubricants and fillers may be specified, for instance to reduce the formation of friction hot-spots within the rope which can be caused by unlubricated fibre-to-fibre contact when a rope is being cyclically loaded. For permanent moorings these should be compatible with any yarn lubricant, show adequate fatigue performance in prototype testing and remain effective through the rope's design life. They should additionally comply with the appropriate requirements given in ISO 4346 (1977) or equivalent standards. Consideration should be given to monitoring their effectiveness of over the life of the installation.

**REFERENCES**

- OCIMF (1987) Guide to purchasing hawsers. Published by Witherby & Co. Ltd, London on behalf of OCIMF.
- OCIMF (1987) Procedures for quality control and inspection during the production of hawsers. Published by Witherby & Co. Ltd, London on behalf of OCIMF.
- OCIMF (1987) Prototype rope testing. Published by Witherby & Co. Ltd, London on behalf of OCIMF.
- ISO 4346 (1977) Steel wire ropes for general purposes - Lubricants - Basic Requirements
- Norsk Hydro JIP (1997) Fibre Rope Testing - Final Report Phase 1 and 2 - A Study into the Mechanical Properties and Heat Build-up Characteristics of Small Scale and Full Scale Polyester and Aramid Rope
- Cloos, P.J. and Bosman, R.L.,(1997) Conference on High Strength Fibre Cables, Institution of Civil Engineers, London, November 26th, 1997.

**APPENDICES MENTIONED**

- Appendix 2 Information from Fibre Producers on Fibre Properties

r1va	DRAFT with mods agreed at meeting	DPD4:003/	16.8.96 17.Sept.96
r2va	modified	jwsh/others	6 Mar 97
r2vax	"	"	16 Mar
r2vb	"	rwps/jwsh/jct	22 Mar
r3va	new rev after SC#4 plus changes by	rwps et al	20 Oct 97
r4va	changes following meeting 16/17 Feb	sjb/mrp	6. Nov 97
r4va	text corrections	tii/nde	16 Feb 98
r4va	changes noted after TTI meeting	rwps	7 May 98
r4va	mods given in TTI fax dated 21.5.98	rwps	21 May 98
r4va	mods noted by TTI fax dated 22/5/98	rwps	21 May 98
r4vb	tii/nde	rwps	11 June 98
r4vb	tii/nde following nfr points	rwps	15 June 98

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### 3. ROPE CONSTRUCTIONS

#### 3.1 FIBRE ROPE COMPONENTS

Most fibre ropes comprise a core to withstand tensile loads and an outer jacket, which often has little tensile load bearing capability. Additional protective coatings or wrappings may be applied after rope manufacture.

The design of the load bearing core will generally be selected by the rope supplier to meet the fibre rope assembly specification set out by the user. Procedures for this are set out in DPD-9.

Optimum design of the outer protective layer may require major input from the user, as set out in DPD-3.3 below.

## 3.2 ROPE CONSTRUCTIONS AND PROPERTIES

### 3.2.1 ROPE TYPES

A review of some common load bearing core constructions for man-made-fibre ropes is provided in EC-3.2. Of these, three offer significantly higher strength per unit weight than the remainder. They are

- Parallel yarn constructions
- Parallel sub-rope constructions (parallel strand)
- 'Wire Rope' stranded constructions

### 3.2.2 EXISTING STANDARDS, GUIDELINES AND SPECIFICATIONS

No commonly accepted standards, guidelines and specifications exist for man-made-fibre ropes for deepwater moorings in the above constructions. In specifying fibre rope assemblies in DPD-9, it is recommended that the philosophy of first building and testing a carefully specified prototype rope as prescribed in the OCIMF (1987) hawser guidelines be followed. Note however that test and termination techniques for deepwater fibre moorings will differ from those for the marine hawsers specified in the OCIMF guidelines.

### 3.2.3 STRENGTH

Tables of average strength/weight and size data for polyester ropes in the above constructions are provided for preliminary information purposes in EC-3 (see Tables EC-3.2.4, 3.2.5 and 3.2.6).

Comparative strength data for 10,000 kN ( $\approx$  1,000 tonne ) rope assemblies made of polyester, aramid and HMPE fibres are set out in DPD-5 (Table 5.2.1).

### 3.2.4 AXIAL STIFFNESS

Definitions of rope stiffness relevant to deepwater moorings are discussed in DPD-5. Comparative axial stiffness data for polyester ropes in the three above constructions are provided for information purposes in EC-3.2.4. Few of these data have yet been verified by testing at the sizes appropriate for deepwater mooring.

Suggested maximum and minimum axial stiffness data for deepwater fibre mooring assemblies based on polyester, aramid and HMPE fibres are set out in DPD-5 (Table 5.3.1).

### 3.2.5 TENSION-TENSION FATIGUE LIFE

Little or no public domain data is available on the comparative fatigue life of man-made-fibre ropes in the above constructions at sizes appropriate for Floating Production System (FPS) deepwater mooring. The recommendation provided in DPD 8.6.2 (Figure 8.6.1) for an appropriate fatigue curve is based on the evidence that the tension-tension fatigue lives of properly terminated fibre ropes is better than steel wire ropes or strand at the sizes tested.



Comparative data for polyester rope in different constructions are set out in EC-5.5.

Recommendations on avoidance of fatigue due to excessive numbers of cycles at low tension are set out in DPD-5.5.3

### 3.3 PROTECTIVE JACKET CONSTRUCTIONS

#### 3.3.1 JACKET DESIGN

Design of the protective jacket will depend critically on location, depth and installation technique.

It is recommended that the jacketing should be provided with a clearly visible longitudinal stripe to allow for initial monitoring of twisting in the rope. In braided jackets this can be provided by at least two strands of the braid, one left hand, one right hand, being made from durable, water resistant coloured yarns.

#### 3.3.2 EXTERNAL ABRASION

An important function of the jacket is to protect the rope from external abrasion, which may occur during transportation, handling at installation or at any other time, or if laid on the sea-bed during the installation procedure. The rope specification should ensure that the protective jacket is adequate to resist damage due to this cause.

#### 3.3.3 PARTICLE INGRESS AND AIR POCKET SUPPRESSION

There have been reported instances of strength loss in fibre ropes attributed to internal abrasion due to water-borne particles and confidential testing programs have confirmed an effect. The fibre rope assembly should thus, if possible, be remote from the sea floor. Otherwise, or in regions where water-borne particles are highly concentrated, suitable jackets which exclude particle penetration whilst allowing water ingress should be provided.

Plastic jackets will be impermeable, unless intentionally punctured to allow water ingress. Braided jackets may allow water penetration, but it is not clear to what extent water will be able to displace air completely from the spaces between strands, yarns and fibres (see Bowie and Williams (1997)). The presence of air pockets may lead to undue heat build up during cyclic loading. Ropes should either be free flooding or impregnated with a suitable blocking compound.

#### 3.3.4 FISHBITE RESISTANCE

Fishbite is a potential problem in some locations at some water depths. If fibre ropes are used where serious fishbite can occur, the specification should ensure that the rope is adequately protected and its condition monitored over the lifetime of the installation.

### 3.3.5 UV RESISTANCE

Polyester ropes have excellent resistance to UV (Ultra Violet) light, and jacket design need not take account of this aspect. Uncovered aramid ropes may suffer degradation of surface yarns if exposed to UV radiation awaiting installation or if permanently deployed, uncovered, in the upper few metres of water. In such cases an opaque cover is recommended.

### 3.3.6 MARINE GROWTH

There are no recorded instances of strength loss in man-made-fibre ropes caused by marine fouling or its by-products.

The presence of marine fouling may affect the ability to inspect the rope. Also if marine growth is to be removed mechanically this must be done in such a way that avoids damage to the rope itself. (see Milne (1970)).

### 3.3.7 JACKET BENDING RIGIDITY

The jacket should be sufficiently flexible to permit the fibre rope assembly to be safely deployed over rollers or sheaves, of diameter to be specified by the system designer, under the design deployment loads. The jacket should be capable of temporary deployment around the bending radius values suggested for installation of fibre ropes in DPD-12.2.4 (Table 12.2.1) and extended storage when wound onto the specified transportation drums.

### 3.3.8 VORTEX INDUCED VIBRATION SUPPRESSION.

In areas subject to steady current over substantial depth, vortex induced vibration may possibly induce bending fatigue, particularly close to terminations. Means of designing against this form of damage include provision of a tapered polymeric jacket to form a bend restrictor which would then form part of the termination (see DPD-4.2.4).

## REFERENCES

- Bowie, M.M. and Williams, I.D. (1997) "Foinhaven mid-depth pipeline and its integration with the TCMs for deepwater developments"; Victoria Oilfield Development; IIR Moorings and Anchors Conference 20/21 October 1997.
- Milne, P.H. (1970) "Fish Farming: A guide to the design and construction of net enclosures"; Marine Research No. 1; Department of Agriculture and Fisheries in Scotland, 1970.
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OCIMF.

OCIMF (1987)

Prototype rope testing. Published by Witherby & Co. Ltd, London  
on behalf of OCIMF.

**Figures**

None

**Tables**

None

**APPENDICES**

None

r1va	Draft supplied by	SJB	24 March 97
r2vb	Mod	SJB	Mar 97
r3va	new rev after SC#4	RWPS	Oct. 97
	plus jwsh suggested changes sent by e-mail received		5 Nov 97
	plus changes	mrp/sjb/rwps	6. Nov 97
	final changes	rwps	16.Nov.97
r4va	Edit	rwps/spo	27 Feb 98
r4va	text corrections	rwps	7 May 98
r4va	changes noted after TTI meeting	rwps	21 May 98
r4vb	tti/nde	rwps	11 June 98
r4vb	tti/nde	rwps	15 June 98

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## 4. ROPE TERMINATIONS

### 4.1 TERMINATION TYPES

#### 4.1.1 END TERMINATIONS

Three main types of end termination may be considered for man-made-fibre rope assemblies for deepwater mooring. These are the socket and cone, the conventional socket and the spliced eye. These are more generally known as

- 'barrel-and-spike'
- 'resin socket'
- 'spliced eye'

terminations respectively.

The key merits and disadvantages of these termination types are discussed in EC-4.1, which also describes current field experience and provides a listing of termination types.

Of the termination types listed above, only the spliced eye has been qualified for strength and resistance to hysteresis heating at sizes of man-made-fibre rope appropriate for deepwater mooring of large structures. The barrel-and-spike termination has been strength tested on fibre rope at over 14,000 kN ( $\approx 1,400$  tonnes). Several companies are currently developing resin socket terminations for man-made-fibre ropes. A list of references to such work is set out in the EC.

#### 4.1.2 IN-LINE JOINTS

Due to limitations of length manufacturing or transportation in large rope size, a number of rope lengths joined together may be required to make a longer line length required for deeper water. Test lengths for removal and testing are also needed. For drilling or temporary moorings, a number of shorter lengths will facilitate reuse in different water depths.

All the terminations types listed above may be joined together with steel hardware similar to that used for connecting wire/chain systems. This has the disadvantage of being heavy and can apply undue bending moments in the area of the in-line joint. Other materials may be used, such as fibre reinforced composites, if they have been proven to be satisfactory by design and testing.

An alternative method of providing permanent in-line joints is by the butt splice method that involves no steel hardware. The butt splice method uses the same splicing technique as the eye splice, except that no eye is formed and each splice is made back-to-back. This method is suited to joining lengths in the rope factory before deployment offshore although in principle such a joints could be made on site during deployment given suitable procedures and quality control. The jacketing of the rope in the vicinity of the butt splice joints would require special attention.

Line with mid-length joints need special consideration when being stored on reels for transportation and deployment so that the weight and shape of the termination hardware does not damage the other parts of the rope on the reel.

## 4.2 MATERIALS

### 4.2.1 EXISTING SPECIFICATIONS

Materials used for spliced, resin socketed and barrel-and-spike terminations should meet, where relevant, the requirements set out in the following specifications

- DNV Certification of Offshore Mooring Steel Wire Ropes, May 1995, paras 2.3, 3.4 and 5
- BS 464 Specification for thimbles for wire ropes
- BS 3226 Specification for thimbles for natural fibre ropes
- BS 7035 Code of practice for socketing of stranded steel wire ropes

These specifications include steels and resins used for steel wire rope and have not necessarily been developed for fibre rope.

Termination materials should also have adequate resistance to corrosion, hydrolysis and adequate flexibility at minimum exposure temperatures throughout design life. It should be noted that corrosion in steel terminations can be difficult to protect against, particularly at junctions remote from the platform.

### 4.2.2 OTHER MATERIALS

A range of materials for protecting and covering terminations will be required for which no existing guidelines or specifications exist. The requirements for such materials may be system and location specific and should be agreed between Manufacturer and Purchaser as detailed in DPD-9.2.7 and DPD-9.2.8.

### 4.2.3 CLOTH PROTECTION FOR SPLICED EYES

For spliced eye terminations, protective cloth will be required between the eye and the pin or bush that fits through the eye. Such cloth should provide low friction and high wear resistance between the fibre rope and the pin or bush.

Alternative eye protective materials may be used. If a thin cover of elastomeric material is used to protect against chafing, then it shall be highly elastic such that the rope is not constrained from stretching or bending. If a thick cover of elastomeric material is used to encapsulate the eye, it shall be applied over a tape or cloth which covers the eye and prevents direct adherence to and penetration into the rope.

#### 4.2.4 BEND RESTRICTORS

Bend restrictors may be required and are typically made from polyurethane elastomers.

Bend restrictors should minimise damage to the fibre rope through unacceptably tight bending, crushing or flex fatigue at the termination/rope interface.

#### 4.2.5 BUSHES, THIMBLES AND PINS

Bushes, thimbles or pins are usually made from steel. Other materials, such as polymers and fibre-reinforced composites may be used if they have been proven to be satisfactory.

### 4.3 TERMINATION STANDARDS, GUIDELINES AND SPECIFICATIONS

#### 4.3.1 PROTOTYPE TESTING

No commonly accepted standards, guidelines and specifications exist for man-made-fibre rope terminations for deepwater fibre moorings. In specifying terminations in DPD-9.2.7 and DPD-9.2.8, it is thus recommended that the philosophy of first building and testing a carefully specified prototype rope be followed.

#### 4.3.2 TERMINATION CONSTRUCTIONAL DIFFERENCES

Note in particular that within each generic termination type a number of specific constructions and assembly methods exist. Since none of the specific termination constructions and assembly methods applicable to deepwater fibre moorings are yet standardised, it is essential that the method used in assembling the prototype rope be fully specified and documented by the supplier.

### 4.4 TERMINATION PROPERTIES AND DIMENSIONS

#### 4.4.1 STRENGTH

Comparative average strength efficiencies for small ropes in various terminations are provided for information purposes only in EC-4.4.1 (Table EC-4.4.1). It is not yet clear how valid these comparisons are for large ropes.

Spliced eye terminations should represent the strength of the installed rope.

The Certified Breaking Strength (CBS) of the fibre rope assembly, by definition, takes account of the strength efficiencies of all terminations within the assembly.

#### 4.4.2 AXIAL STIFFNESS

The axial stiffness of man-made-fibre ropes may be taken as being independent of termination type for fibre mooring assembly lengths exceeding 20 metres.

#### 4.4.3 TENSION-TENSION FATIGUE LIFE

No data is available on the comparative fatigue life of man-made-fibre ropes in the above terminations at sizes appropriate for deepwater mooring. Comparative data for smaller sizes of aramid, polyester and HMPE rope in different terminations are set out in EC-4.4.3 (Figures EC-4.4.2 through EC-4.4.7).

#### 4.4.4 FLEXURAL RIGIDITY

The transition of flexural rigidity between termination and clear rope should be gradual and without sudden changes of rigidity that could cause localised bending fatigue.

#### 4.4.5 FORCES AND MOMENTS AT CONNECTIONS

When a termination on the end of a fibre rope is connected to other components in the system via a pin the effects of frictional forces and torque arm at this connection should be considered to ensure that undue bending moments are not imparted in the termination and that separate legs of the splice are not overloaded (see Figure 4.4.1).

#### 4.4.6 SPLICED EYE HARDWARE

Spliced eyes will require hardware in the form of a pin, bush or thimble fitted into the eye to make a connection between a fibre rope and other components in the mooring system.

The selection of D/d ratio, bearing diameter of the eye hardware 'D' over rope diameter 'd' is critical to provide adequate strength and fatigue performance. The minimum acceptable D/d ratio to be used should be set to ensure full Certified Breaking Strength of the assembly and to avoid excessive pressure between rope and spool. The maximum D/d ratio should be set to avoid excessive abrasion and fusion between rope and spool due to rope stretch.

Table 4.4.1 summarises D/d ratios used by rope makers for selecting eye hardware in conventional fibre rope constructions in polyester. The table also gives suggested values for D/d ratios provided by rope makers for deepwater mooring lines.



Table 4.4.1

**Suggested D/d Ratios for Spliced Eye Hardware**

(based on recommendations of Ropemakers)

Fibre Rope Types	D/d ratios for eye hardware for fibre ropes
Conventional Rope Constructions in polyester and nylon	1.5 - 4.0
Deepwater Mooring Ropes	1.5 - 6.0

Notes: D= pin or bush diameterd=rope diameter

For guidance, four samples representing two of the materials and rope constructions here considered have been qualified at full scale in the Norsk Hydro JIP (1997) at D/d ratios between 4.4 / 1 and 4.9 / 1.

There is no other public domain test data available at full scale and in the rope constructions proposed for deepwater fibre mooring.

## 4.5 TERMINATION SELECTION

The rope termination should meet the fibre rope assembly tensile requirements (see DPD-9.3.2).

The following properties specific to the mooring concerned should also be specified:

- Termination maximum weight/dimensions
- Bending limitations which apply to shipment and installation
- Restrictions on electrochemical potential of any metallic components

Such information should allow the rope supplier to offer a suitable termination.

## REFERENCES

- |                        |  |
|------------------------|--|
| API RP 2SK (1997)      | "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997) |
| OCIMF (1987)           | OCIMF Guide to purchasing hawsers. OCIMF Procedures for quality control and inspection during the production of hawsers. OCIMF Prototype rope testing. Published by Witherby & Co. Ltd, London on behalf of OCIMF. |
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TTI (1992)	US NAVY CONTRACT N62474-87-C-3073
DNV (1995)	Certification of Offshore Mooring Steel Wire Ropes ( <u>Cert. Note No 2.6</u> ), paras 2.3, 3.4 and 5, <u>May 1995</u>
BS 464 (1958)	Specification for thimbles for wire ropes
BS 3226 (1960)	Specification for thimbles for natural fibre ropes
BS 7035 (1989)	Code of practice for socketing of stranded steel wire ropes

**Appendices**

None

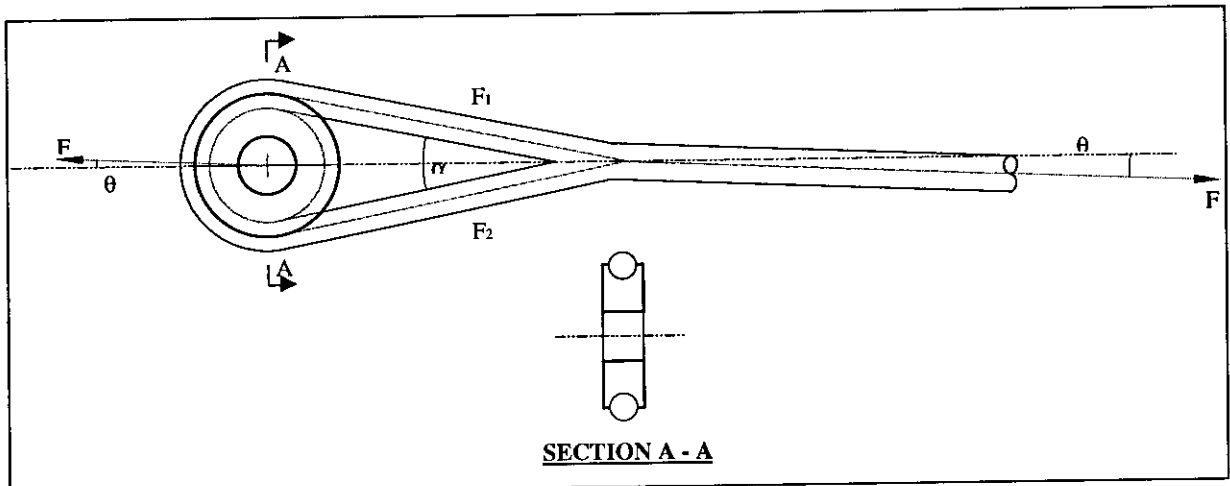
**Figures**

4.4.1

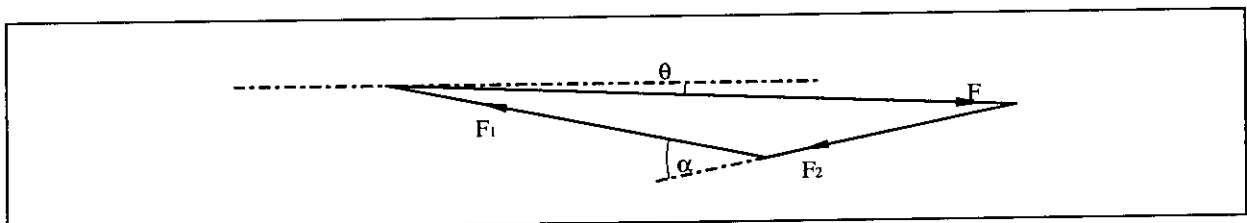
**Tables**

4.4.1

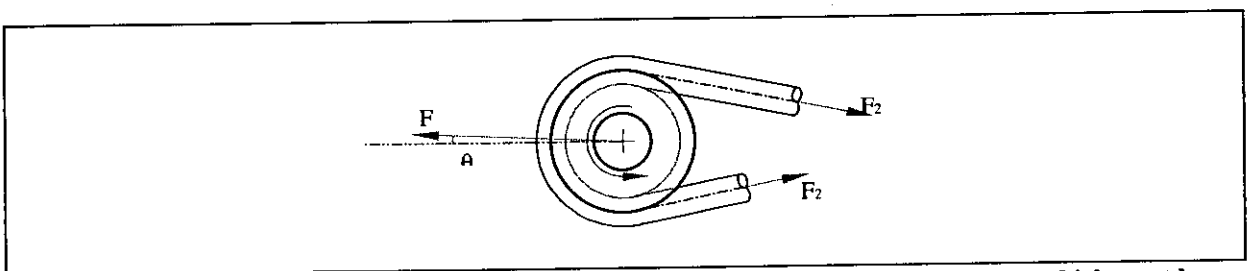
**Figure -4.4.1**  
**Forces and Moments at Spliced Eye Connections**



a) Spliced eye with line deviating from central alignment by  $\theta$  as a result of "No-Slip" at the Pin/Spool.



b) Force Diagram of Equilibrium Loads at splice.



c) Equilibrium Forces at Pin and Spool. Out of balance force in lines causes moment which must be carried by friction between rope and spool and spool and pin.

r1va	DRAFT DPD6:002/5.9.96/	MRP jwsh	11 September 1996
r1vb	with mods agreed at meeting on 17.Sept.96	rwps	
r2va	New DPD5(old DPD6) with mods by jwsh	rwps	11 Mar 97
r2vax	mods	jwsh	16 Mar
r2vb	mods	jwsh/jct/rwps	18/22 Mar
r3va	new rev after SC#4	rwps et al	20 Oct 97
	plus jwsh 'B' comments + sundry other changes including rwps/mrp dated		4.Nov.97
	plus jwsh changes in e-mail received		5.Nov.97
r3vb	plus changes by mrp/rwps 5.Nov.97 to remove "requirements" etc		
	plus changes to include comments by jwsh		11.Nov.97
	final mods	rwps	16.Nov.97
r4va	changes following tti/nde meeting	tti/nde	17.Feb.98
r4va	text corrections	rwps	7.May.98
r4va	changes noted after TTI meeting	rwps	21.May.98
r4va	mods given in TTI fax dated 21/5/98	rwps	21.May.98
r4vb	tti/nde	rwps	11.June.98
r4vb	tti/nde following nfr	rwps	15.June.98

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**5. ROPE ASSEMBLY PROPERTIES**

5.1 INTRODUCTION

The key technical characteristics for fibre rope assemblies, combining rope and termination are set out below.

5.2 SIZES AND STRENGTH

*5.2.1 STRENGTH DEFINITION*

In conformity with API RP 2SK (1997) the strength of the terminated fibre rope assembly is defined by the Certified Breaking Strength (CBS) guaranteed by the manufacturer, which is the minimum strength of the assembly. Other strength definitions are set out in Appendix 1.

5.2.2 TYPICAL VALUES

Typical values, for first design purposes, of weight in water and rope diameter (with jacket) for rope assemblies of 10,000 kN ( $\approx 1,000$  tonne) certified break strength are set out in Table 5.2.1 below. To a first approximation, strength will scale with weight in air or diameter squared.

Table 5.2.1

**Typical Rope Weights And Sizes For 10,000 kN ( $\approx 1,000$  tonne) Break Strength  
 (including Jacket)**

	polyester	aramid	HMPE	steel (for comparison)
total weight in air ,kg/m	23	12	8.4	57
total weight in water, kg/m	5.9	3.3	buoyant	48
typical overall diameter, mm	175	120	125	108

5.2.3 EFFECTS OF LENGTH ON STRENGTH

Chains and ropes are only as strong as their weakest section and so become weaker with increasing length. Provided variability is minimised by quality control during manufacturing, the strength loss in the ropes being considered would be small and covered by the safety factors for maximum line tensions given in Table 8.2.2.

5.2.4 CREEP RUPTURE

All fibre ropes will fail after long times under loads less than the break load measured over the time of a tensile test. For polyester and aramid ropes under typical mooring loads, the times involved would be extremely long. Any limited effect will be within the uncertainty of measures of break load. Only if ropes were seriously weakened by fatigue would creep rupture become significant as the final mode of failure.

HMPE yarns creep substantially although the amount of creep is very dependent on the particular HMPE yarn in question. When using HMPE ropes for deepwater mooring the risk of creep rupture should be evaluated in consultation with the yarn supplier and ropemaker, taking account of the expected loading history and other conditions.

### 5.3 ELONGATION AND STIFFNESS

#### 5.3.1 INTRODUCTION

The elongation of a fibre mooring assembly depends partly on the applied force acting on the rope stiffness and partly on unrecovered elongation resulting from previous loading. The stiffness of a fibre mooring assembly depends on many parameters. Of these the most important are load, strain range, loading history and, in some specific cases, cycling frequency. Similarly, the unrecovered elongation depends on the detail of the previous loading history. These are discussed in more detail in the EC-5.3. However more research is needed to fully characterise these properties.

An alternative approach is to simplify the problem by defining linear minimum and maximum stiffness values. The minimum stiffness values are then used to calculate maximum platform offset and the maximum stiffness to determine line loadings. This is the simplified approach for design provided by this document as set out in detail in DPD-8.4.1. It is assumed that the unrecovered elongation is taken up by retensioning the lines.

If the mooring analysis is to use non-linear rope load-extension curves, which are different in recovery and change with history, then either extensive testing will be needed or an enhanced, computable, rope extension model will be required together with validation data. Such procedures are not yet available.

#### 5.3.2 STIFFNESS DEFINITIONS

The load-elongation properties of fibre ropes (discussed in EC-5.3), which, in detail, are complicated, can be reduced to a number of linear elastic stiffness values for mooring calculations.

Stiffness below is defined by the quantity  $E.A$  where

$$E.A = \text{Rope Stiffness (in units of force)} = \text{force/strain}$$

and where

$$A = \text{the cross sectional area of the rope (area)}$$

$$E = \text{the effective elastic modulus of the rope (force per unit area per unit strain)}$$

Note that rope area can be defined in various ways and it is necessary to ensure consistency in calculations. For rope tensile properties, it is most convenient to use the rope fibre area, namely the area occupied by fibres in the cross-section; this is preferably restricted to the load-bearing fibres excluding the jacket. For some other purposes, the total rope area, based on an external measurement of diameter or circumference, is appropriate.

The rope stiffness  $E.A$  is equivalent for an elastic spring system to  $K.L$

i.e.  $E.A = K.L$

where

$K$  = the effective elastic spring coefficient (force per unit length extension)

$L$  = the length of the spring (in units of length):

$E.A$  is also equal to specific modulus times rope weight (or, strictly, mass per unit length).

The minimum and maximum stiffness values that are recommended for the mooring analysis are defined as:

**Post-Installation Stiffness :**  $E.A$  (**Post-Inst.**) is the stiffness over the load or strain range of interest in quasi-static loading immediately after installation. It is the stiffness which corresponds to the extensibility of the mooring lines under quasi-static loads once the Minimum Installation Tensioning (see DPD-12.5.4) has been performed during installation.

**Storm stiffness :**  $E.A$  (**Storm**) represents the maximum stiffness in cycling from the mean load during the maximum design storm to the cyclic strain limits predicted in the maximum design storm. This stiffness will result in the largest loads being generated in the mooring lines as the platform moves compliantly in the storm.

The stiffness will increase if a more severe tensioning regime is applied after the Minimum Installation Tensioning specified above or following periods of operational cyclic loading. These *Intermediate stiffness* values may be substituted for the Post-Installation Stiffness, if this is necessary to reduce offset, provided the appropriate installation and operation procedures are adopted.

Note that insufficient data currently exists to establish formal relationships between the above measures of fibre mooring line stiffness. However an example based on data from a polyester rope is illustrated in Figure 5.3.1.

### 5.3.3 TYPICAL ROPE STIFFNESSES

Typical values of maximum ("Storm") and minimum ("Post-Installation") stiffness data, for deepwater fibre moorings suitable for the initial design calculations, based on polyester, aramid and HMPE fibres, are given in Table 5.3.1. To a first approximation these stiffness values will scale with the break strength of the rope.

Table 5.3.1

Typical stiffness values for parallel yarn, parallel strand, and wire-rope construction ropes  
 (based on a 10,000 kN ( $\approx$ 1,000 tonne) Breaking Strength Rope)

rope material	Post-installed stiffness	Intermediate stiffness	Storm stiffness
	E.A(Post-Inst)/kN	E.A(Int)/kN	E.A(Storm)/kN
	post-inst		storm
polyester	100,000	100,000-300,000	300,000-450,000
aramid	330,000	330,000-600,000	600,000
HMPE	350,000	350,000-700,000	700,000

Where stiffnesses as specified in Table 5.3.1 are inadequate to assure compliance with fatigue, offset, maximum load and minimum load limits, precise loading conditions should be defined to allow exact values of relevant load/extension data to be determined on a prototype rope. Suggested testing methods are discussed in DPD-9.2.3. Typical intermediate stiffness values are included in Table 5.3.1.

5.3.4 UNRECOVERED ELONGATION

Total elongation of the fibre rope assembly throughout the design lifetime should neither exceed the take-up capacity of the winch system nor lead to creep rupture. Elongation in fibre rope assemblies results from bedding-in of the rope structure and terminations and from both instantaneous extension and creep in the yarns. It will occur to a greater or lesser degree in all fibre rope assemblies under both steady and cyclic loads.

The designer and installer should be informed by the rope manufacturer of the amount of elongation due to bedding-in and creep to be expected on loading during installation. The designer may calculate the effect of increase of line length between retensioning.

For polyester and aramid ropes, the continuing elongation due to creep tends to be a constant amount for each equal increment of log(time) at a given load. As discussed further in EC-5.3.4, the creep in one decade of log(time) in FIBRE TETHERS 2000 (1995) tests of polyester and aramid yarns ranged from 0.01% to 0.16% extension at 30% of break load.

HMPE yarns showed much greater creep, ranging from over 10% per decade of log(time) at 15% of break load in the worst case to 1% at 30% of break load in the best case. As noted in DPD-5.2.4 above, creep in HMPE is highly dependent on the particular yarn type and the temperature and is less in ropes than in yarns. Some guidance is given in EC-5.3.4, but the extent of creep elongation in HMPE ropes should be estimated in consultation with the yarn supplier and ropemaker, taking account of the expected load history on the rope.



## 5.4 HYSTERESIS HEATING AND DAMPING

### 5.4.1 HYSTERESIS HEATING

High internal temperatures can occur in tension-tension fatigue cycling of ropes at high strain amplitudes. The maximum temperature rise depends on diameter, internal pressure, constructional type, sheath type and thickness, lubricant, presence of water or fillers and many other factors. As mentioned in EC-5.4.1, joint industry studies indicate that heating effects will be small in large polyester ropes for strain amplitudes less than 0.25%.

Temperature limits for PET, HMPE, nylon and aramid fibres are set out in Table EC 5.4.1. The designer should consider alternate constructions and materials if prototype tests indicate that equilibrium temperatures exceed the values there indicated.

### 5.4.2 DAMPING

Taut fibre rope moorings will contribute damping to the system from internal energy dissipation (hysteresis) in the rope and external energy dissipation due to movement in the water.

The drag force will vary linearly with rope external diameter and thus for fibre rope mooring systems it will generally be equal to or greater than drag force for steel ropes of the same strength for equivalent motions. The computation of the fluid damping is covered in DPD-8.3.4.3.

Line hysteresis damping factors for polyester parallel strand and steel wire rope are compared in Table EC-5.4.2. The longitudinal axial damping factors for fibre rope are less than those for steel wire rope for similar motions but rise steeply with applied strain. Data is not currently available on the energy absorbed by the other modes of internal damping (bending, shearing and torsional) of fibre ropes, but these modes are considered to be the least significant.

## 5.5 FATIGUE

### 5.5.1 FATIGUE EXCITATION MODES

Deepwater fibre mooring assemblies are subject to fatigue loading and the effect of fatigue on the mooring system should be considered.

Since the fibre mooring assemblies covered by this guideline will be terminated to chafe chain at both ends, bend-over-sheave fatigue loading will be limited to any which occurs in deployment or retrieval operations. Tests are currently in hand to establish suitable D/d ratios for such deployment or retrieval purposes.

It is here assumed, as in DPD-5.8, that the whole mooring system will be torque free, so avoiding rotational loading fatigue, especially at terminations. (It is important to note that even nominally torque balanced fibre rope constructions can exhibit torque under tensile load due to variability between rope components)

Tension free-bending fatigue loading on taut mooring lines should be addressed by design of articulated terminations that minimise bending moments.

Two forms of axial fatigue loading are discussed below.

### 5.5.2 TENSION-TENSION FATIGUE

Figure 5.5.1, based on extensive evidence discussed in EC-5.5.2, shows that the tension-fatigue life of polyester ropes is greater than that of steel chain or wire ropes. Indications are that a similar situation exists for aramid and HMPE ropes.

It should be noted that little of the above data has been derived on ropes of comparable construction or size to those required for FPS moorings. Appropriate tests should be conducted on prototype ropes where analysis indicates inadequate life.

In the case of HMPE and other fibres data on ropes of appropriate construction is scanty, and design should be based on appropriate tests on prototype ropes backed by modelling.

### 5.5.3 AXIAL COMPRESSION FATIGUE

Axial compression fatigue, which may occur when a rope experiences an excessive number of cycles at low tension, can cause failures, but with proper precautions is avoidable. Although axial compression fatigue also occurs in steel, it is not generally a concern in catenary moorings because the weight of the rope ensures that substantial tension is maintained at all times. In taut moorings, the rope tension may fall to low values at certain times, or even go slack on leeward lines during storms. Under these conditions, axial compression fatigue, which is a consequence of repeated sharp kinking of fibres, may be a problem after a large number of cycles.

In order to prevent some rope components going into axial compression, it is not sufficient to maintain a positive tension on the rope as a whole. There are two reasons for this. (1) In an ideal rope construction, every component would have exactly the right length to fit the rope geometry; in other words, all components would be just at zero tension when the whole rope was at zero tension. In practice, this is not possible. Due to varying tensions on components or other aspects of manufacturing variability, some components will be longer and some shorter than the ideal equalising length. Consequently, at zero rope tension, components will have a range of tensions from negative (compression) to positive (tension). A certain minimum tension will be needed to ensure that all components are under tension. (2) When a rope twists, the lengths of components at different positions within the rope change. In the simplest case of a single twisted yarn, the outer helical path will become longer as twist is increased and shorter when it is decreased. In a parallel yarn rope, with zero initial twist, twist in either direction will increase the path length at the outside of the rope. In other ropes, which are multiply twisted structures, the geometry is more complicated, but length changes will always occur on twisting. Once again, this means that components forced to take longer paths will be under tension, while those following shorter paths will be under compression, when the tension on the whole rope is zero. A minimum tension is needed to maintain tension on all components.

The problem of axial compression fatigue raises two practical questions for the mooring system designer, installer and user. What minimum tension on the rope is necessary in order to avoid components going into compression? How many cycles of axial compression can occur without serious damage to the fibres?

No general answer can be given to the first question, because the first compression mechanism is dependent on the quality of the rope manufacture in minimising variability and the second compression mechanism depends on the torsional mechanics of the total system.

In some laboratory tests, axial compression fatigue has been found in certain constructions of aramid ropes when cycled with minimum tensions in excess of 10% break load, though other constructions are unaffected (see EC-5.5.3). In a follow-up of FIBRE TETHERS 2000 (1995) tests, a polyester rope showed no evidence of axial compression fatigue after 12 million cycles at 20 +/- 10% of break load, i.e. a minimum of 10% break load. Provided the ropes are well made and not subject to significant twisting, the risk of axial compression should be small if the tension in polyester ropes does not fall below 5% of break load. Indeed there is substantial unpublished evidence that axial compression fatigue does not cause strength loss in some polyester ropes down to minimum loads of 2.5% CBS. This lower limit might be adopted after appropriate tests and in particular cases.

In the absence of fuller test data, the guideline is here provisionally set at 5% CBS for polyester ropes and 10% CBS for higher modulus ropes.

Based on yarn buckling tests carried out in FIBRE TETHERS 2000 (1995), provisional guidance can be given on how many axial compression cycles yarns can stand before serious strength loss occurs. Table 5.5.1 gives the summary results of these tests and includes a guideline figure for the number of allowable cycles below the minimum tension level.

Table 5.5.1

**Axial Compression Fatigue in Yarn Buckling Tests****(from FIBRE TETHERS 2000(1995))**

<u>Yarn Material</u>	<u>Cycles to Failure</u>		
	<u>Detectable Strength Loss</u>	<u>Guidance Design Limit</u>	<u>Severe Strength Loss</u>
polyester	<u>50,000</u>	<u>100,000</u>	<u>1,000,000</u>
HMPE	<u>20,000</u>	<u>40,000</u>	<u>200,000</u>
aramid	<u>1,000</u>	<u>2,000</u>	<u>40,000</u>

### 5.6 STRENGTH FALL-OFF DURING DESIGN LIFE

Limited data currently exists to quantify the rate of strength fall-off experienced by full scale man-made-fibre rope assemblies for FPS moorings (available results are discussed in EC-4.5.4 and EC-5.6). Such moorings would typically be required to possess a 20 year design life. However there is no evidence to suggest performance inferior to that of steel wire rope. For steel ropes it is assumed that break strength and fatigue life are independent of each other.

For fibre ropes the exceptions (which can be avoided by sensible design) are where axial compression fatigue or internal abrasion are significant mechanisms. These can cause a steady reduction in residual strength during cycling as shown in Figure EC-5.6.1. In such cases, safety factors should be increased appropriately.

### 5.7 DELAYED ELASTIC RECOVERY

Instantaneous elastic extension is naturally recovered when loads are reduced. However part of the creep under high loads is primary creep, which is recovered over time, when loads are reduced. This is known as delayed elastic recovery and can occur after storm conditions and affect mooring line tensions.

### 5.8 TORQUE AND TWIST EFFECTS

Twisting of a fibre rope changes its strength and, more seriously, is a source of axial compression and structural fatigue. All components of a deepwater fibre rope mooring system should be torque-balanced, in order to minimise these problems. However, twisting cannot necessarily be completely eliminated during installation and operation. It can result from effects including: torque balance may not be perfect at all tensions; rope variability may lead to twisting; buckling into three-dimensions is accompanied by twist; and twist may occur in handling. The relationship between axial strain and twist varies significantly depending on the type of rope construction being used.

If the deviation from torque balance in the system is appreciable, a full analysis must be carried out.

There should be no problem if this strain difference is less than 0.1%, which is about 1% of break strain, in order to avoid problems due to twisting. This allows for a maximum of 1 turn in 50 rope diameters. As with the recommendations for maintaining minimum tension, a limited number of cycles at higher twist levels may be allowed during installation or at other times. However, it is suggested that these should not exceed 1 turn in 20 diameters.

### 5.9 MINIMUM BENDING RADIUS

The bending effects, particularly at terminations, of any lateral vibration of the line as a result of vortex shedding should be considered in the design.

During repeated cycling such as would result from Vortex shedding parallel construction ropes should not be bent to a radius of less than 500 diameters. These restrictions do not apply to transportation, deployment or retrieval operations for which cycling to higher curvatures is allowable as set out in DPD-12.2.4.

### 5.10 OTHER ENVIRONMENTAL EFFECTS

Most fibre ropes are highly resistant to UV and chemical attack even when unsheathed, as set out in EC-2 (Table EC-2.2.2.2). Other external causes of degradation such as fishbite and external wear are a function of jacketing material, as discussed in DPD-3.3.

Synthetic fibres suitable for moorings are unlikely to show any chemical degradation as a result of exposure to marine growth.

Loss of strength due to hydrolysis in polyester ropes will not occur to an appreciable extent unless the temperature is greater than 30°C for long periods of time. HMPE is not subject to hydrolysis. Aramid yarns are more affected by hydrolysis and, although this will not be a problem in most circumstances, the possible loss of strength should be evaluated in consultation with the yarn supplier.

### 5.11 HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONS

#### 5.11.1 SNAP BACK AT FAILURE

Considerable energy will be stored elastically in the tensioned lines of a taut leg mooring and the safety implications for the crews and equipment of the floating platform if one of the lines was to break should be considered.

The problem should be considered both during the installation of the rope (see DPD-12.2.11) and when periodic adjustments of mooring line tensions (DPD-13.2) are made during the lifetime of the installation.

#### 5.11.2 ENVIRONMENTAL POLLUTION

Basic fibre materials do not give rise to any pollution problems.

### 5.12 EFFECT OF WATER DEPTH

At 2,000 meter depth, the hydrostatic pressure is 20 MPa, which is about 2% of the strength of polyester or nylon yarns and a smaller fraction of the strength of the other yarns. This should have a negligible effect on yarn mechanical properties, and would only be responsible for a small transverse strain and the accompanying axial strain on a rope. The weight of the rope will also cause changes in tensile stress along the rope, together with some bending of the mooring. At 2,000 meters, these effects are probably negligible, but, certainly for much greater depths, a proper analysis and experimental check is desirable.

**References**

- API RP 2SK (1997) "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)
- Aker Omega (1993) Deep water aramid mooring line Joint Industry Project Phase 2: Final Report.
- Fibre Tethers 2000 (1995) Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.
- Whitehill, A.S., and Whitehill, E.C. (1995) "Tension-tension fatigue test results for aramid and wire ropes"; Oceans '95; San Diego, California; Oct. 9/12 1995.

**Figures**

- Figure 5.3.1 Three stiffness values recommended for use in mooring analysis (based on polyester ropes).
- Figure 5.5.1 Tension-tension fatigue life of polyester ropes compared with values for steel chain and wire ropes from API RP 2SK (1997) (Figure 21)

**Tables**

Table 5.2.1

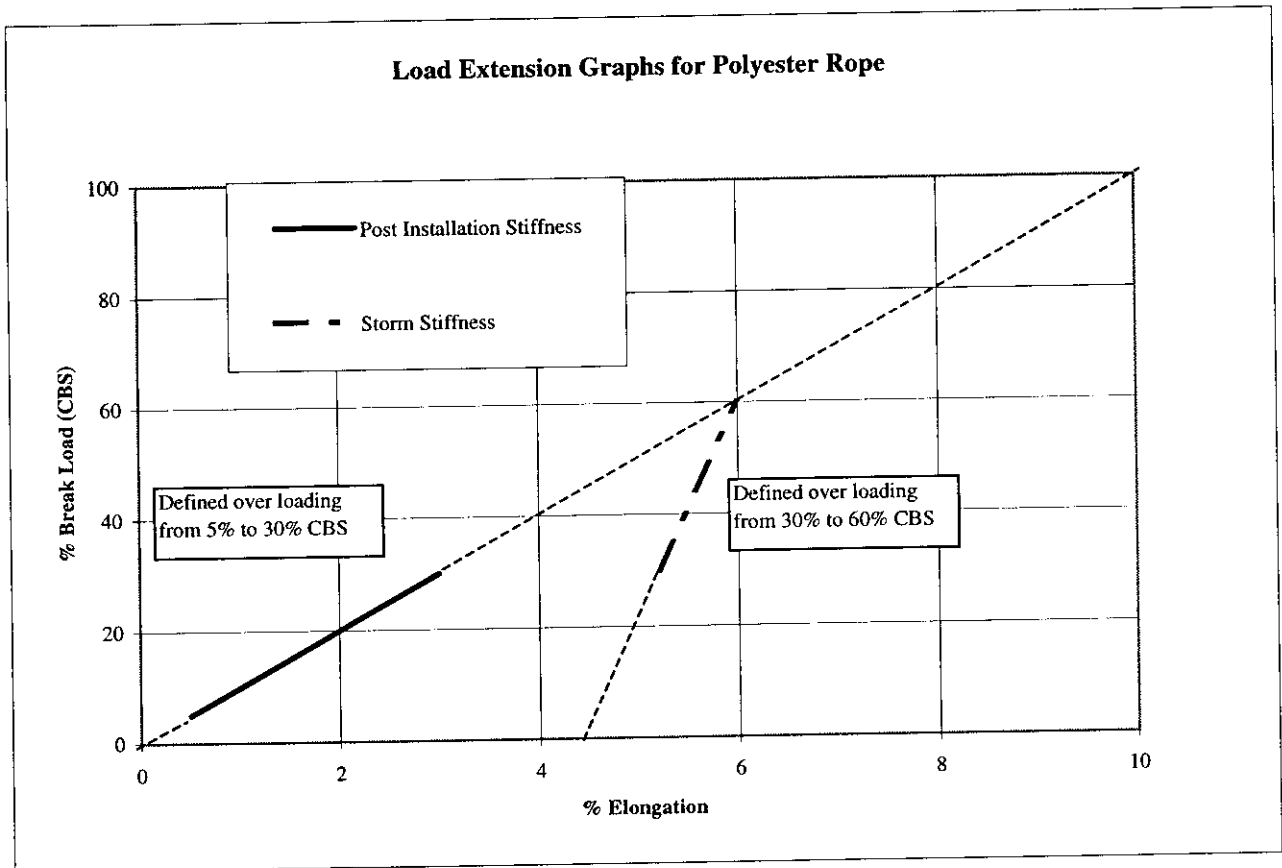
Table 5.3.1

Table 5.5.1

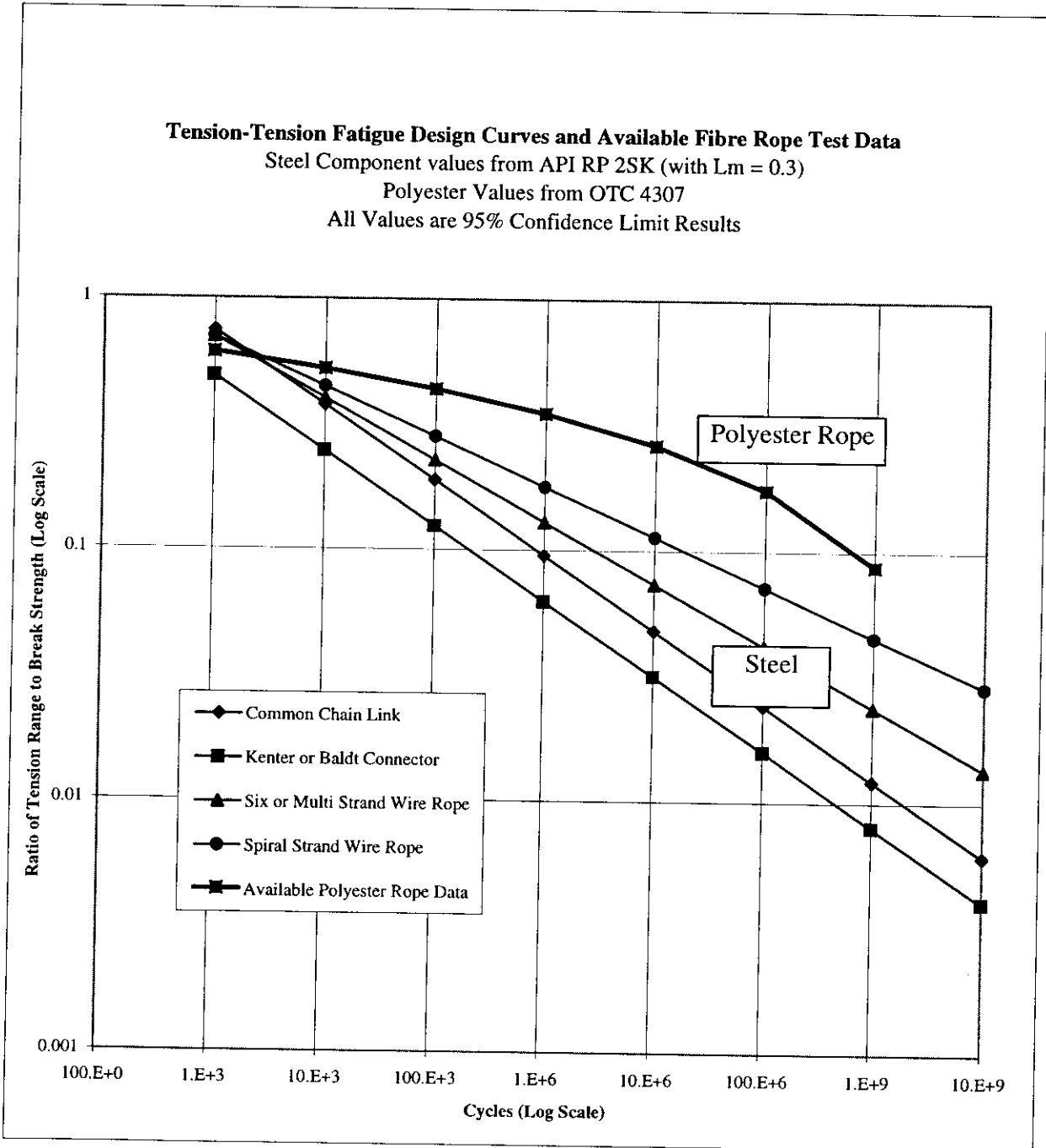
**Appendices**

Appendix 1 Terminology

**Figure 5.3.1**  
**Linearised Stiffness Limits Recommended for Use in Mooring Analysis of Polyester Mooring Lines**



**Figure 5.5.1**  
**Tension-Tension Fatigue Design Curves for Conventional Mooring Elements (as per API RP 2SK) compared with Available Test Data for Polyester Ropes**





r1va	DRAFT	Y.Luo	August 96
r1vb	edited	RWPS	September 96
r2va	edited	RWPS	March 97
r3va	new rev after SC#4	rwps et al	Oct 97
	plus final mods + add winches	rwps	
	plus final changes	rwps	
r4va	mods from scm5	rwps	
r4va	changes noted after TTI meeting	rwps	
r4vb	tti/nde	rwps	

DPD

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**PART B**

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## 6. OTHER MOORING LINE COMPONENTS

### 6.1 GENERAL

In addition to the fibre rope assembly considered in DPD-5 additional items will be required to complete the mooring system. These will include some or all of the following:

- anchors
- chain cable
- steel wire rope
- connecting hardware
- clump weights
- spring buoys
- pennant lines
- winches
- swivels
- installation buoys

As in conventional moorings items such as buoys, clump weights, chain and steel wire rope can be used to change the profile of the fibre mooring line and thus modify the load excursion characteristics.

All items in the moorings system should meet International Association of Classification Societies (IACS) requirements and be designed to meet their requirements for both maximum load and fatigue life.

The following guidance concerns the effect that these items may have on a fibre mooring line.

## 6.2 ANCHORS

Insert line catenary mooring systems in which there is no uplift at the anchor may use conventional anchor types such as drag-embedment anchors which are not designed to resist vertical forces.

Taut leg mooring systems require anchors capable of resisting vertical loads at the seabed.

The types of anchor available for resisting vertical loading include:

- piled anchors
- suction (or caisson) anchors
- Vertical Loaded Anchors

The selection of the type of anchor for fibre moorings depends on a number of factors such as soil condition, installation equipment and anchor positioning accuracy.

## 6.3 CHAIN CABLE

Design guidance for chain is provided by API RP 2SK Section 3.1.2. It is the traditional mooring line material and has been widely used for moorings in shallow to medium water depth. When it is used with fibre ropes, its heavy weight and high resistance to seabed abrasion make it the ideal component to be used near the touch down point. Such an arrangement can effectively prevent contact between the fibre rope and sea floor. The heavy chain also acts like a distributed clump weight to reduce the vertical load on the anchor. Chain is an inherently torque balanced construction. When taut it has a significant resistance to applied torque.

Chain cable may also be deployed for connection to the fairlead zone and used for winching operations.

When used with fibre rope care is needed to ensure that the chain does not damage the fibre rope during installation or operation.

## 6.4 STEEL WIRE ROPE

Design guidance for wire rope is provided by API RP 2SK (1997) Section 3.1.3. Wire rope has reduced weight in comparison to chain cable of the same strength and has reasonable resistance to handling and wear. The likely application of wire rope in fibre rope moorings is for the top connection to the platform thus allowing the fibre rope to remain clear of the fairlead and winching system. It may also be connected to anchors where it can cut into the soil more effectively than chain and thereby lower the uplift load applied by the soil reverse catenary.

Wire rope may have very different torque-twist characteristics from fibre rope and if used in series with a fibre rope the designer should ensure that the torque and twist limits for both the steel wire rope and the fibre rope, stated by the manufacturer, are not exceeded.

## 6.5 CONNECTING HARDWARE

Shackles, swivels and connection links are used to connect different line components. Design guidance is provided by API RP 2SK (1997) Section 3.1.7. These items should have adequate strength and fatigue reserve to maintain the integrity of the mooring line.

Swivels should only be used if they are consistent with the torque behaviour of the mooring line. Lines which develop significant torsion under axial loading should not be used with swivels which would release the twist and weaken the rope.

## 6.6 CLUMP WEIGHTS

Clump weights are considered in API RP 2SK (1997) Section 3.1.5. They provide a mass, usually deployed near the line touch down position, to modify the compliance of the mooring line. For fibre rope systems they are able to help reduce the vertical uplift load on the anchor and maintain axial tension in the leeward lines at large platform offsets.

## 6.7 SPRING BUOYS

Spring buoys are considered in API RP 2SK (1997) Section 3.1.6. They provide a buoyancy load at a point along the mooring line. This alters the catenary shape of the line and can be used to optimise a mooring system.

Spring buoys will have an effect on the dynamic behaviour of the mooring line and such effects should be studied during the mooring analysis. An appropriately deployed mid-water buoy may be able to reduce the line dynamic tension by altering the natural period of the mooring line.

Surface buoys used to provide temporary support for fibre ropes in advance of the arrival of the platform must be used with caution. If fibre ropes are left buoyed but un-tensioned their low weight in water can result in fibres going into compression as a result of modest environmental loading. Recommendations for the maximum number of low tension load cycles that various fibre materials can withstand are given in DPD-5.5.3 (Table 5.5.1).

## 6.8 PENNANT LINES

Pennant lines are required to mark anchors with surface buoys and are also used to recover the anchor when a mooring is retrieved. It must be strong enough to pull the anchor out of its embedded position. The length of line used should be kept short enough so that the bottom of the pennant does not drag over and damage the fibre mooring rope at the seabed.

Consideration should be given to the dynamic loads seen by pennant lines during the deployment of anchors. The use of heave compensation equipment may assist in minimising the dynamic loads seen in these lines.

## 6.9 WINCHES

Various types of winches are considered in API RP 2SK (1997) Section 3.2. They allow the line to be tensioned after the mooring spread has been connected. In fibre rope mooring systems it is likely that the tensioning of the line at the platform end will be done by winches acting on chain or wire rope in order to avoid the fibre rope passing over the rig fairlead.

The winch must have sufficient tensioning capacity to tension the lines in order to remove the effects of initial extension and provide the installation tension required by the mooring design. During the life of the platform the winches will be required to remove creep extension in the lines and restore the mooring system line pre-tensions. The mooring design may also require the winches for periodic removal, inspection and replacement of the lines.

### References

API RP 2SK (1997)

“Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures”; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)

### Appendices

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## 7. SITE AND PLATFORM DATA

### 7.1 SITE LOCATION DATA

Adequate details on the site location data are required for the mooring design.

Details required will include:

- water depth
- seabed geotechnical details
- locations of other equipment located on seabed (pipelines, well-heads, anchors etc.)
- other relevant operations in vicinity

The design process may also require data on the following topics which should be assembled from existing data bases or specially commissioned monitoring programmes:

- propensity for marine growth on mooring lines at the location and any available data on how this may be distributed over the depth of the water column
- experience of fish bite damage at various depths in the vicinity of the location (see Berteaux et al (1987))
- ambient water temperature which may influence hysteresis heating, creep and stiffness for certain materials.

### 7.2 SITE ENVIRONMENTAL LOADING DATA

The governing criteria for environmental loading is the same as used by API RP 2SK (1997) in which the mooring system is designed for the maximum design condition .

For Permanent Moorings the return period for the maximum design condition is specified as 100 years.

For Temporary Moorings the maximum design period is specified as 5 years in open locations and 10 years if adjacent to structures or pipelines.

Environmental data should be available for all the significant loading effects including where relevant:

- wave spectrum (wave height and associated periods)
- current (speed and direction at relevant water depths)
- wind (mean speed and direction and wind gust spectrum)
- tidal rise
- storm surge

The mooring system should be designed for the combination of wind, wave and current causing the extreme load in the design environment.

Where appropriate a risk analysis may be conducted to justify either longer or shorter recurrence intervals. The recommendations of API RP 2SK (1997) may be followed or alternative approaches may be adopted if they can be justified.

### 7.3 FISHBITE DATA

The intended platform location should be checked against the fishbite database held by Woods Hole Oceanographic Institute, MA 02543, USA. In areas where fishbite is perceived to be a major problem, rope sheath design should be chosen in accordance with the Woods Hole field trial results.

### 7.4 PLATFORM DATA

Adequate platform data is required for the mooring design.

Details to be defined include:

- Platform dimensions, windage, displacement etc.
- Platform Risers
- Platform thruster capability
- Platform mass and mass moments of inertia
- Positions and design of fairleads
- Location, number and operation of mooring line winches
- Load capacity of winches
- Platform operating draft and airgap
- Length and specification of on-board mooring lines
- Motion Response Amplitude Operators ( i.e. Transfer Functions) from model tests or diffraction analysis
- Wave Drift Force Coefficients from model tests or diffraction analysis
- Steady wind force coefficients (calculated or from wind tunnel tests)
- Steady current coefficients (calculated or from wind tunnel tests)

The designer needs adequate information on the platform based mooring system hardware which will influence the installation, inspection and retrieval of the mooring lines.

Platform crane data (capacity and reach) may be required in order to develop installation and retrieval of the mooring line.

**References**

API RP 2SK (1997) "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)

Berteaux, H.O., Prindle, B. and Putnam, S.S. "Monitoring fishbite activities and protecting synthetic fibre ropes used in deep sea moorings"; Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA.

Berteaux, H.O., and Prindle, B. (1987) "Deep Sea Mooring Fishbite Handbook"; Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA, 1987.

**Appendices**

None

**Figures**

None

**Tables**

None

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r3vb	revised by mrp/rwps + items from	jwsh	5.Nov.97
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## 8. MOORING DESIGN CRITERIA, ANALYSIS AND MODEL TESTING

### 8.1 GENERAL

Moorings analysis is required to compute the response of a mooring system to the given environmental and other loads.

The mooring analysis should predict the behaviour of a proposed fibre rope mooring design in certain critical conditions to determine if it complies with the acceptance criteria recommended by appropriate Rules and Guidelines.

As an alternative, or to complement the mooring analysis, model testing may be undertaken.

The following section is based on the recommendations given in API RP 2 SK (1997) - Section 6 (Design Criteria) and Section 7 (Mooring Analysis). Modifications needed to cover the case of fibre rope mooring lines are noted.

### 8.2 DESIGN CRITERIA

#### 8.2.1 GOVERNING CRITERIA

The criteria to be considered in the mooring analysis include those which are particularly important to fibre rope:

- Installation Pre-Tension
- Minimum Line Tensions (and number of occurrences)
- Creep Extension of Line during Lifetime
- Clearance of Fibre Rope from Seabed

and those which are general for all moorings:

- Platform Offset
- Maximum Line Tensions
- Anchor Holding Capacity
- Line Fatigue Life
- Allowance for Thruster Assistance

These items are discussed in more detail in this section.

8.2.2 BASIC CONSIDERATIONS (API RP 2 SK SECT. 6.1)

Due to the shortage of experience in using fibre rope moorings a dynamic mooring analysis is recommended for both permanent and temporary (mobile rig) moorings as shown in Table 8.2.1. Dynamic analysis should include both

- dynamics of the platform in both wave and low frequency regimes
- dynamics of the line in order to determine both the maximum and minimum tensions

Table 8.2.1

Analysis Types Recommended

Type of Mooring	Analysis Method	Condition to be Analysed
<b>Permanent Mooring :</b>		
• final design	dynamic	intact/damaged/transient
• fatigue design	dynamic	intact
<b>Temporary (Mobile) Mooring:</b>		
• clear of other structures	dynamic	intact/damage
• mooring lines over pipeline	dynamic	intact/damaged
• next to other structures	dynamic	intact/damaged/transient

8.2.3 OFFSET (API RP 2 SK SECT. 6.2)

The method of combining offsets given by API is recommended for use with fibre rope mooring systems.

The offset limits defined by the operational requirements of the platform due to limitations imposed by the drilling and production risers will define the allowable offsets for the mooring system.

Advice on appropriate limits for riser offset should be obtained from riser manufacturers.

8.2.4 LINE TENSION (API RP 2 SK SECT. 6.3)

The method of combining tensions given in API is recommended for use with fibre rope mooring systems.

The choice of tension limit, as a percentage of the rope's certified breaking strength (CBS), may be determined by requirements of the Operator, Certification or Regulatory Authority.

**8.2.4.1 Maximum Line Tension**

A discussion of the various values of maximum tension limits that are currently being proposed is contained in EC-8.2.4. On the basis that fibre ropes and wire ropes can be considered as comparable the table of allowable tension limits suggested by API (see Table 8.2.2 below) may be used unless Operators, Certification or Regulatory Authorities have other requirements.

**Table 8.2.2****Recommended Maximum Tension Limits**

Condition	Analysis Method	Maximum Tension Limit (Percent of CBS)	Equivalent Factor of Safety
Intact	Dynamic	60%	1.67
Damaged	Dynamic	80%	1.25
Transient	Dynamic	95%	1.05

**8.2.4.2 Minimum Line Tension**

As discussed in DPD-5.5.3, axial compression fatigue may occur after an excessive number of cycles with low minimum tension. The minimum tension value should be calculated. If this is less than the current guideline of 5% CBS load for polyester ropes and 10% CBS load for higher modulus ropes, an axial compression fatigue analysis as described in DPD-8.2.9.3 should be carried out.

**8.2.5 STATISTICS OF PEAK VALUES (API RP 2 SK SECT. 6.4)**

The method of defining and using statistics of peak values given in API is recommended until more statistical information is available.

**8.2.6 LINE LENGTH (API RP 2 SK SECT. 6.5)**

The selection of the design line length is critical for deepwater fibre mooring systems where the stiffness characteristics of the moored platform depend on the length chosen.

The extension at installation and possible additional bedding-in and creep extension during the mooring lifetime must be allowed for in the design analysis so that the top end of the insert fibre rope is always clear of the platform fairlead. The highest level of the installed fibre rope should be at a depth where it is clear of mechanical damage from workboats and surface marine activity, sunlight penetration and salt encrustation. Design for creep response is considered in DPD-8.5.

If additional short line lengths are provided for mid-life performance testing (see DPD-13.3.3) these should be located at the end adjacent to the platform fairlead allowing removal to shorten the line length if unanticipated extension occurs (see Figure 8.2.1).

### 8.2.7 ANCHOR HOLDING CAPACITY (API RP 2 SK SECT. 6.6)

The comments in API on anchors are relevant for fibre as well as conventional steel mooring lines except that taut leg mooring systems will require anchors able to resist vertical as well as horizontal loads.

Conventional drag embedment anchors have only a limited uplift capacity and may need significant amounts of seabed chain and clump weights in order to operate within their design envelope.

The recently introduced types of Vertical Lift Anchor (VLA) may be suitable for use with fibre rope mooring systems. The capabilities of these anchors are considered in API RP 2 SK Appendix B.8 (1997).

Conventional Pile Anchors may be designed to resist both horizontal and vertical load and are suitable for use in fibre rope mooring systems. Methods of design are provided in API RP 2A (1993) "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms".

Caisson Foundation or Suction Anchors can be designed to resist both horizontal and vertical loads and are suitable for use in fibre rope mooring systems.

API recommend that a mooring test load of 100% of the maximum storm load (determined by dynamic analysis for the intact case) should be applied to each line. This is principally done in order to confirm the holding capacity of embedment type anchors. Where such loading is required it may in practice become part of the minimum installation tensioning routine for the fibre rope component of the line.

For new anchor types and temporary moorings special consideration may be needed to determine the load that should be used for testing the anchor. The practicality of undertaking test loadings of the mooring system may depend critically on the winching capacity of the platform or installation vessel.

### 8.2.8 THRUSTER ASSISTANCE (API RP 2 SK SECT. 6.7)

The recommendations given by API RP 2SK (1997) for the effective thrust available to reduce mooring line loads may be used for fibre rope mooring systems.

### 8.2.9 FATIGUE LIFE (API RP 2 SK SECT. 6.8)

#### 8.2.9.1 Tension-Tension Fatigue

In general the data for fibre ropes suggests that under tension-tension fatigue conditions fibre ropes perform at least as well as or better than steel wire ropes. Fibre ropes do not suffer seawater corrosion as does steel and therefore are free from fatigue corrosion problems.

As recommended in API RP 2SK fatigue design is required for permanent moorings only. A predicted mooring component fatigue life of three times the design service life is recommended.

The fatigue analysis should also take account of the fatigue strength of other elements in the system (i.e. Chain, Kenters, Shackles and wire rope) which may have lower fatigue strengths and therefore be dominant in a fatigue design.



**8.2.9.2 Bending-Tension Fatigue**

There is little information with regard to bending-tension fatigue of fibre ropes, although this is likely to be less severe than for steel wire rope. It is important that the fibre rope mooring be designed such that potential for bending fatigue is minimised. It is recommended that fibre ropes mooring lines are not permanently deployed around sheaves or fairleads until sufficient bending fatigue and bending tension fatigue data is available.

Bending fatigue may also occur in fibre ropes close to terminations or other discontinuities in the mass or drag diameter of the mooring line. The dynamic behaviour of the line (particularly at the end close to the platform where the largest dynamic movements will occur) must be carefully considered to determine if significant line bending is present.

**8.2.9.3 Axial Compression Fatigue**

The number of cycles with minimum tension below the guidelines of 5% CBS for polyester ropes and 10% CBS for higher modulus ropes, as suggested in DPD-5.5.3, should be calculated. The total number of cycles below these levels should not exceed the values shown in Table 8.2.3

**Table 8.2.3**

**Maximum Recommended Cycles At Tensions Below The Minimum Value**  
**(provisional recommendation)**

<u>Yarn Material</u>	<u>Maximum Recommended Low-Tension (Cycles)</u>
polyester	100,000
HMPE	40,000
aramid	2,000

**8.3 MOORING ANALYSIS****8.3.1 DESIGN ASSESSMENT**

The design assessment process should use analysis tools to determine the values or characteristics of the mooring system during its design life and compare them with the criteria established in DPD-8.2.

If any of the design criteria are not satisfied, the mooring configuration should be modified and the design process repeated, or operational procedures adjusted until a satisfactory solution is obtained.

The analysis tools suitable for use are considered below.

### 8.3.2 BASIC CONSIDERATIONS (API RP 2 SK SECT. 7.1)

Three categories of environmental effects should be considered:

- Steady state forces (current, mean wind, mean wave drift force)
- Low frequency vessel motions due to wind and waves
- Wave frequency vessel motions

Thruster assistance may be considered as detailed in DPD-8.2.8

Methods which account for the restoring forces provided by riser systems may be used.

The approach for determining the **extreme response**, and **fatigue damage** of fibre ropes is based on API RP 2SK. In addition a method for designing for **creep response** is provided in this DPD.

### 8.3.3 DYNAMIC ANALYSIS (API RP 2 SK SECT. 7.2)

Detailed methods such as dynamic analysis are recommended for determining the behaviour of fibre rope moorings. An analysis of both Platform Dynamics (including the effects of slow drift behaviour) and individual Line Dynamics (particularly the maximum and minimum tensions in the windward and leeward lines) is required.

### 8.3.4 DYNAMIC ANALYSIS NON-LINEARITIES (API RP 2 SK SECT. 7.2)

#### 8.3.4.1 Fibre Rope Stiffness

As noted by API the axial stretching of fibre lines is significantly different than for steel chain or wire rope as it is generally non-linear. The load extension characteristics of fibre ropes are considered in DPD-5.3 and lead to the recommendations to adopt upper and lower bound linear elastic stiffness for analysis purposes.

#### 8.3.4.2 Changes in mooring geometry

Large changes in the shape of the mooring line will cause geometric non-linearity. For taut leg moorings in deep water it is unlikely that these shape changes will be significant but for fibre rope insert lines with large catenary length components this geometric change should be accounted for.

#### 8.3.4.3 Fluid Loading

The dynamic analysis undertaken should account for the relevant lateral fluid loads applied to the line. The most important non-linearity that should be considered is the fluid drag on the line. This depends on rope diameter, shape, surface roughness and whether the line is subjected to vortex induced vibration.

Marine fouling is location specific and will affect drag. Any increase in drag will increase current loading and damping of platform dynamics. This will in turn influence peak platform motions and line loads.

The available evidence (see EC-3.3.6) suggests that the maximum diameter increase due to marine fouling does not exceed initial rope diameter. Where drag caused by marine fouling is judged to be of serious concern, consideration should be given to jacketing in materials inherently resistant to marine fouling (such as Low Density Polyethylene) and to incorporation of anti-fouling additives in the jacket.

For lines not subject to vortex induced vibration a drag coefficient value of  $C_d = 1.2$  is commonly used.

If vortex induced vibration is present this will increase the effective diameter of the line and this effect should be accounted for in the analysis. A common method of doing this is by using a  $C_d = 1.8$  in such cases in analogy with wire rope mooring analysis. (See DnV Posmoor (1996)).

#### **8.3.4.4 Bottom Effects**

For taut line systems with little or no bottom line in contact with the seabed this non-linear aspect will not exist. For insert fibre lines with large seabed catenary lengths it needs to be approached in the conventional way outlined by API RP 2SK (1997).

## **8.4 EXTREME RESPONSE**

### **8.4.1 DYNAMIC ANALYSIS (API RP 2 SK SECT. 7.2)**

Under extreme response the following should be checked:

- Vessel Excursions
- Line Touchdown
- Maximum and Minimum Line Tensions
- Anchor Loads
- Number of occurrences of Minimum line tension

The procedure outlined by API should be used to determine line loads and vessel excursions. For fibre rope mooring systems both frequency domain and time domain analyses methods are acceptable in principle although for systems that are highly non-linear a time domain approach may be required to provide adequate accuracy.

Note that the vertical stiffness of a fibre rope mooring system may have a significant effect on the vertical axis motion response characteristics of the vessel and this should be taken into account in a dynamic analysis. Thus the dynamic analysis method must be capable of providing the vertical motions at the fairleads.

A consistent method of combining line tensions and vessel offsets should be used such as that proposed by API.

The mooring system analysis should incorporate the line load-extension characteristics as described below.

#### **8.4.1.1 Upper Limit Stiffness Calculation**

The storm stiffness, as defined in DPD 5.3.2, should be used to determine as the upper bound axial stiffness. This value will be used in the analysis in order to determine the maximum and minimum mooring line loads and check whether they are within the limits defined by the criteria.

The maximum tension limits are given in Table 8.2.2.



In the case of minimum tensions a guideline minimum tension is provided in DPD-8.2.4.2 and the number of loading cycles below that level should not exceed the value specified in Table 8.2.3. The loading cycles experienced both prior to installation (for instance during the pre-deployment of a fibre mooring line) and throughout the design life of the platform must be considered.

#### 8.4.1.2 Lower Limit Stiffness Calculation

The post-installation stiffness, as defined in DPD 5.3.2, should be used to determine the lower bound axial stiffness which is used to estimate the excursions of the platform and to confirm that these are acceptable for the platform's excursion criteria.

The use of the post-installation stiffness provides a conservative estimate of the lower limit stiffness of the mooring following the minimum installation routine. If the limiting excursion criteria are satisfied with this calculation it indicates that even when the fibre mooring lines have only been subjected to limited levels of strain conditioning they result in an adequately stiff mooring assembly. If the riser criteria cannot be satisfied using this stiffness value the analysis should be repeated using an intermediate stiffness value, as defined in DPD 5.3.2. It will then be necessary to demonstrate either:

- that sufficient additional tension cycling is applied following installation to achieve the required intermediate stiffness

or

- that the platform excursions are still within the criteria during the period of time while the line stiffness is developing from the Post-Installation value to the intermediate stiffness value. Such an increase in stiffness can be expected under the environmental loadings operative during this period, i.e. under a smaller environmental loading than that for the 100 year extreme storm.

#### 8.4.1.3 Mooring Sensitivity to Line Stiffness

The upper and lower stiffness mooring analysis should be examined in order to establish the sensitivity of the mooring to changes in axial stiffness values. An assessment should then be made of whether the upper and lower bound stiffness values used in these analyses are adequate to identify the maximum and minimum line loads and platform excursions. Information from this sensitivity appraisal may be valuable in further defining the axial stiffness characteristics which are required from the specified fibre mooring line.

### 8.4.2 TRANSIENT ANALYSIS (API RP 2 SK SECT. 7.3)

Methods of undertaking transient analysis are provided in the API document. These methods may be used for fibre mooring systems.

The transient analysis should consider upper and lower bound line stiffnesses in order to determine the critical cases for both line tension and platform excursion.

### 8.4.3 HULL SET-DOWN AND AIR-GAP

The effect of taut leg mooring systems on hull set-down and air gap should be considered in the design process.

## 8.5 CREEP RESPONSE

### 8.5.1 LINE CREEP ELONGATION: RETENSIONING

An estimate of line non-recoverable extension is required in order to check that the upper connector of the fibre rope is kept sufficiently clear of the platform fairlead and below water level as specified in DPD-8.2.6

The maximum shortening required in the upper chain connector line during the platform lifetime as a result of line extension consists of the following components:

- fibre line bedding-in experienced during installation and subsequent use.
- fibre line material creep in use.

For aramid and polyester moorings operating in water temperatures below 20°C the following procedure for estimating the required line shortening is recommended:

- Determine the bedding-in component using test routines such as described in DPD-9.2.3. For conservative estimates, these should be based on the maximum design line load, i.e. (CBS + safety factor).
- The line material creep over a 20 year design life can be taken as no more than 1.2% of line length.

For other materials and constructions or where more precise values of creep are required the analytical techniques set out in EC-5.3.4 and EC-8.5.1 may be adopted.

### 8.5.2 LINE CREEP RUPTURE

As indicated in DPD 5.2.4 creep rupture should not be a hazard in polyester and aramid lines under the loads expected in deepwater moorings. The conditions of use of HMPE ropes should be reviewed in consultation with the yarn supplier and rope maker in order to ensure that there is no possibility of creep rupture.

## 8.6 FATIGUE ANALYSIS

### 8.6.1 BASIC CONSIDERATIONS (API RP 2 SK SECT. 7.5)

A recommended procedure for a detailed tension-tension fatigue analysis is described in the API document. This may be adopted for fibre rope mooring systems.

Due to the lack of data on bending-fatigue performance this mechanism should be avoided by designing systems to avoid fibre ropes being bent around sheaves.

Axial compression fatigue may be avoided during design by adopting the minimum line tensions indicated in DPD-8.2.4.2 or by limiting the number of minimum tension cycles to less than those indicated in Table 8.2.3.

In order to provide a conservative estimate of mooring line stress range the upper bound axial line stiffness (Storm Stiffness defined in DPD-5.3.2) should be used in the dynamic analysis of the mooring lines fatigue loads. This stiffness value can be determined experimentally as detailed in DPD-9.2.3.

### 8.6.2 TENSION-TENSION FATIGUE DESIGN CURVES

Fatigue data for fibre ropes is limited. The only data for large size ropes relates to tension-tension fatigue loading.

In the absence of more accurate data the nominal tension fatigue lives of fibre rope assemblies can be based on the T-N curve presented in Figure 8.6.1 which was justified in DPD-5.5.2 and is based on the API recommendations for spiral strand steel wire rope. The form of the curve is given by the following equation:

$$N \cdot R^M = K$$

or

$$\log(N) = \log(K) - M \cdot \log(R)$$

where:

N = number of cycles

R = ratio of tension range (double amplitude) to certified breaking strength

M = slope of T-N curve

K = Intercept of T-N curve

For polyester, aramid and HMPE ropes in parallel yarn, parallel strand and low-twist wire rope constructions the following values may be used:

$$M = 5.05$$

$$K = 166$$

As in the case of chain and wire ropes, the mean tension level may have some effect on the fatigue life of the rope. For fibre rope mooring lines this effect can be analysed when test information becomes available.

## 8.7 MODEL TESTING

### 8.7.1 BASIC CONSIDERATIONS (API RP 2 SK SECT. 8.1)

Recommendations for undertaking model tests are provided in the API document. These may be adopted for fibre rope mooring systems.

Methods currently under consideration for model testing of platforms in very deep water include:

- testing in conventional test tanks at very small scale
- testing of moderate scale models in very deep test locations such as fjords and lakes
- hybrid model testing and computer modelling

For fibre moorings the particular feature that the model tests should represent is the non-linear load extension behaviour of the lines.

In practice it may be very difficult to provide a model mooring line system with the correct representation of line stiffness and thus appropriate linear springs may have to be inserted to model the system. A range of stiffness values could be examined covering the predicted stiffness characteristics of the design fibre rope.

Both upper and lower bound line stiffnesses should be considered in order to determine critical model behaviour.

### References

- API RP 2SK (1997) "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)
- DNV Posmoor (1996) DNV Rules for Classification of Mobile Offshore Units; Special Equipment and Systems, Additional Class; Part 6 Chapter 2 Position Mooring (POS MOOR); January 1996
- FPS-2,000 JIP (1992) Mooring Line Damping - Summary and Recommendations. Part 1.5 of FPS-2,000 Mooring and Positioning JIP
- API RP 2A (1993) "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms"; 20th edn; American Petroleum Institute; July 1, 1993

### Appendices

None

### Figures

Figure 8.2.1

Figure 8.6.1

### Tables

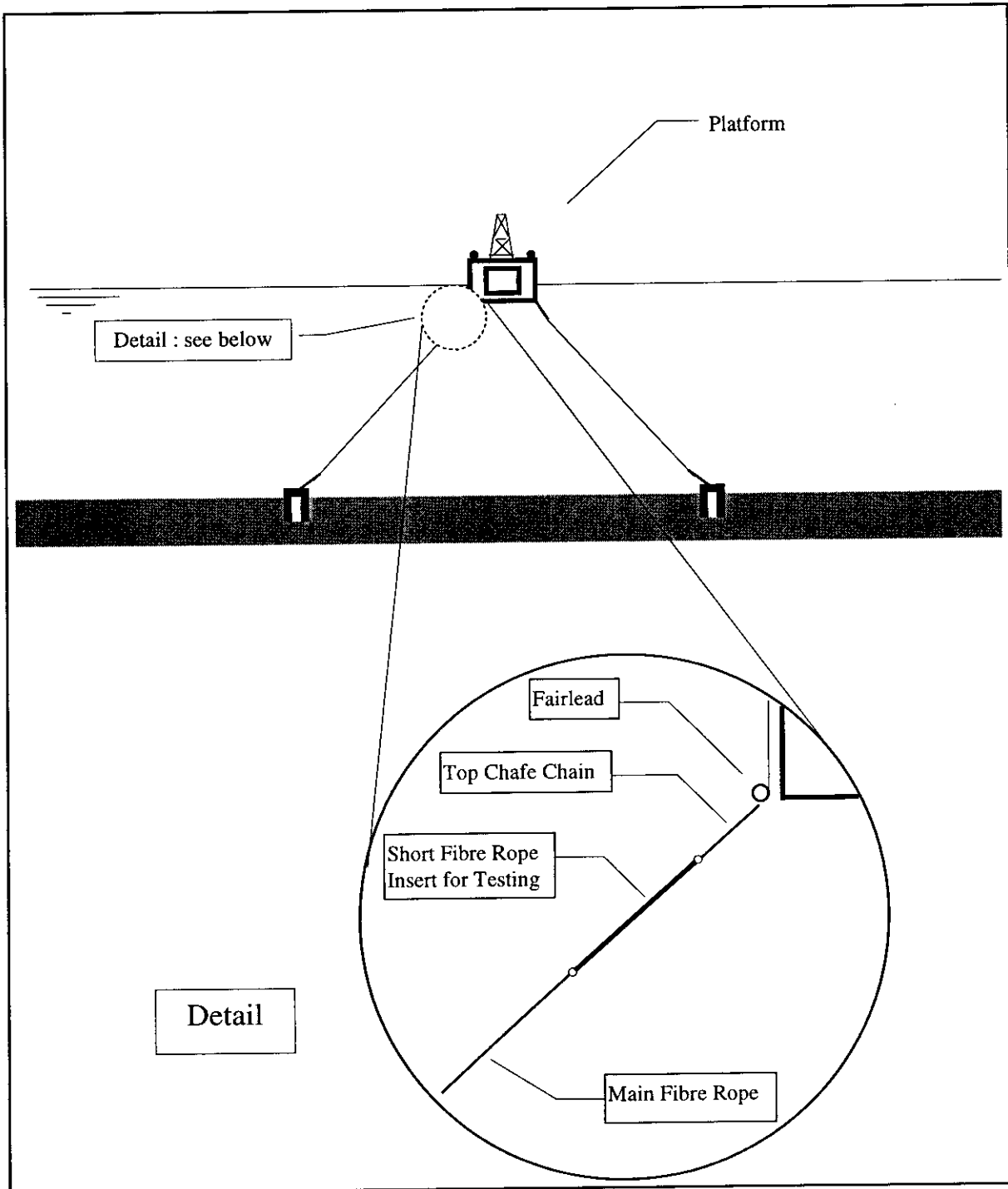
Table 8.2.1

Table 8.2.2

Table 8.2.3

Figure 8.2.1

Proposed Location of Short Test Lengths in Fibre Rope Mooring System



**Figure 8.6.1**  
Recommended Design Tension-Tension Fatigue Life Curves for Fibre Ropes  
(Polyester)

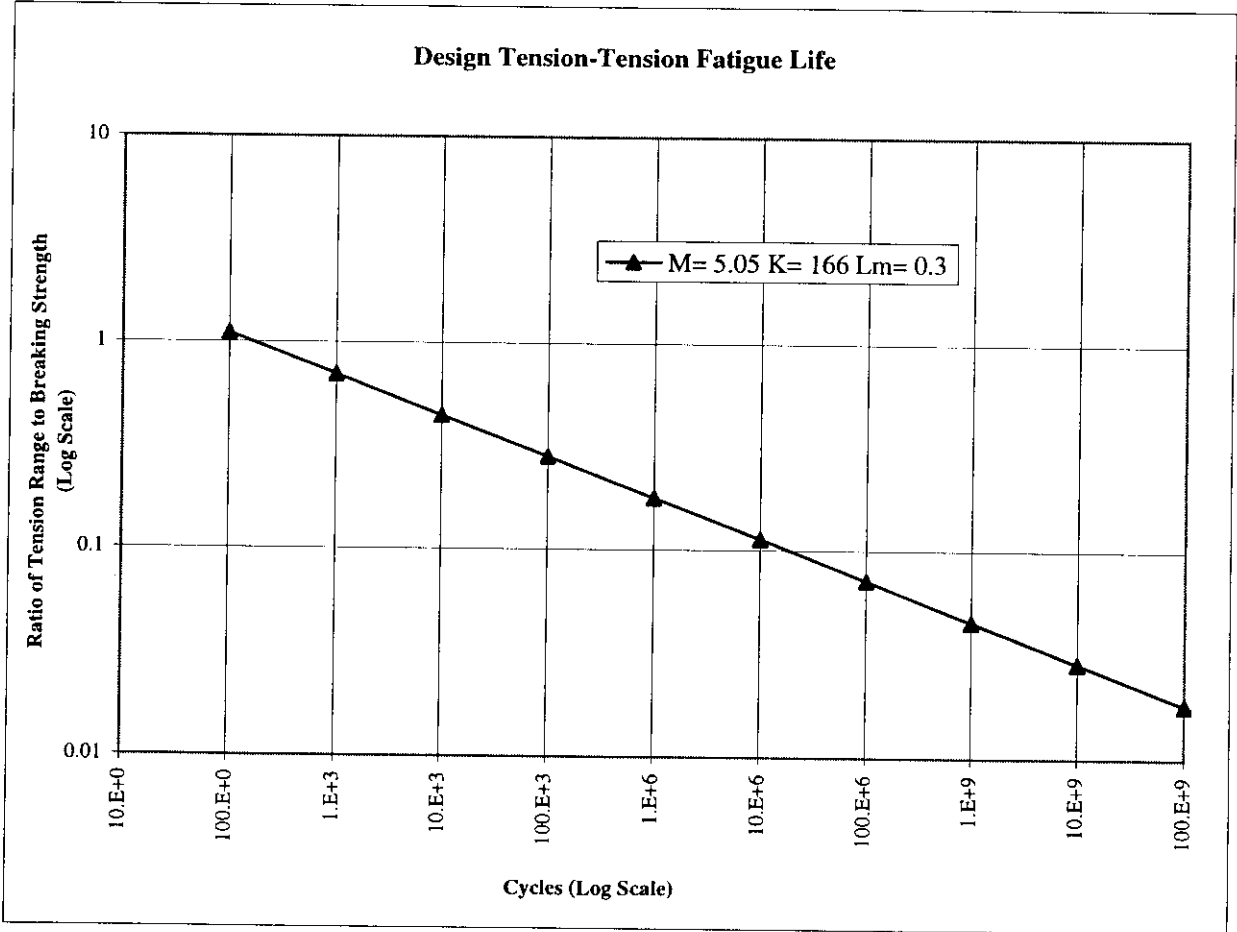
$L_m$  = Ratio of Mean Load to Break Strength (CBS)

Note that API RP 2SK provide curves for Steel Wire Spiral Strand and Six/Multi-Strand Rope that are functions of the mean load value  $L_m$ . For Fibre Ropes insufficient data currently exists for this effect to be defined. However the recommended design curve for Polyester Fibre Ropes is taken as the API recommended curve for Spiral Strand Rope with  $K=166$  (i.e.  $L_m=0.3$ )

Equation of Line:

$\log(N) = \log(K) - M \cdot \log(R)$

where  $N$ = number of cycles  
 $R$ = ratio of tension range (double amplitude) to nominal breaking strength (CBS)  
 $M$ = slope of T-N curve  
 $K$ = intercept of T-N curve



r2va	New Draft from	MRP	11 Mar 97
r2vb	Mod following changes by J added by	RWPS/JCT	21 Mar 96
r3va	new rev after SC#4	rwps	20 Oct 97
	plus reference and fig no. changes	rwps	12.Nov.97
	final changes	rwps	16.Nov.97
r4temp	changes by TTI	tii	17.Feb.98
r4va	edits	rwps/spo	27 Feb 98
	part updating	rwps	19 May 98
	changes noted after TTI meeting	rwps	21 May 98
	mods in TTI fax dated 21/5/98	rwps	22 May 98
	add Class Society Refs	rwps	5 May 98
r4vb	tii/nde	rwps	12 June 98
r4vb	tii/nde	rwps	15 June 98

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**9. SPECIFICATION**

9.1 INTRODUCTION

9.1.1 GENERAL

It is assumed that purchasers will wish to write an initial specification for tendering purposes including, but not limited to, the generic fibre material type, rope certified breaking strength (CBS), overall length, the limiting extension and modulus values, marking, packing and shipping requirements. Following discussions with potential suppliers of products satisfying these requirements a final specification will be issued specific to the chosen fibre rope performance.

This section provides best current guidance available for the specification of the properties of rope assemblies, made in the materials and constructions described in DPD-2 and DPD-3, which are primarily intended for use as deepwater fibre moorings.

Other relevant information may be contained in documents issued by Certification Authorities for testing critical parameters (e.g. ABS (1998), Bureau Veritas (1997), DnV (1998), Lloyds (1997)).

### 9.1.2 REQUIREMENTS

No methods have yet been agreed for testing many of the critical parameters for deepwater fibre rope assemblies. Until such guidelines are available designers may wish to specify the provisional test methods set out below.

No performance criteria have yet been agreed for many of the critical parameter for deepwater fibre rope assemblies. Until such criteria are available, designers may wish to consult the results obtained in Joint Industry Studies or test programs.

In setting out these specifications it is assumed that Rope Manufacturers will establish complete and detailed documentation of their deepwater fibre mooring assemblies. As set out in DPD-11.2 this should cover design, material and manufacturing specifications of the assembly and its constituent parts.

It is further assumed that the important properties of the production mooring assemblies have been determined through tests conducted on a sample prototype rope of the given material, construction and size.

Nothing in the specification, however, shall be construed to preclude the use of rope designs, materials, methods or techniques which have been developed and demonstrated by the Manufacturer and agreed to by the Purchaser.

If a Purchaser, when purchasing fibre rope assemblies, wishes these Specifications to be applicable, he should specify that they are to be applicable and specify the certified breaking strength (CBS) required.

## 9.2 SPECIFICATION AND TEST METHODS

### 9.2.1 ROPE ASSEMBLY LENGTH BETWEEN BEARING POINTS

The purchaser should specify the length of rope required either before installation at reference tension or in the installed assembly at a specified tension load.

The reference tension is that non-zero tension used to straighten out and so define the length of a rope. For ropes of the length and diameter required for FPS moorings the reference tension may be set at 2% CBS rather than the lower levels set out in ISO 2307 Annex A (1990).

The length of rope produced can be determined using data on the unit rope weight also derived in accordance with EN 919 (1995). (see DPD-11.3.6 and DPD-11.3.10)



### 9.2.2 CERTIFIED BREAKING STRENGTH OF THE TERMINATED ROPE ASSEMBLY

The break strength tests should be conducted on the prototype ropes, to the method set out in the OCIMF document on Prototype rope testing, Chapters 7.1/7.3 and 8.1/8.3. (OCIMF (1987))

For each separate material and construction, a minimum of 3 break tests shall be conducted on the prototype rope, all of which should exceed the CBS. The break tests should be conducted in the wet state.

### 9.2.3 ROPE IN SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES

In order to determine rope elongation properties, prototype rope assemblies of the chosen rope in lengths exceeding 5 metres should be made up and tested to indicate likely properties in use. A minimum of one prototype rope assembly should be tested for elongation properties. Tests on ropes should be conducted in the wet condition.

The test sequence should be selected to provide estimates of the following rope properties:

- post-installation stiffness, after a loading sequence approximating the minimum installation routine, as defined in DPD 12.5.4
- storm stiffness, after a loading sequence corresponding to expected storm conditions
- intermediate stiffnesses at any required intermediate loading histories.
- unrecovered elongations in selected cyclic loading sequences

There are not, at present, agreed specified procedures for carrying out such tests so as to obtain the best estimates of the above properties. Test sequences which have been suggested or are the subject of current tests are given in Appendix 3 "Proposed Prototype Rope Testing Procedure".

Alternatively, the loads, load rates and relaxation times may be defined by the purchaser for the project in question.

### 9.2.4 TENSION-TENSION FATIGUE LIFE

If sufficient information is not available from existing sources, including test reports from Joint Industry Studies and field data, the purchaser should specify additional fatigue testing requirements for mean load, load range and frequency appropriate to the application.

### 9.2.5 ROPE JACKET

The Purchaser may specify the type and quality of rope jacket: in particular requirements for exclusion of particulate matter, and for free flooding of the rope structure.

If not specified the Manufacturer shall propose the type and quality of chafe protection for the Purchaser's approval, bearing in mind the factors concerning protective rope jacket constructions described in DPD-3.3.

### 9.2.6 OVERALL FIBRE ROPE ASSEMBLY

The Purchaser shall agree with the manufacturer a specification for the manner of assembly and the type of end fitting.

If the rope assembly is of an unusual nature, the Purchaser should completely specify and describe the manner of assembly.

Drawings of the rope assembly may be provided as part of the order. If not they should be provided by the Manufacturer.

If there is a conflict between the drawings and the specification, the Manufacturer should contact the Purchaser.

### 9.2.7 SPLICED EYES OR BUTT SPLICES

The Manufacturer or assembler of the rope shall follow the splicing procedures in the applicable Rope Manufacturing Specification.

The Purchaser may specify the type and dimensions of hardware and the quality and strength of the materials used. If not specified, the Manufacturer shall propose the type and quality of hardware, suitable for the intended service, for the Purchaser's approval. If non-metallic hardware is specified the designer should check that heat build-up at the back of the eye during the lifetime is not sufficient to be detrimental to the behaviour of the assembly.

Unless otherwise specified, the eye size shall be determined as the dimension from the inside back of the eye to the crotch of the eye with the two legs of the eye close together as shown in Figure 9.2.1. The tolerance shall not be less than the stated dimension nor more than 20% greater than the stated dimension.

Hardware may take the form of one piece fittings or of separate bushes and shrouds. In the latter case the bushes acts as the interface between the rope eye and the connecting shackle pin. The shroud, which fits over the bush, retains the eye in position preventing asymmetric loading and protecting against abrasion. The bush should be a neat fit on the shackle pin and the root diameter should be specified. The crush resistance of the bush material should be such that it can withstand the CBS of the rope assembly. This should be demonstrated through prototype testing.

Hardware shall be free of sharp edges and rough surfaces which might cut or abrade the rope or chafe protection. The mouth of a thimble shall be flared and rounded to reduce chafing. When the thimble is shackled to a chain, the thimble design shall have provision to prevent the shackle from moving forward and contacting the rope.

Unless otherwise specified, the load at which the thimble starts to yield shall be greater than the CBS of a single leg of the rope assembly. The strength of the thimble shall be demonstrated through testing of a prototype of a representative size no smaller than 96 mm diameter (rope size 12)

If not specified, the Manufacturer shall propose the type and quality of eye chafe protection for the approval of the Purchaser when offering the product (see DPD-4.2.3).

### **9.2.8 SOCKETS AND OTHER TERMINATIONS**

As an alternative to spliced eyes the rope assemblies may be fitted with socket terminations. These may be applied using cast resin cones, by the use of barrel-and-spike or by using a combination of these techniques. The choice of termination will, to a large extent, be dictated by the rope construction. The effectiveness of the termination will have been demonstrated through prototype testing.

The socket shall be designed to have a yield strength greater than the CBS of the fibre rope such that the connection pin can be removed and replaced without unreasonable application of force on completion of a breaking load test.

Socket design and material selection should address factors such as fatigue and corrosion to ensure that the termination is adequate for the lifespan of the mooring system.

Resin systems must be chosen with care to ensure chemical compatibility with the rope materials and suitability for prolonged sea water immersion.

The manufacturer should have detailed socketing procedures incorporated in the Fibre Rope Assembly Specification which match the procedures used for the prototype testing although the prototype work may have been carried out on dummy sockets with the same basket profile as production fittings.

### **9.2.9 IDENTIFICATION**

The Purchaser should specify the markings required where these differ from those set out in DPD-11.2.8.

### **9.2.10 BEND LIMITERS**

Bend limiters may be specified to ease the transition from the heavy, stiff end fitting to the lightweight, relatively flexible, fibre rope. (see DPD-4.2.4 and DPD-4.4.4).

### **9.2.11 PACKING**

The purchaser may specify the type of package on which the fibre rope assembly is to be delivered. This may well be governed by the size of the fibre rope elements or the installation technique to be adopted.

For extremely long lengths of large rope diameters it may be necessary to utilise cable laying techniques and for the rope to be laid into special storage tanks on a dedicated vessel.

In most situations however the rope assemblies will be supplied on reels. Logistics, installation techniques and economics will determine whether installation or transportation reels are specified.

Installation reels can be taken directly from the production facility to the installation vessel and used for deployment. In this case the purchaser must specify not only the dimensions of the reel but its strength and the winding tensions required to ensure trouble free installation.

Transportation reels are used for storage and transportation only, the rope subsequently being rewound onto a more substantial reel for installation. In this case the purchaser should specify the reel dimensions to suit the rewinding operation.

In both cases reels should be constructed with two compartments. The larger compartment to hold the major component of the rope length, the smaller one to hold the two ends of the rope complete with terminations. The reel should be large enough to accommodate the complete assembly without any portion protruding above a flange.

Reels should ideally be provided with lifting lugs on the outer flanges and spreader or lifting beams to facilitate handling by crane as illustrated in Figure 9.2.2.

Metal end fittings should be individually wrapped or otherwise kept separate to prevent chafing of any underlying fibre rope. The finished package should be securely wrapped with weather proof material and battens secured between the flanges.

Each reel should be clearly labelled to identify the contents.

### 9.3 PERFORMANCE CRITERIA AND TOLERANCES

#### 9.3.1 ROPE ASSEMBLY LENGTH BETWEEN BEARING POINTS

The tolerance on rope assembly length inspected in DPD-9.2.1 shall generally be set at +/- 1%

It is to be understood that the rope assembly length will change subsequent to measurement due to relaxation of the rope structure, reefing strains and changes in load, humidity and temperature during shipment and handling.

#### 9.3.2 CERTIFIED BREAKING STRENGTH OF THE TERMINATED ROPE ASSEMBLY

The Purchaser shall specify a required Certified Breaking Strength (CBS).

The CBS for rope assemblies of a particular material and construction and termination will have been derived from the prototype data, the Rope Design Specification and the Rope Manufacturing Specification.

At least three samples of the appropriate design rope size are to be used for prototype testing.

#### 9.3.3 ROPE IN-SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES

Performance criteria for service length and permanent elongation will be agreed between purchaser and supplier.

Values for Post-Installation and Storm stiffness will be made available for detailed design calculations. These stiffness values will be based on prototype ropes tested to an agreed routine (see, for example, Appendix 3).

**9.3.4 AXIAL COMPRESSION FATIGUE RESISTANCE**

In order to avoid axial compression fatigue, the general recommendation, given in DPD-8.2.9.3, is that ropes should not be exposed to low minimum tensions for more than a limited number of cycles. If ropes are predicted to be exposed to tensions below the guideline limit for more than the number of cycles specified in Table 8.2.3, the yarns selected for use shall retain 90% of their strength after testing in a restrained buckling test to the expected number of cycles, using test methods described in FIBRE TETHERS 2000 (1995).

**9.3.5 ROPE WEIGHT AND SIZE**

Rope core weight and size will be derived as in DPD-11.3.6.

Overall rope weight and size will be dependant upon the jacket design agreed between manufacturer and purchaser.

**References**

- American Bureau of Shipping (1998) "Guide for Synthetic Ropes in Offshore Mooring Applications"; Draft in Progress, 1998
- Bureau Veritas (1997) "Guidance Notes for Certification of Synthetic Fibre Ropes for Mooring Systems"; Document Reference NI 432 DTO R00 E, Bureau Veritas, Paris La Defense, 1997.
- Det Norsk Veritas (1998) "Certification of Offshore Mooring Fibre Ropes"; Certification Note 2.13; Draft in Progress, 1998
- FIBRE TETHERS 2000 (1995) "Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.
- ISO EN 919: (1995) "Fibre ropes for general service. Determination of certain physical and mechanical properties". BSI; 1995
- ISO 2307: 1990 Ropes - Determination of certain physical and mechanical properties". 2nd edition; 1990-09-15; ISO 1990
- Lloyds Register (1997) "Fibre Rope for Offshore Mooring Systems"; LR Report OS/TR/97008; Draft in Progress; December 1997
- OCIMF (1987) "Prototype rope testing". Published by Witherby & Co. Ltd, London on behalf of OCIMF; 1987

**Appendices**

- Appendix 3 "Proposed Prototype Rope Testing Procedure"

**Figures**

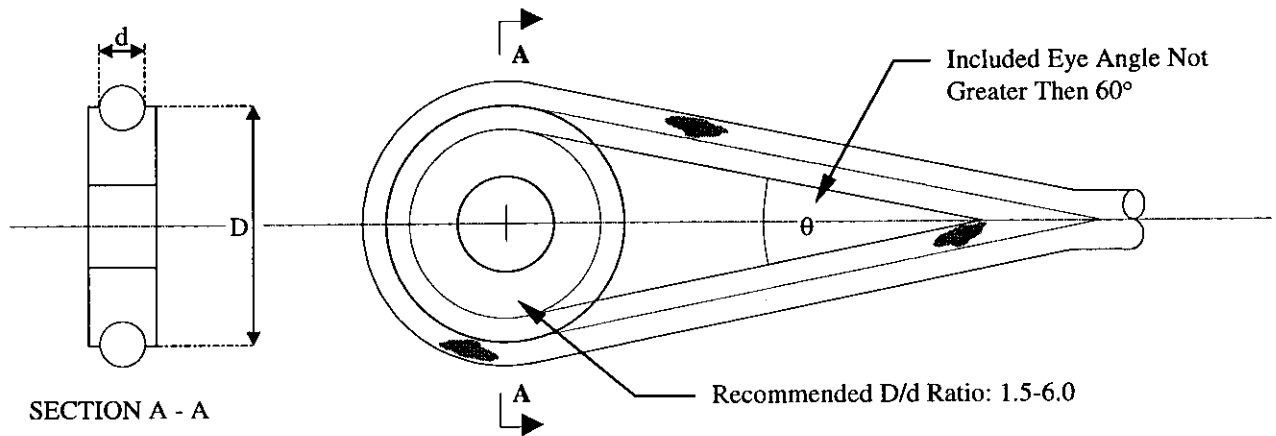
- 9.2.1 Eye-Splice Geometry
- 9.2.2 Lifting lugs and spreader beams for handling reels.

**Tables**

None

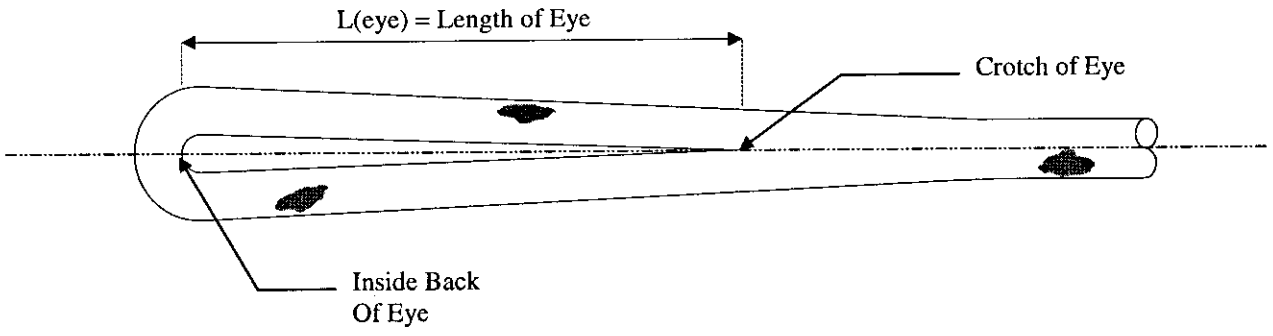
Figure 9.2.1

DIAGRAM OF EYE SPLICE SHOWING FEATURES AND TOLERANCES



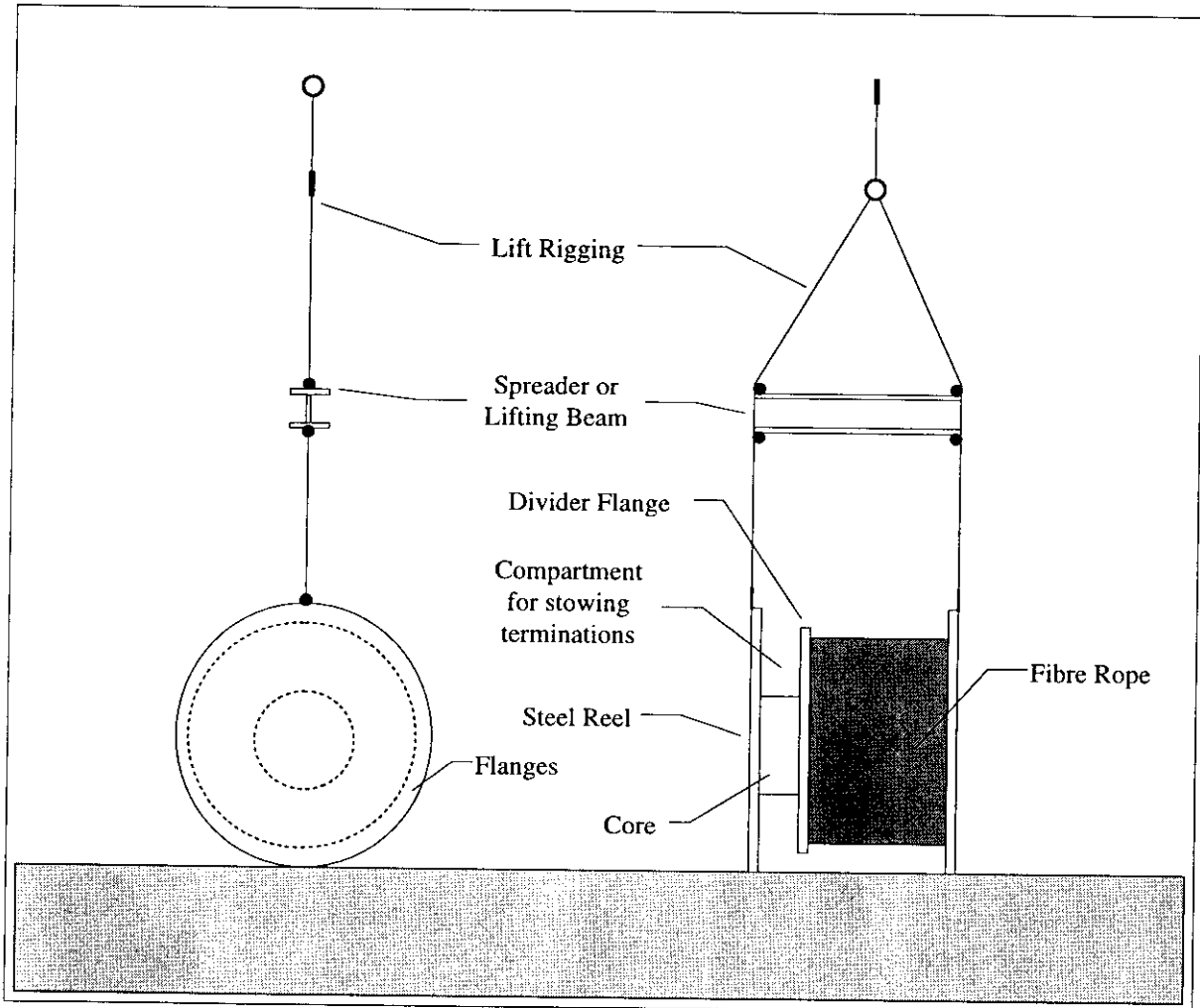
LIMITS ON D/d RATIO  
 $1.5 < D/d < 6.0$

LIMITS ON EYE ANGLE  
 $\theta < 60^\circ$



TOLERANCE ON EYE LENGTH  
 $(\text{DESIGN DIMENSION}) < L(\text{eye}) < 1.2(\text{DESIGN DIMENSION})$

**Figure 9.2.2**  
Typical Storage Reel and Lifting Arrangement





r2va	Orig Draft by	MRP	
	Drafts. by	MRP	
r2vb	Mod following changes by JY added by	RWPS/JCT	21 Mar 96
r3va	new rev after SC#4	rwps	20 Oct 97
	reduced - balance moved to EC	rwps	30 Oct 97
	plus editorial update	rwps	12.Nov.97
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**10. MANUFACTURE**

**10.1 GENERAL**

The Manufacturer shall provide a rope product which meets the requirements of the Rope Design Specification and the rope shall be constructed in accordance with a Rope Manufacturing Specification (see DPD-11.2.2.3) which should be prepared by the manufacturer.

The Manufacturer shall provide a quality assurance (Q.A.) procedure agreed with the purchaser and the appropriate Certification authority.

**10.2 ROPE FIBRE MATERIAL**

In offering product, the manufacturer shall be free to choose fibre material to best meet the assembly specification set out in DPD-9.

The Manufacturer shall certify that the rope fibre material used in the rope product supplied is identical, within stated tolerances, to that of the previously tested prototypes.

**10.3 CONSTRUCTION**

Rope production should conform to the Rope Manufacturing Specification (see DPD 11.2.2.3) agreed between the manufacturer, purchaser and certification authority. This should correspond to the manufacturing process utilised for the preparation of the prototype rope used to determine key physical properties of the rope design.

The manufacturing process used to produce the rope should be identical for all the rope product prepared for a given specification unless modifications to this approach are agreed with the purchaser and certification authority.

An agreed quality assurance (Q.A.) system should be part of the manufacturing process and records of rope production as required by the Q.A. scheme should be maintained. This document should be available for scrutiny by the purchaser's inspector (see DPD-11.3.10).

#### 10.4 TERMINATION

The termination system will have previously been agreed between customer and supplier to ensure compatibility with other mooring components. It is vital however that the termination reflects that utilised for the prototype test programme i.e. a socket should not be substituted for a spliced eye unless further tests are undertaken to verify the strength and fatigue performance.

The Fibre Rope Assembly Specification prepared by the manufacturer shall fully describe the termination procedures to be adopted (see DPD-11.2.2.4) and shall include a Quality Plan.

#### 10.5 PACKING

Packing and transportation of the finished rope assemblies should have been discussed between manufacturer and client in detail prior to production. The manufacturer should have included packing in the Fibre Rope Assembly Specification. Typically rope will be stored for transport on reels or in storage tanks.

All reels must be sufficiently large to accommodate the complete length of rope and fitting without any material protruding above a flange.

#### References

#### Appendices

#### Figures

#### Tables

r2va	"Drafts Only. by MRP"		
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## 11. QUALITY CONTROL, INSPECTION AND CERTIFICATION

### 11.1 INTRODUCTION

This chapter is based on the premise that Rope Manufacturers will have established complete and detailed documentation of their fibre rope assemblies, and established their important properties through tests conducted on prototype specimens.

Through appropriate quality assurance procedures they must be able to demonstrate that fibre rope assemblies manufactured against any specific order have the same qualities as the prototypes and so can be expected to have the same properties without requiring further prototype testing.

Based on that premise DPD-11 provides the best current guidance available for quality control inspection and certification of deepwater fibre mooring assemblies made in the materials and constructions specified in DPD-2 and DPD-3.

It is believed that the quality control and inspection techniques set out herein based on the replication of prototype ropes will, when developed, represent the most cost effective method of assuring consistent and adequate quality.

However nothing in this chapter shall be construed to preclude the use of quality control methods and inspection techniques agreed between manufacturer and purchaser.

Guidance on quality control, inspection and certification is available from Classification Societies in documents such as those of ABS (1998), Bureau Veritas (1997), DnV (1998), Lloyds (1997),

### 11.2 QUALITY CONTROL

#### 11.2.1 GENERAL PROCEDURES

The Manufacturer shall establish his own design for fibre rope assemblies intended for use in deepwater fibre moorings which he shall document in a Design Specification, a Material Specification and a Manufacturing Specification. The Manufacturer shall then produce prototype rope specimens and determine the rope properties by the tests described.

The Manufacturer should appoint an Independent Inspector to witness these tests.

These test results shall be furnished to the Purchaser or his Inspector upon request.

The Manufacturer shall establish his own quality assurance procedures and criteria and set normal values for manufacturing the rope. The values may be measured and set when producing prototype rope, but these values shall not subsequently be changed.

### 11.2.2 PRODUCT DESIGN DOCUMENTATION

#### **11.2.2.1 Rope Design Specification**

The Manufacturer shall prepare a Rope Design Specification adequately describing a prototype rope. The specification shall include drawings or photographs showing the construction of the rope and indicating the numbers and arrangements of strands and shall indicate the rope pitch for each size of rope. The specification shall designate the material chemical composition, the material type, and the manufacturing method, but these may be coded, e.g. type A, method 1.

This Specification shall be available for examination by the Inspector and shall be furnished upon request to the Purchaser.

#### **11.2.2.2 Material Specification**

The Rope Manufacturer shall prepare a Material Specification describing the rope fibre material and its properties. The specification shall designate the material chemical composition, fibre producer, fibre type and grade. The specification shall indicate the values and allowable tolerances for the following yarn properties:-

- wet and dry breaking strength and elongation,
- linear density (tex),
- melting point
- yarn-on-yarn friction or abrasion

The first three tests are intended to ensure that the fibre material is as specified and the fourth to ensure that the finish has not been changed. Test methods for yarn-on-yarn friction and abrasion are given in FIBRE TETHERS 2000 (1995).

This specification may be confidential but shall be available for examination by the Purchaser's Inspector.

#### **11.2.2.3 Rope Manufacturing Specification**

The Manufacturer shall prepare a Manufacturing Specification completely describing how the rope is manufactured. A separate specification may be needed for each rope size. The specification shall designate the manufacturing method, but the method may be coded (e.g. Method 1.) for each step in the manufacturing process.

This specification shall be confidential but shall be available for examination by the Purchaser's Inspector.

#### **11.2.2.4 Fibre Rope Assembly Specification**

The manufacturer shall prepare a Fibre Rope Assembly Specification, including drawings, describing the complete rope assembly including the finished length and weight, the type and dimension of end fittings and any specific after treatment applied to the rope (see DPD-9.2.6). It shall specify the procedures for splicing or fitting end terminations, handling, packing, storage and despatch of the finished assemblies and identify critical inspection and hold points in a quality plan.

This specification may contain confidential elements but these shall be available for examination by the Inspector.

### **11.2.3 QUALITY ASSURANCE PRACTICES AND REPORTING**

#### **11.2.3.1 Quality Assurance Manual**

The Manufacturer shall prepare a Quality Assurance Manual completely documenting his normal procedures and practices. These quality assurance procedures and practices shall as a minimum include the procedures and practices given herein. The Purchaser and his Inspector may examine the Manufacturer's Quality Assurance Manual.

#### **11.2.3.2 Quality Assurance Supervisor**

The Manufacturer shall designate an individual who shall be responsible for following and adhering to all quality assurance procedures and criteria.

This individual and any designated deputies shall not be under the authority of the manufacturing or the sales branch of the Manufacturer's company organisation. He or his deputies shall have the authority to suspend production of any rope being produced whenever quality assurance is less stringent than the documented procedures or whenever material or production quality deviates from the prescribed tolerances given herein.

#### **11.2.3.3 Notification**

The Manufacturer shall promptly notify the Purchaser and his Inspector of any deviation which may be reason for rejection or which may significantly delay production.

#### **11.2.3.4 Quality Control Report**

A Quality Control Report shall be prepared for each product ordered which shall include the completed Quality Control Check List. The complete Quality Control Report signed on behalf of the Manufacturer, shall be presented to the Inspector for examination and signature. The Report shall then be filed by the Manufacturer and shall remain available for review by the Purchaser for five years after completion of the order or such longer time as may be agreed.

#### 11.2.3.5 Quality Control Check List

The Quality Control Check List, should be used during rope production to document adherence to certain practices and criteria. The Manufacturer shall adapt this form for his particular rope product, manufacturing method and splicing procedure.

### 11.2.4 ROPE FIBRE MATERIAL QUALITY

#### 11.2.4.1 Certification

The Rope Manufacturer shall certify that the fibre material used in the rope is that called for in the Rope Design Specification and shall obtain certification from the Fibre Producers attesting to the type, and grade of material.

The Fibre Producer shall prepare a yarn certificate which shall give the nominal values or allowable tolerances for the following yarn properties:-

- wet and dry breaking strength and elongation,
- linear density (tex),
- melting point
- yarn-on-yarn friction

for every shipment of fibre material to the Rope Manufacturer. (The yarn certificate could be a data sheet specific to the type and merge of yarn in the consignment and as such the certificate might be applicable to more than one shipment.) The Rope Manufacturer shall file the certificate along with documentation of the fibre shipment, and these shall remain available for review by the Purchaser for five years after completion of the order or such longer time as may be agreed.

#### 11.2.4.2 Material Testing by Rope Manufacturer

The Rope Manufacturer shall conduct sufficient tests in representative samples of fibre material to assure that it is the material stated on the Fibre Producer's yarn certificate. Suitable tests are listed in EC-11.2.4.2.

Tests shall be performed on at least 3 yarn samples taken at random from different portions of a given lot of material received by the Rope Manufacturer. The maximum lot size shall be no more than 20,000kg (44,000lb) of material.

#### 11.2.4.3 Material Control Procedures

The Rope Manufacturer shall establish and follow procedures by which all fibre material to be used in producing ropes are identified and controlled throughout storage and production.

**11.2.4.4 Rope Manufacturer's Fibre Material Labelling**

The fibre material control procedures shall include the use of labels which uniquely identify the particular material. Such labels shall be affixed to each material container at the time the material has passed the material quality tests.

**11.2.4.5 Material Storage**

Prior to entering the rope production process, the fibre material shall be labelled, stored in a controlled area and segregated from other materials.

**11.2.4.6 Intermediate Labelling and Storage**

Once the fibre material enters the rope production process, labels shall be affixed to each container, bin or pallet whenever the material is moved to another step of production or placed in storage. These labels shall be cancelled or removed when that material is removed. Alternatively, distinctive containers, bins or pallets shall be used only for that particular material.

**11.2.5 ROPE PRODUCTION QUALITY****11.2.5.1 Rope Making**

The Manufacturing Specification shall describe manufacturing methods adequately and cover all processing steps fully.

**11.2.5.2 Setting of Rope Production Parameters**

The Manufacturer shall set the nominal values for the rope production parameters indicated in the Rope Production Quality Control Check List. These nominal values may vary with the actual certified breaking strength (CBS) specified but shall be consistent with good rope making practice. These nominal values and allowable variations for rope production parameters shall be documented in the Manufacturing Specification.

**11.2.5.3 Quality Control Checks**

Quality control checks shall be performed at each step in combining the textile yarns to form intermediate and rope yarns. These checks shall as a minimum include the direction and magnitude of twist and the magnitude of yarn tension. The individual responsible for quality assurance or his representative shall personally check the set-up of the creel, stranding machines and or closing machine at least once during each production shift and at least during each rope run. An experienced operator shall attend the rope braider or closing machine and monitor the quality of the product throughout production noting the position and frequency of allowed joints in load bearing elements as described in the Rope Manufacturing Specification.

**11.2.5.4 Finished Rope Quality**

The finished rope quality shall as a minimum meet the criteria specified below in the Rope Design Specification.



### *11.2.6 TERMINATION QUALITY*

Currently, only spliced eye terminations have been satisfactorily evaluated over the range of breaking loads required for deepwater fibre moorings, though some comments relevant to the Quality Assurance and Certification of other terminations are included here for completeness.

#### **11.2.6.1 Spliced Eye Terminations**

The Manufacturer shall completely document all splicing procedures in the Fibre Rope Assembly Specification. The Rope Manufacturer or other party assembling the hawser shall follow these splicing procedures when making splices.

Such procedures should include specification of thimble material and dimensions as well as tucking, thinning, tensioning procedures and check marks to verify that the length relationship between rope elements has been preserved during splicing.

#### **11.2.6.2 Socket Terminations**

The manufacturer shall have specifications covering the design and production of sockets including all necessary material quality checks, radiographic examination etc.

The manufacturer shall have documented procedures for the production and fitment of sockets. These should include procedures to ensure that retention of length relationships in rope elements, socket alignment, handling and bending restrictions on the rope, pull in loads and, if resins are employed. Detailed instructions on the storage, mixing and pouring of resin and the quality assurance procedure are to be observed such as are found in BSS 7035 (1989).

### *11.2.7 FINISHED ASSEMBLY QUALITY*

The Fibre Rope Assembly Specification shall include methods to assess the conformance of the finished assembly. These shall include, but not be limited to, means of assessing the finished effective length, the quality and security of end fittings, jacket integrity, coatings, bend restrictors, packing and marking.

### *11.2.8 IDENTIFICATION OF ROPE ASSEMBLY*

#### **11.2.8.1 Rotation strip**

Unless by agreement of the purchaser all rope assemblies shall include a fluorescent strip of at least 25mm thickness along the entire length of the rope, in order that any undue rotation in installation or in early operation can be observed by divers or from ROV's (Remote Observation Vehicles).

#### **11.2.8.2 Marker Tape**

A marker tape shall be run in the centre of the core for the entire length of each rope. The marker tape shall be of flexible, durable, waterproof, oil resistant material, legibly marked. Printing on this tape shall be with a permanent, water and oil resistant ink.

The tape shall be clearly imprinted, in English, with the following information: The Manufacturer's name, material of rope and year manufactured. (The Purchaser may specify that certain additional information be imprinted on an additional tape to be included alongside this marker tape). Information shall be repeated at least every 0.5 m for the entire length of the tape.

#### 11.2.8.3 Assembly Marking

Each termination of each assembly should be clearly and indelibly marked with the Manufacturer's Identification, date of production, assembly drawing number, item number, end identification and inspector's stamp.

### 11.3 INSPECTION

#### 11.3.1 GENERAL PROCEDURES

If the Purchaser employs an Inspector to conduct inspections of the rope the following general procedures shall be followed.

The Manufacturer shall provide the Purchaser and Inspector with appropriate notice of when the product is ready for each inspection step. Unless otherwise agreed, adequate notice shall be at least five working days. The Manufacturer shall provide the Inspector with the accommodation and facilities required for the proper accomplishment of his work and shall provide any assistance or data required by the Inspector for verification, documentation or release of material. The Inspector shall have the right of access to any area of the Manufacturer's or his sub-contractor's premises where any part of their work is being performed. The Inspector shall be afforded unrestricted opportunity to verify conformance of the material with the Purchaser's order and specification requirements. The Manufacturer shall make this inspection equipment and personnel to operate such equipment available for reasonable use by the Inspector for verification purposes.

The Manufacturer shall arrange the production and assembly schedule to accommodate the inspection steps. At the option of the Purchaser and with the agreement of the Rope Manufacturer, the inspection steps and procedures may be carried out during one visit or may be carried out during several visits. The Inspector may visit the factory at any time during production and assembly, but unless specified at the time of placing the order, production and assembly will not be scheduled to accommodate visits which are not intended to carry out designated inspection steps.

An Inspection Check List and Report Form should be completed for each rope certified by the Inspector, and made a part of the inspection report.

#### 11.3.2 ESTABLISHMENT OF INSPECTION CRITERIA

When producing prototype fibre rope assemblies the Manufacturer shall measure and set values for the rope properties specified in DPD-9 which shall not subsequently be changed. These values shall be stated in the Rope Design Specification.

### *11.3.3 MANUFACTURING QUALITY*

The Inspector will review the Rope Design Specification, the Material Specification, the Rope Manufacturing Specification, the Fibre Rope Assembly Specification, the Quality Assurance Manual, the Quality Control Report and the Quality Control Check List. The Inspector may reject any rope product which does not meet the applicable specifications, for which set values deviate from the prescribed tolerances, or for which quality assurance has been less stringent than the criteria given herein.

### *11.3.4 INSPECTION OF SAMPLE OF ROPE SECTION*

In determining the length of rope to be manufactured, the Manufacturer shall make allowance for taking a sample rope section, which will later be cut from the finished rope before splicing, and a test rope assembly of at least 5 metres length.

### *11.3.5 SELECTION OF SAMPLE ROPE SECTION*

The Inspector shall select the end of rope from which the sample rope section is taken prior to splicing. The Purchaser may waive this requirement and allow the Manufacturer to select the sample rope section. Only one such sample rope section will be taken for each rope run.

The length of rope shall be pulled from the reel on which it was made, laid out on a smooth surface and loaded to the reference tension (recommended value of reference tension is 2% CBS; see DPD-9.2.1) for two minutes by means which do not damage the rope. At the end of this time, a length of 2 metres shall be marked accurately on the surface of the rope. The load shall be released, the rope cut cleanly and squarely at these marks and the ends suitably secured to prevent unravelling.

### *11.3.6 WEIGHT OF SAMPLE ROPE SECTION*

The two metre sample rope section shall be weighed to an accuracy of 1% and the weight divided by 2 to determine the weight per metre.

The non-loadbearing outer jacket of the sample should be carefully removed and the weighing operation repeated to determine the weight per metre of the loadbearing core.

### *11.3.7 CONSTRUCTION OF ROPE SAMPLE SECTION*

The total number of strands in the load bearing core shall be counted and recorded. The numbers and dispositions of the strands shall be the same as given in the Manufacturing Specification. Extra coloured marker strands are not counted.

The total number of rope yarns in one strand shall be counted and recorded. For strands containing less than 50 yarns, the number and distributions shall be the same as given in the Manufacturing Specification. For strands containing more than 50 yarns the number shall be within  $\pm 4\%$  of the value given in the Manufacturing Specification. One extra yarn caused by an over run shall be permitted.

The Inspector will examine the coloured strands, the marker tape and all identification marks to ensure they comply with DPD-11.2.8.

### *11.3.8 DETERMINATION OF ROPE STRENGTH*

The strength of the rope shall be determined on a minimum of 3 specimens (each of at least 5 metres length) by the method set out in DPD-9.2.2. This measured strength shall not be less than the CBS.

The average rope strength shall exceed the certified break strength (CBS). If the difference between the lowest and the highest is greater than 10% of the average of the highest/lowest, then two additional rope specimens of identical design may be retested for the respective rope property. If the average performance falls below the CBS, then two additional rope specimens of identical design may be retested. After retesting, the average of all such tests shall be used in calculating the average value. If the average value for four or more tests is more than 10% higher than the lowest test result, then the lowest tests result may be discarded and the average of the remaining three or more test results may be reported.

### *11.3.9 FIBRE MATERIAL IDENTIFICATION TESTING*

The Inspector will remove samples of fibre material to be tested from the sample rope section or the finished rope product. The Manufacturer shall, in the presence of the Inspector, conduct sufficient testing to identify the fibre material used to produce the rope. The tests which may be conducted are described in the OCIMF Procedures (1987)

### *11.3.10 ASSEMBLY INSPECTION*

The Inspector will examine the entire length of rope for surface defects or damage which may have occurred during the loading routine and check the security and workmanship of the end fittings. The Inspector must be satisfied that no damage occurs during re-reeling.

The Inspector will check the assembly length by weighing the finished rope (following rope manufacture and prior to final assembly) and calculating the length using the unit rope weight determined in DPD-11.3.6. Alternatively other agreed methods of measuring length may be used. The measured length should be used to determine the positioning of end fittings.

Prior to commencing assembly the Inspector will review the Quality Plan. The Inspector will review the Rope Production List for conformance with the Rope Manufacturing Specification. The Inspector will check the termination procedures (as DPD-11.3.11) and will subsequently check the final packing.

### *11.3.11 INSPECTION OF TERMINATIONS*

#### **11.3.11.1 Inspection of End Fittings**

The Inspector will review design calculations, welding procedures and prototype tests and witness appropriate material tests on end fittings including chemical analysis, non-destructive testing and mechanical testing (textile and impact tests), such as are required by the governing certification authority documentation.

The Inspector will check the surface finish of fittings in critical areas particularly the bearing surfaces of hardware.

#### 11.3.11.2 Spliced eyes

Splices will be examined by the Inspector after they have been completed and before they have been covered by auxiliary gear, making the following observations and measurements.

Splices shall be certified to have been made in accordance with the Manufacturers normal procedures as given in the Rope Design Specification. The Inspector will examine the selected splices in detail, making reference to the splicing procedure given in the Manufacturing Specification and to the completed Quality Control Check List, to assure that this has been done.

The selection of splices for inspection shall be at the discretion of the Inspector but at least one splice shall be witnessed for each rope design and splice type.

#### 11.3.11.3 Sockets

The Inspector will review the Socketing Procedures and witness at least one socketing operation. The terminations and termination procedure should be fully detailed in the Rope Design Specification (DPD-11.2.2.1) and the Rope Manufacturing Specification. (DPD-11.2.2.3) and this should include minimum bending radius of rope during handling, control and distribution of individual rope elements and alignment control of rope and socket.

In the case of resin secured sockets the Inspector will witness material tests on samples of resin to verify hardness, compressive strength and compressive modulus. These tests to be carried out on 40 mm test cubes poured immediately after mixing from resin used for the first three, last three and middle three socket pours.

#### 11.3.11.4 Bend Limiters

The Inspector will verify that any bend limiters have been manufactured and fitted in accordance with the Fibre Rope Assembly Specification (see [DPD-11.2.2.4](#)).

### 11.4 CERTIFICATION

#### 11.4.1 GENERAL

Certification of the fibre rope assembly may be required by the purchaser as part of the activities for Certification of the whole mooring system by a suitably qualified and experienced Certification Authority.

The activities required for such certification include:

- design appraisal of the mooring system
- design appraisal of components (anchors, connectors etc.)
- certification of the ropes

- certification/inspection at works of other components
- survey of installation
- periodical survey of in-service systems

**References**

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**Appendices**

None

**Figures**

None

**Tables**

None

Old 15 r1va	DRAFT	Stuart Guy	Sept.96
Old 15 r1vb	Edited	RWPS	Oct 96
r2va	edited	RWPS	March 97
r3va	new rev after SC#4	rwps	28 Oct 97
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r4va	edits	rwps/spo	27 Feb 98
r4va	part updating	rwps	20 May 98
r4va	changes noted after TTI meeting	rwps	21 May 98
r4va	mods from TTI fax dated 21/5/98	rwps	22 May 98
r4vb	tti/nde	rwps	12 June 98
r4vb	tti/nde following nfr	rwps	15 June 98

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## 12. INSTALLATION OF FIBRE ROPE MOORING SYSTEMS

### 12.1 INTRODUCTION

This section summarises the handling characteristics of fibre ropes that must be considered during installation and reviews other factors that will affect the method for installation, such as the make-up of the mooring system, anchor types, vessels and equipment and outline installation procedures.

The deepwater fibre mooring systems being considered (which are described in DPD-1) are:

- taut leg fibre moorings
- fibre rope insert catenary moorings

Installation of these systems will require:

- emplacement of anchors
- installation of mooring lines
- hook-up of mooring lines to the floating platform
- tensioning and testing of the lines of the mooring system

The advice of Rope Manufacturers should be taken when developing installation procedures for the mooring lines.

### 12.2 FIBRE ROPE HANDLING CHARACTERISTICS

#### *12.2.1 MATERIAL AND CONSTRUCTION*

The various fibre rope materials and rope constructions are described in detail in DPD-2 and DPD-3 respectively. Rope assembly properties are considered in DPD-5.

#### *12.2.2 END FITTINGS*

The end fittings for fibre ropes are discussed in DPD-4. The main termination types are:

- splice with hard eye (thimble, pin and bushing or spool)
- resin socket
- barrel and spike with or without resin

The present recommendations are that terminations should be made from steel and the weight of the termination will therefore be significant in comparison with the distributed weight of the rope itself. This may complicate the handling of the terminated ends of the line as care must be taken to ensure that excessive bending is not applied to the fibre rope which might cause compression damage to fibres. Bend restrictors fitted to the end of the fibre rope may be advantageous in avoiding or reducing this problem.

Lighter weight terminations and fittings using materials other than steel, such as composites, may be used if their performance has been proven to be satisfactory.



In the case of very long lines it may be necessary to provide mid length connections either by means of hard connectors such as spliced eyes with thimbles and connection shackles or alternatively as mid length butt-splices. In either case special consideration will need to be given to handling of the connection parts of the rope.

### 12.2.3 WEIGHT AND SIZE

Fibre ropes have significantly lighter weights (both in water and in air) than do steel wire rope or chain lines of equivalent strength and this feature makes them particularly attractive for installation of moorings in very deep water.

Rope diameters of fibre ropes (particularly for polyester) are likely to be bigger than steel wire rope and this influences the space required to store the lines prior to deployment.

Dimensions and weights of typical 10,000 kN breaking strength fibre ropes made from different materials are compared with steel wire rope in DPD-1 (Figure 1.2.2). To a first approximation for other rope specifications, weight and area scale with strength and diameter with square root of strength.

Ropes that are positively buoyant may present some handling problems during deployment. However the exact level of buoyancy for a rope depends not only on the fibre density but also on the flooding characteristics of the rope and the density of the jacket.

### 12.2.4 BENDING RADIUS

Deepwater mooring fibre ropes should not be permanently installed around bollards or fairleads. This is because of the limited knowledge of their long term behaviour under fatigue tension and bending and the potential for significant wear and internal fibre damage to occur in the length of rope in contact with the bollard or fairlead.

During deployment rope assemblies will need to be stored and reeled around drums, fairleads and rollers. Some suggested minimum bending radii for storage and installation of fibre ropes with braided and extruded jackets are provided in Table 12.2.1. These values relate to bending with very small amounts of line tension. Significant levels of tension in the line will reduce the compression of the concave part of the bend and thus may reduce the tendency for compression damage of the fibres.

Failure of the external rope sheath (particularly if of the extruded polymer type) may result in a local bending stiffness discontinuity. This could become a site for bending fatigue damage to concentrate. Adequate steps must be taken in the design and installation to avoid this type of damage.

Recent tests (NFR(ongoing)) are being conducted to determine the relationship between rope residual strength and bending radius/number of cycles. When available these results should enable the preliminary recommendations contained in Table 12.2.1 to be confirmed and extended.

Table 12.2.1

## Typical Minimum Bending Ratio (D/d) for Storage and Installation of Ropes

(i.e. with very small values of tension in the line)

(D = diameter of drum; d = diameter of rope)

Construction and Jacket	Fibre Ropes (all materials and constructions)	steel spiral strand (for comparison)	steel wire rope (for comparison)
<u>No Jacket</u>	<u>Not Applicable</u>	<u>24<sup>1,2</sup></u>	<u>14<sup>1,2</sup></u>
<b>Braided Jacket</b>	6-15 <sup>3</sup>	Not Applicable	Not Applicable
<b>Extruded Jacket</b>	20-30 <sup>3</sup>	24 <sup>1,2</sup>	14 <sup>1,2</sup>

<sup>1)</sup> from Firth and Sefton (1997)<sup>2)</sup> allowable bend radius also depends on tension in line and strength of sheathing material<sup>3)</sup> various ropemakers**12.2.5 TWIST AND TORSION**

Torque or twist should not be applied to fibre ropes, as degradation in the fatigue life may occur as discussed in DPD-5.8.

During installation care should be taken to avoid introducing unnecessary twist. Ropes should be marked with a reference line (see DPD-11.2.8.1) during construction to assist in avoiding such twist.

Note that deploying ropes by unreeling sideways from a static reel or basket will introduce one revolution of twist for each lap unreeled. This can be avoided by unreeling in-line and allowing the reel or basket to rotate.

**12.2.6 CUTTING DAMAGE**

Fibre ropes should not be run over surfaces (bollards, rollers, decks etc.) which have sharp edges, grooves, nicks or other abrasive features and which may result in the surface of the rope being cut or torn. Surface finishes for steel equipment which are not worse than "Coarse Grade" according to ISO 8503 (1988) should be acceptable.

**12.2.7 SHEARING FORCES**

Care should be taken when applying shearing forces to fibre ropes. Shear can be induced by friction as a rope runs over a bollard, or when gripping the rope to apply tension. Shearing loads may result in damage to the rope jacket or core. Rope manufacturers recommendations should be adhered to where available.

**12.2.8 HEAT DAMAGE**

Low temperatures encountered offshore have no detrimental effect on synthetic fibres.

Fibre ropes can melt or degrade when their temperature is raised to a sufficiently high level. Values of melting temperatures are given in DPD Figure 1.2.1 (f) and temperatures at which strength starts to diminish are given in EC-2.2.1.8 through to EC-2.2.1.14.

The following precautionary measures should therefore be taken with regards to reducing the potential for thermal damage:

- Fibre ropes should be stored away from sources of heat.
- There should be no hot work, such as welding, in the vicinity of fibre rope. If such work is unavoidable sufficient thermal protection must be provided.
- Frictional heat from excessive slippage of the fibre rope over a capstan, drum, or other rope, should be avoided. Hauling in and paying out operations should therefore be carefully monitored. Frictional heat will build up more quickly where contact surfaces are insulated. Thus ropes running over a painted steel surface may suffer higher heat build up than is the surface had been left unpainted. Cooling and lubricating ropes by means of pumped seawater as they are deployed over rollers may be beneficial.

12.2.9 CHEMICAL AND UV DAMAGE

Some fibre ropes can be weakened by the influence of UV light and strong chemicals.

It is desirable to protect fibre ropes from contamination from any chemicals during the installation process. The installation process is unlikely to be long enough for UV degradation to be significant but the effects can be eliminated by suitable shading.

The main fibre materials are considered in Table 12.2.2 and further information is provided in the EC.

Table 12.2.2  
 Resistance to Chemical and UV weakening  
 (from Table EC-2.2.2.2)

	polyester	aramid	HMPE	steel (for comparison)
Chemicals	good	good <sup>(1)</sup>	excellent	varies <sup>(2)</sup>
UV light	good	poor	good	excellent

- Notes:
- (1) attacked by strong alkalis and acids
  - (2) corroded by water, acids etc.

12.2.10 GENERAL CARE

The user should follow the advice of the rope manufacturer concerning handling of rope assemblies.

Fibre ropes are easily damaged if the rope becomes tangled or knotted. Every care must be taken to ensure that these conditions are avoided.

Care should be taken to avoid sharp gritty materials coming into contact with fibre ropes.

Although the rope jacket (either braided or extruded) is not considered to contribute directly to the strength of the rope any significant damage to these coverings is unacceptable during deployment.

Fibres which are alternately wetted with salt water and allowed to dry out can suffer from abrasion damage from salt crystals. For the deepwater mooring lines this will not occur during deployment as the ropes will be permanently submerged. Simple precautions will avoid this type of damage during transport and deployment.

#### 12.2.11 SNAP BACK BEHAVIOUR

If lines fail under tension during the installation stage there is significant potential for injury to personnel and damage to equipment as a result of rope snap-back energy. The installation phases should be planned to minimise the risk of such an incident.

Personnel should be kept clear of fibre ropes under tension.

Methods of designing against or minimising snap-back damage include:

- minimising line tension during operations when personnel are working close to the rope
- minimising opportunities for the taut line to be abraded or touched by other items of equipment during installation - particularly when under tension

### 12.3 MOORING SYSTEM TYPES AND EXAMPLES

#### 12.3.1 GENERAL

The detailed arrangements for installation of a deepwater fibre rope mooring will be specific to the platform and design. The general categories considered here are:

- temporary or permanent installations
- taut leg or catenary insert lines
- anchor type
- pre-deployment of the line or deployment directly from the vessel

The following notes consider the main features that influence the installation of deepwater mooring lines.

#### 12.3.2 TEMPORARY MOORINGS

Insert line catenary moorings (see DPD-1; Figure 1.1.2) are most likely to be used in temporary moorings. For these lines a substantial amount of catenary line weight is required at the seabed which could be provided by chain, wire, or additional clump weights. As a result the uplift load seen at the anchor is reduced or eliminated and conventional drag anchors may be feasible.

Temporary moorings must be capable of simple retrieval operations and capable of frequent and rapid installation in a range of water depths. For convenience it is desirable that the fibre ropes will be light and have a relatively small diameter to reduced storage volume and bending radius problems in order to make them easy to handle on a repeated basis. The high strength to weight ratio and resulting compactness of aramid and HMPE ropes would be a particular advantage for temporary moorings.

### 12.3.3 PERMANENT MOORINGS

Permanent moorings are more likely to take advantage of taut line mooring systems (see Figure 1.1.1) which require anchors capable of resisting substantial uplift. In these moorings the mooring line compliance comes from the fibre rope extensibility. As a result only a small amount of chain is required at the top and bottom of the line and this is provided to give protection against seabed abrasion and avoid bending over the fairlead.

### 12.3.4 ANCHOR TYPES

The main anchor types which can be considered for deepwater fibre moorings are:

- conventional drag embedment anchors
- new generation Vertical Lift Anchors (VLA's) (Sometimes referred to as Plate Embedment Anchors)
- conventional piled anchors
- short length suction anchors or caissons

With the exception of the conventional drag embedment anchor all these types are suitable for loadings which include a significant component of vertical load. VLA's and suction anchors are recent developments and less is currently known of their behaviour in the full range of potential seabed types.

The accuracy with which these different anchor types can be installed varies. Pile and Suction anchors are positioned directly on the seabed target location by surface vessels and the accuracy with which this is achieved depends largely on the seabed and surface positioning system being used and the position keeping capabilities of the installation vessel. Generally the most critical aspect of installing such piles is the heading orientation of the mooring connection padeye.

VLA and conventional drag anchors have to be dragged (sometimes referred to as "flown") into position below the seabed surface. This makes the plan position of the installed anchor rather difficult to predict and installation may have to be repeated until the required installation criteria (position and depth) are both met. Methods for pulling such anchors include tensioning from the platform, pulling by means of the anchor handling vessel (AHV) or using a bottom cross tensioning device in which two anchors are pulled towards each other by a surface vessel exerting a vertical load at the mid point of the line joining the two anchors. This last method allows large horizontal forces to be generated by relatively modest vertical loads as a result of the connection geometry. However cross tensioning requires chain and thus affects the lengths of chain that are deployed on the seabed.

### 12.3.5 CONNECTION TO ANCHORS

Connection of the mooring line to the anchor may be made either on the surface or after the anchor has been installed. The ability to make a subsea connection of the line to the anchor will depend on the type of connection hardware specified and the power and capability of the available Remote Operation Vehicle (ROV).

If the mooring line has to be connected to the anchor before deployment it is also possible, but not inevitable, that the fibre rope will be used to install the anchor. Thus embedment or vertical lift anchors could be pulled into position by the mooring line rope itself. In this case care must be taken to avoid damage to the fibre rope as a result of contact with adjacent equipment. The likely damage features that should be avoided are:

- abrasion or fouling of the mooring line with the anchor equipment including anchor, chain, steel wire rope and connectors
- uncontrolled twisting of the fibre line due to lack of torque balance in the ropes being used
- twisting of adjacent wire ropes. For instance this can occur as a result of axial line tension in a wire rope being reduced as the weight of (say) an anchor is transferred to the fibre rope due to line load being transferred to the fibre line.

It is envisaged that all anchors will be connected to the fibre mooring line with a length of chain or wire to allow the fibre line to be kept clear of the seabed and thus avoid abrasion damage. If wire is used it should be torque balanced.

Normal mooring line deployment activities which use chasers to run over the steel wire rope or chain between the anchor and the platform when lifting anchors should not be used for fibre rope moorings. Instead anchors will need to be provided with buoyed pennant lines for recovery. In deepwater this may be a significant marine undertaking. The length of such pennant lines must be designed to avoid them dragging over and hence damaging the deployed fibre mooring lines.

## 12.4 INSTALLATION PLANNING

### 12.4.1 GENERAL

Comprehensive planning is required to ensure that fibre ropes are installed without damage and in a condition which allows them to perform adequately during their lifetime.

### 12.4.2 INSTALLATION ACCURACY

Installations in deepwater will need a suitable positioning system both for the seabed equipment (anchors etc.) and for the surface vessels.

The mooring system must be installed with adequate accuracy to allow the mooring lines to operate within the limits established by the mooring analysis. The most critical accuracy parameter is the location of the anchors. This is particularly important for fibre rope moorings where the length and angle of the fibre rope line governs the compliance of the system. As in conventional moorings the heading angle of the mooring lines must also be adequately defined for any specified mooring system. In the case of drag embedment anchors the accuracy of positioning must also account for any anchor slip during anchor proof loading.

In addition the anchor positioning accuracy must be consistent with the length of the delivered mooring line. It is envisaged that fibre mooring lines in a taut leg system will be terminated to give a pre-determined length although this length will increase as a result of bedding-in during first loading and also as a result of subsequent creep. The length of the platform chafe line must be sufficient to absorb these extensions and any anchor positioning inaccuracy.

## 12.5 INSTALLATION OPERATIONS

### 12.5.1 GENERAL

Installation operations will depend upon the mooring system being installed, the equipment available for the installation, prevailing weather conditions and sound site decisions.

### 12.5.2 LINE CONTROL DURING DEPLOYMENT

During deployment the fibre rope should be separated from the termination hardware by means of split reels or special wrapping of the hardware as discussed in DPD-9.2.11.

Damage can be caused if fibre ropes are unreeled from loosely tensioned drums with the result that the line becomes buried in the lower wraps of rope. This must be avoided by designing the rope reeling tension to be consistent with the tension applied during deployment.

Shark jaw type stoppers designed for use with steel wire rope or chain should not be used for handling fibre rope.

Only a small proportion of the strength capacity of a rope can be transferred in shear by means of gripping the rope with linear winch grips or stoppers. Traditional methods of gripping ropes by means of rope handling stoppers wound around the mooring rope circumference are not recommended due to the difficulty of controlling the forces they will exert. Grips or stoppers should only be used within load limits established by the rope manufacturer. In such cases the jaws must be free of sharp edges and to a design compatible with the type of rope in use.

**12.5.3 AVOIDANCE OF FIBRE COMPRESSION FATIGUE DAMAGE**

Fibre ropes are susceptible to strength degradation during cyclic loading at low mean loads due to fibre axial compression fatigue. Specific advice is given in DPD-8.2.9.3 on checking minimum tension levels and the allowable number of load cycles which may dip below this during installation and the installed lifetime. During marine installation operations care must also be exercised to ensure that the rope is not damaged as a result of significant numbers of minimum load cycles.

Provided the installation routine does not result in more than 1,000 load cycles of loading in which the line load goes below the guideline value of 5% CBS for polyester ropes or 10% CBS for higher modulus ropes no further consideration is required.

Activities which might result in such load ranges include: deployment of anchors, anchor proof loading and environmental loads when pre-deployed lines are awaiting the arrival of the platform.

If the installation methods results in more than 1,000 cycles dipping below the guideline limit then further analysis will be required to demonstrate acceptability. An analysis should demonstrate that the total number of load cycles going below the guideline tension for both the installation phase and the remaining lifetime of the installation does not exceed the limiting value listed in DPD-Table 8.2.3.

**12.5.4 MINIMUM INSTALLATION TENSIONING**

After installation it is essential to apply a tensioning routine to the mooring lines to remove constructional stretch from the lines. The Post-Installation stiffness defined in DPD-5.3.2 is achieved by applying a load of 30% CBS to each line as laid out in Table 12.5.1.

This installation tensioning routine may be modified if specified by the mooring designer in which case it should be consistent with the mooring analysis adopted.

**Table 12.5.1  
Recommended Installation Tensioning Routine**

<b>Item</b>	<b>Recommended Value</b>
<u>Maximum initial load</u>	<u>30 % CBS</u>
Duration to hold maximum load	at least 1 hour

**12.5.5 NORMAL PRE-TENSIONING**

After the installation tensioning of the lines the design normal pre-tensioning should be set.



## 12.6 FIBRE ROPE PRE-DEPLOYMENT

### 12.6.1 GENERAL

For permanent moorings it is likely that project scheduling will require the fibre ropes to be pre-deployed to await the arrival of the completed surface platform. However the installation sequence must prevent the fibre ropes being left so that they may be damaged while waiting to be hooked up to the platform.

### 12.6.2 SURFACE BUOYED LINES

It is recommended that pre-deployed lines should **not** be left buoyed at the surface awaiting connection to a platform unless the minimum tension requirements of DPD-12.5.3 are maintained. The possibility of independently buoyed lines being allowed to rotate should also be considered. These requirements are intended to avoid the fibres in the line undergoing compression with the possibility of buckling fatigue and subsequent damage and failure.

Pre-deployed, surface buoyed lines which are tensioned together in groups while awaiting platform arrival (see Figure 12.6.1) are one method of keeping lines in tension and avoiding multi-turn twisting of mooring lines.

A bottom length of chain or wire should be provided to avoid seabed thrashing damage.

### 12.6.3 BOTTOM LAID LINES

Fibre Ropes which lie on the seabed (temporarily or permanently) require a jacket in order to:

- protect them against external abrasion from the seabed
- prevent ingress of particles that will result in accelerated yarn-on-yarn abrasion

Following careful study it may be possible for lines may be laid on the seabed to await arrival of the platform. The top end of the line will need to be weighted to keep it firmly on the seabed and the actual weight of the fibre rope in water should be carefully considered to ensure that it is not able to lift off under the effects of seabed currents. The HMPE and HMPE-MS fibres which are positively buoyant may not be suitable for this form of deployment unless fitted with a suitably heavy jacket. Alternatively the buoyancy of such lines may allow them to be pre-deployed as a reverse catenary as shown in Figure 12.6.2 but in this case the design should keep the fibre ropes clear of abrasion damage at the touch down locations.

Seabed storage will require careful evaluation of the rope jacket. Impermeable extruded jackets which prevent ingress of soil particles may be preferable to braided jackets. Particular care should be paid to the design of the jacket at the termination to prevent soil ingress at the end of the rope. However if the jacket does not flood the implications for submerged weight and cooling of the fibres should be taken into account.

The recovery line required at the top end of the laid down mooring should be suitably tensioned to prevent it from dragging over and damaging the fibre rope. This may require the provision of additional clump weights.

#### *12.6.4 MID SPAN SUSPENDED LINES*

Lines may be pre deployed so that they are suspended along their length clear of the seabed but below wave action. In this arrangement the suspended line must be capable of surviving movement due to current. The suspension buoy must be large enough to maintain sufficient tension in the line to prevent fibre buckling fatigue (see minimum tension requirements of DPD-8.2.4.2) and to also hold the end terminations clear of the seabed. This mode of installation may be most feasible for fibre ropes which are inherently positively buoyant. However the method relies heavily on the mid length buoy which is an added complication during deployment and which must be built to withstand significant hydrostatic pressures. Failure of the buoy would result in the fibre rope being dropped in an uncontrolled fashion to the seabed with attendant concerns about what, if any, damage it would have sustained.

### **12.7 TYPICAL FIBRE ROPE MOORING INSTALLATION SCENARIOS**

#### *12.7.1 INTRODUCTION*

Descriptions of some concept installation schemes are provided in the Engineering Commentary.

**REFERENCES**

- ISO 8503-1 (1988). "Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates - Part 1 : Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces".
- Firth, K.M., and Sefton, S.L., (1997) "The installation of Spiral Strand Mooring Cables in Deep Water"; Bridon Structural Systems, Technical Report, Bridon, Doncaster, October 1997

**Appendices**

None

**Figures**

12.6.1

12.6.2

**Tables**

12.2.1

12.2.2

12.5.1

Figure 12.6.1

Surface Buoys Tensioned Together to Maintain Fibre Rope in Tension

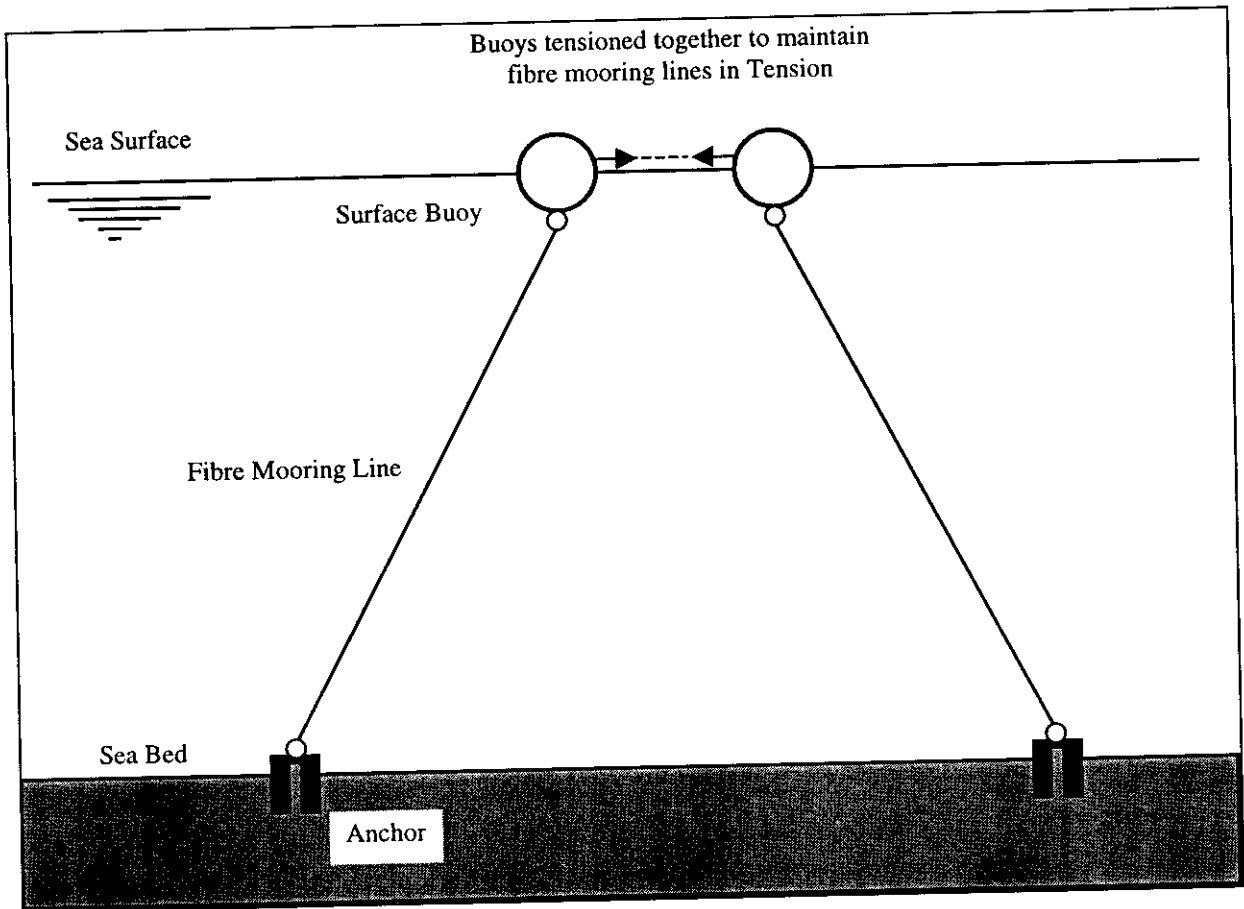
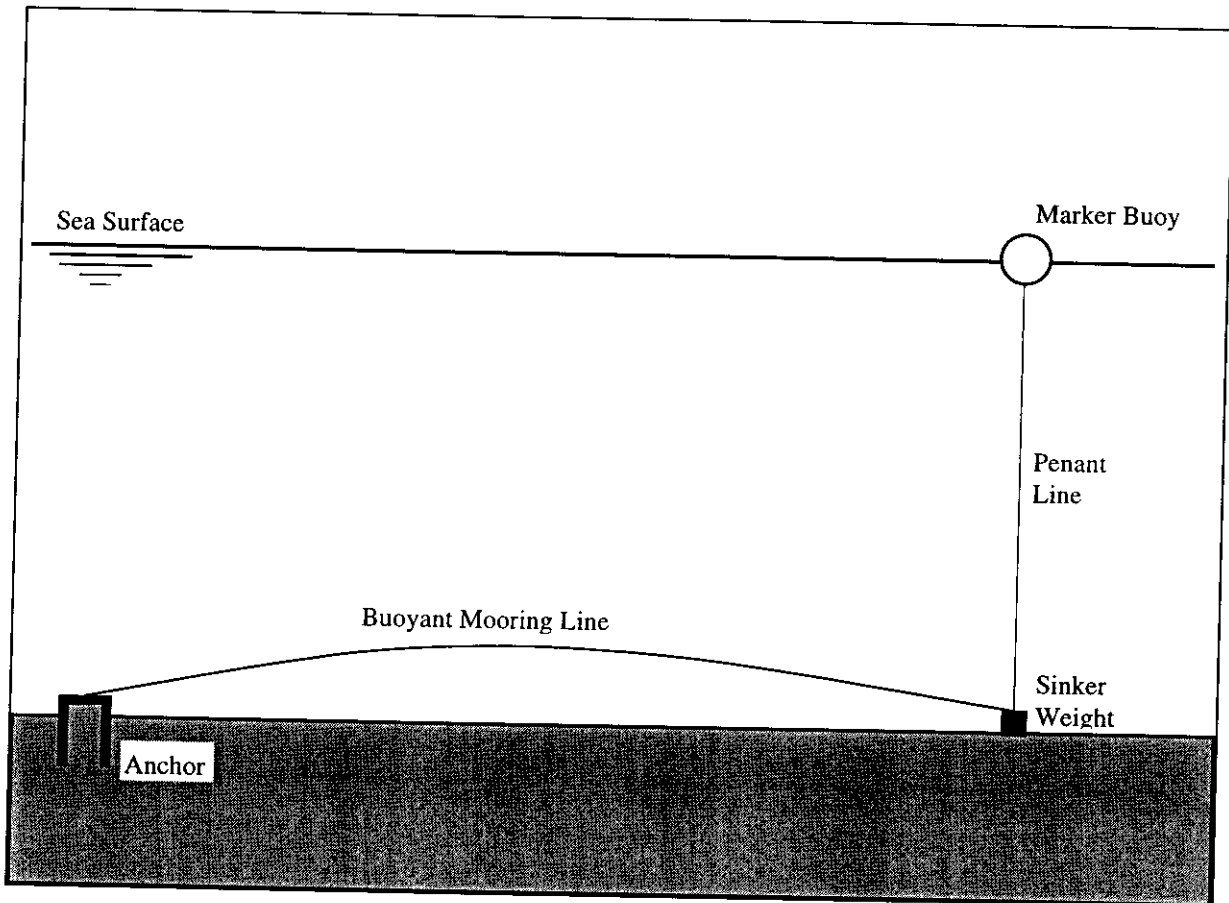


Figure 12.6.2  
Bottom Laid Buoyant Line



No Draft for Rev1 was produced

This section now incorporates what was to be

	Section 16	Lifetime Inspection and Operation	
	Section 17	Retirement	
r2va	drafted	RWPS	26 March 97
r3va	new rev after SC#4	rwps	28 Oct 97
	final changes	rwps	16 Nov 97
r4va	part updating	rwps	20 May 98
r4va	changes noted after TTI meeting	rwps	21 May 98
r4vb	tii/nde	rwps	12 June 98
r4vb	tii/nde	rwps	15 June 98

<b>13. OPERATION, LIFETIME INSPECTION AND RETIREMENT</b>	<b>1</b>
13.1 INTRODUCTION	1
13.2 OPERATION	1
13.2.1 TENSION CONTROL AND MONITORING	1
13.2.2 PERIODIC INSPECTION	2
13.3 LIFETIME INSPECTION	2
13.3.1 GENERAL	2
13.3.2 EXTERNAL CONDITION INSPECTION	2
13.3.3 INTERNAL CONDITION ASSESSMENT	3
13.3.4 DESTRUCTIVE TESTING	4
13.3.4.1 Break Tests	4
13.3.4.2 Detailed Rope Core Examination	4
13.3.4.3 Yarn Finish, Lubricants and Filler Drability	4
13.4 RETIREMENT	4

## 13. OPERATION, LIFETIME INSPECTION AND RETIREMENT

### 13.1 INTRODUCTION

The comments provided in this section is concerned with fibre rope assemblies which have been designed, manufactured and installed in accordance with the provisions of this document.

### 13.2 OPERATION

#### 13.2.1 TENSION CONTROL AND MONITORING

During the lifetime of the mooring system periodic adjustments may be required to the mooring lines in order to remove slack from the lines caused by creep of the rope material. The platform operators should maintain the line tensions (under nominal environmental conditions) within a prescribed set of tension limits.

Line tensions should be monitored over the lifetime of the installation. Records should be kept of the net extension of lines over the life of the mooring system.

### 13.2.2 PERIODIC INSPECTION

Periodic ROV (Remote Observation Vehicle) inspection may be needed to confirm that the terminations at the fairlead end of the fibre rope are well clear of the fairlead zone.

## 13.3 LIFETIME INSPECTION

### 13.3.1 GENERAL

A specification for the extent and frequency of external inspection and internal condition assessment should be developed by the Operator of the mooring system in conjunction with the Certification Authority on a case by case basis to provide consistency with the overall safety assessment for a given installation.

Various strategies exist for assessing the condition of the fibre rope during its lifetime. These can be divided into:

- methods for assessing the condition from external inspection
- methods to determine the core mechanical strength

### 13.3.2 EXTERNAL CONDITION INSPECTION

Various visual examination methods have been developed for fibre ropes (i.e. Fibre Tethers 2,000 (1995)) but need further development for deepwater mooring line ropes.

Remote Observation Vehicles (ROV's) can be used to "fly" over the installed rope and take video footage of the line. This kind of inspection would be capable of detecting:

- extent of marine growth
- significant cuts in the rope jacket (and, on closer inspection extent of core damage)
- contact of rope with any other potentially damaging equipment (wires, etc.)
- general condition of terminations
- evidence for twist in the line (from any longitudinal stripe)
- structural distortion and change in shape of the rope surface

The completeness of such a survey would depend on underwater visibility and extent of marine growth. It might be necessary to clean marine growth in advance of a visual survey of the rope and if this is done care is needed to ensure that the cleaning does not damage the rope jacket or core.

External damage criteria for repair or replacement would need to be developed by the operator in conjunction with the manufacturer.

Deployment of the ROV would probably be done by a suitable boat to allow ROV inspection over the full radius of the mooring pattern. The ease of ROV inspection depends greatly on the currents experienced at the site.

All mooring lines should be inspected as part of the platform installation operation. Thereafter lines should be inspected at least every year or in accordance with the inspection scheme developed by the Operator.

### 13.3.3 INTERNAL CONDITION ASSESSMENT

No field-deployable non-destructive equipment is currently available (1997) which is capable of running over a fibre rope and determining its internal mechanical condition.

Removal of all mooring lines for periodic on-shore mechanical testing is impractical as replacement lines would have to be provided and the process of line retrieval is intrinsically risk-prone. Furthermore it is impractical with available shore testing facilities to proof load complete mooring lines. Instead shore testing should be used for shorter insert lines which are removed periodically for destructive testing.

As a result of these limitations as much other data as possible should be gathered to allow the condition of the rope throughout its lifetime to be determined. In particular, instrumentation of the loads seen by the lines throughout their lives should be undertaken where possible. In addition periodic replacement of mooring lines on a rolling schedule together with destructive testing on the recovered lengths should be used to build up a profile on the performance of mooring lines under installed conditions.

Test samples should be provided from either complete mooring lines or special insert lines recovered from the mooring system. If insert lengths are used they should be sited near the top of the main length of the fibre rope. They should be of similar size, construction and material to the main fibre rope and in particular have the same termination details. Recovery and replacement of these representative insert lines should be considered at the time the complete mooring system is being designed. When developing the methods of recovering and replacing these lengths care should be taken to minimise the chances of damage to the part of the mooring line which will be left in place, the new replacement length and the insert being taken for testing.

The number of lines recovered from the mooring and the frequency at which they are replaced will depend on experience with similar mooring lines and platform locations. Currently there is very little applicable experience. The number of lines recovered and the frequency of recovery should be in accordance with the inspection scheme developed by the Operator in agreement with Certifying Authority.

An example of the kind of inspection routine which might be used as a basis for an agreed scheme is as follows:

- **After 1 years service:** recover two lines (or line inserts) for destructive testing. The recovered lines should be selected as representing the mooring lines which would have experienced the most severe loading condition (this may include, for example, the line with the largest tensions, the line with the lowest minimum tension, the line with the largest range of tensions or the line with the most significant visible damage).
- **After 3 years service:** recover two lines (or insert lines) for destructive testing. The recovered lines should be selected on the basis of a careful review of the predicted line loads and any other relevant operational factors.
- **Thereafter:** further recovery and replacement will depend on a judgement of the



residual strength of the lines and by agreement with the appropriate Certification Authority.

#### 13.3.4 DESTRUCTIVE TESTING

If fibre ropes are retrieved for destructive testing the following recommendations should be considered. For cases where a complete mooring line has been recovered it is preferable to select the fairlead end for detailed inspection. Other portions may also be selected depending the observed condition of the rope when it is recovered. If a short insert line is recovered for testing again this should be one that was located at the fairlead end of the line.

Removal of lines or insert lines for shore testing requires long term planing and scheduling. It should be noted that available testing facilities for large mooring lines are limited and may require booking well in advance.

##### 13.3.4.1 Break Tests

Only a few large rope testing machines are available world-wide and the size of ropes they can accommodate depends on the extensibility, strength and length of the specimen.

Residual fatigue life tests may also be conducted to assess rope condition.

##### 13.3.4.2 Detailed Rope Core Examination

An alternative to break tests as a method of determining the condition of the recovered rope is to undertake a detailed examination of the rope and record breaks and residual strength of yarns taken from the rope. This has the advantage of detecting any incipient fatigue mechanisms that rope strength testing may not detect.

##### 13.3.4.3 Yarn Finish, Lubricants and Filler Drability

The rope should be examined to assess any loss of yarn finish, lubricant or filler.

#### 13.4 RETIREMENT

A mooring line retirement plan should be developed at the mooring design and specification stage. This should take account of the data accumulated from detailed rope core examination and break tests.

The reports from the periodic visual rope inspections should also be carefully assessed to determine if premature retirement is necessary.

If adequate data is available for similar fibre ropes being used in similar mooring types at similar locations it may be acceptable to retire the lines at the end of a previously determined design life with no intermediate destructive testing of the ropes.

**References**

API RP 2SK (1997)

"Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)

Fibre Tethers 2000 (1995)

Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.

**Appendices**

None

**Figures**

None

**Tables**

None

## APPENDIX 3

### “PROPOSED PROTOTYPE ROPE TESTING PROCEDURE”.

#### **ROPE IN SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES**

##### **1. Introduction**

Pending issue of agreed guidelines for deepwater fibre mooring assemblies, the following test method routine is suggested for polyester ropes. Suitable adaptations may be required for ropes with higher stiffness or creep.

Prototype rope assemblies of the chosen rope in lengths exceeding 5 metres should be made up and tested to indicate likely properties in use. Tests on ropes should be conducted in the wet condition.

##### **2. Proposed Test Procedure**

At least 24 hrs after manufacture of test assemblies they should be put through the following experimental routine as illustrated in Figure A-3.1, with continuous recording of extension and elongation both between bearing points and on a pre-marked 1m length of rope. All cycles are to be sinusoidal. Cycles a) to g) and j), k) are to be conducted at a cyclic period between 1 and 10 minutes. Cycles h) are to be conducted at a period of between 5 and 15 seconds

- a) First loading to 30% CBS, recording lengths at reference tension and at 30% load (To establish reference lengths)
- b) Relax to 10% CBS for at least one hour
- c) Reload to 30% CBS (Define minimum post-installation stiffness as secant stiffness between 10% and 30% CBS on this cycle)
- d) Relax to 10% CBS
- e) Without pause, cycle up to 50% CBS and down to 10% CBS for 5 further cycles
- f) Hold at 10% CBS for at least one hour
- g) Reload to 30% CBS (Define minimum drift stiffness as secant stiffness between 10% and 30% CBS on this cycle)

- h) Cycle over a strain range of +/- 0.25% around a mean load of 30% CBS for 10,000 cycles (Define maximum storm stiffness as the maximum tangent stiffness on the 10,000th cycle)
- i) Increase load to 60% CBS. Hold for 3 hours. Drop to 30% CBS. Immediately record length between bearing points. (Define total elongation at 30% as length i ) - length a )
- j) Hold at 30% CBS for 24 hrs and remeasure (Define permanent elongation at 30% CBS as length j ) - length a )

Alternatively, the loads, load rates and relaxation times may be defined by the purchaser for the location in question.

**[TTI to clarify the rational behind the strain range of +/- 0.25 % which is a function of material, water depth, mooring line geometry and platform dynamic excursion**

### **3. Alternative Test Porocedures**

In addition to the test procedure provided above, other testing proposals have been suggested including that by Bureau Veritas (1997).

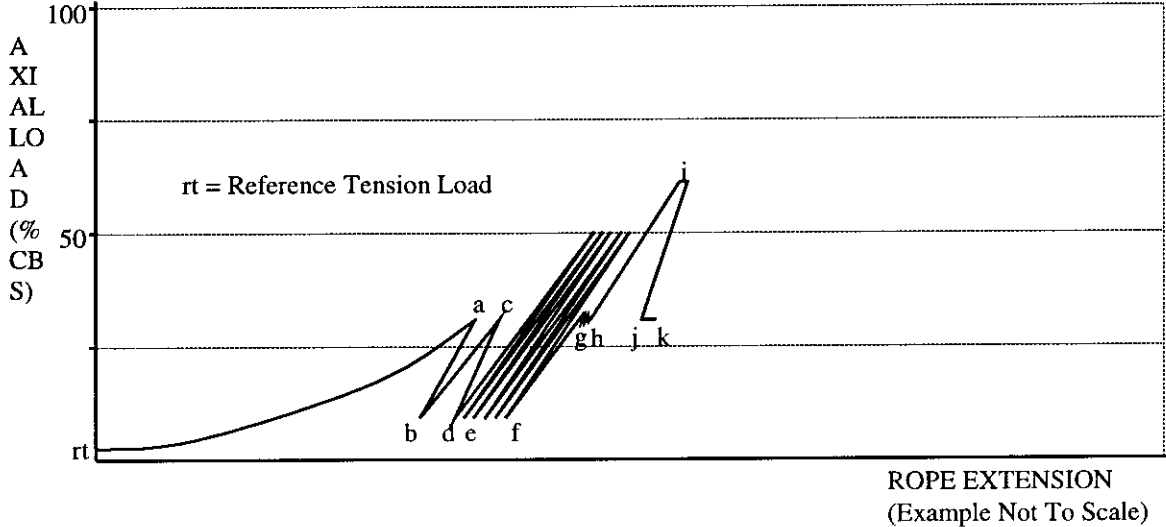
#### **References**

Bureau Veritas (1997)

"Guidance Notes For Certification Of Synthetic Fibre Ropes For Mooring Systems; Document Reference Ni 432 Dto R00 E, Bureau Veritas, Paris La Defense, 1997.

Figure A-3.1

**Recommended Test Loading Cycles**  
**Proposed Prototype Rope Testing Procedure**



**APPENDIX 4****WORKED EXAMPLE****DRAFT****Contents**WORKED EXAMPLE  
Rev 1.

PART A

1. **Introduction**
2. **Organisation and Contents of Report**
  - 2.1 **Notes on Dynamic Analysis of Fibre Rope Moorings (3 sheets)**
  - 2.2 **Data Necessary to Complete the Mooring Analysis and References to DPD (1 sheet)**
  - 2.3 **Flowchart for the mooring line system design (1 sheet)**
  - 2.4 **Data for Mooring Analyses in the Latest Configuration (1 sheet)**
  - 2.5 **Worked example "a" Turret Moored FPSO- Atlantic Margin (46 sheets)**
    - 2.5.1 Sensitivity Study (1): increase of the diameter (and strength & stiffness) of the Fibre Rope (5 sheets)
    - 2.5.2 Sensitivity Study (2): increase of the normal drag coefficient of the Fibre Rope (5 sheets)
    - 2.5.3 Fatigue analysis (10 sheets)
  - 2.6 **Worked example "b" - Semi Sub - Atlantic Margin (risers not included) (33 sheets)**
  - 2.7 **Worked example "c" - Semi sub - Brazilian Margin (including risers) (3 sheets)**

## 1. Introduction

Worked Examples have been prepared for two different vessel types and two geographic locations:

**Vessels:**

Turret Moored FPSO with 12 lines

Semisubmersible with 16 lines

**Locations:**

Norwegian Sea / Atlantic Margin; 1,000 metres and 1,500 metres water depth

South Atlantic (offshore Brazil); 1,000 metres water depth

Data for platforms and environmental conditions have been drawn from realistic conditions but is not intended to represent any particular installation. The intention has been to provide by means of the worked examples an illustration of how the provisions of the Engineers Design Guide for Deepwater Fibre Moorings can be used to design a fibre rope mooring system.

## 2. Organisation and Contents of Report

The report has been organised in the following sections:

### ***2.1 Notes on Dynamic Analysis of Fibre Rope Moorings (3 sheets)***

The method of using upper and lower bound linear stiffnesses to determine maximum platform excursions and extreme line loads is summarised

### ***2.2 Data Necessary to Complete the Mooring Analysis and References to DPD (1 sheet)***

The items of data required to perform a mooring analysis in accordance with the DPD are listed and references are given to the appropriate parts of the DPD.

### ***2.3 Flowchart for the mooring line system design (1 sheet)***

A simple flowchart is provided illustrating the design cycle investigations required for the DPD.

### ***2.4 Data for Mooring Analyses in the Latest Configuration (1 sheet)***

A table is used to summarise the data used for the three worked examples conducted:

- ( a ) Turret Moored FPSO; Atlantic Margin; 1,000 metres water depth

- ( b ) Semisubmersible; Atlantic Margin; 1,500 metres water depth
- ( c ) Semisubmersible; South Atlantic (offshore Brazil); 1,000 metres water depth

## ***2.5 Worked example “a” Turret Moored FPSO- Atlantic Margin (46 sheets)***

Various stages of analysis work are contained for this example:

Input data is summarised and referenced to the DPD.

A design cycle is completed to show that a satisfactory design can be provided by means of a 15,000 kN break strength polyester fibre rope with top and bottom chafe chains. Platform excursion, line minimum and maximum loads and number of cycles below the guideline minimum tension are checked.

This is followed by several sensitivity studies illustrating the effects of:

***2.5.1 Sensitivity Study (1): increase of the diameter (and strength & stiffness) of the Fibre Rope (5 sheets)***

***2.5.2 Sensitivity Study (2): increase of the normal drag coefficient of the Fibre Rope (5 sheets)***

***2.5.3 Fatigue analysis (10 sheets)***

## ***2.6 Worked example “b” - Semi Sub - Atlantic Margin (risers not included) (33 sheets)***

Results from an initial run of the analysis are presented.

## ***2.7 Worked example “c” - Semi sub - Brazilian Margin (including risers) (3 sheets)***

Results from an initial run of the analysis are presented.

### **References**



**Notes on Dynamic Analysis of Fibre Rope Moorings**

**(3 sheets)**

## Worked Example:

### Notes On

## Dynamic Analysis of Fibre Rope Moorings

### 1. INTRODUCTION

A dynamic mooring analysis program is required to undertake the analysis of platform excursions and line tensions. It should be capable of modelling the dynamics of the platform under the restraint of mooring line stiffnesses and of calculating the dynamically varying tensions in individual lines under the effects of platform motions.

The worked example cases have been conducted using the DMOOR-4.0 program, which is capable of analysing the dynamics of the platform and of the mooring lines. Some calculations of line dynamics were also checked using ORCAFLEX.

Frequency Domain analysis was generally used for determining platform dynamics and maximum line tensions but Time Domain analysis may also be used to determine minimum line tensions.

Extreme line tensions (maximum and minimum) and their frequency of occurrence are required to check against axial tension and axial compression fatigue.

### 2. CALCULATION OF PLATFORM EXCURSIONS

The platform excursions are first calculated. The analysis is repeated for various values of mooring line stiffness as described in DPD-8.4.

#### 2.1 *Static Excursions With EA minimum (Post Installation Stiffness)*

A static analysis is used to obtain the excursion ( $\chi_s$ ) due to wind, current and mean wave drift forces.

#### 2.2 *Dynamic Excursions With EA minimum (Post Installation Stiffness)*

Both wave frequency motions analysis and low frequency tension analysis are used to obtain the maximum first order motion ( $\chi_1$ ) and the significant second order motion ( $\chi_2$ ) of the platform.

The static excursion, the maximum first order motion and the significant second order motion are combined to obtain the extreme excursion ( $\chi_E$ ):

$$\chi_E = \chi_s + \chi_1 + \chi_2$$

Note that if the excursions from this analysis are too large it is permissible to use a higher line stiffness value if this can be justified operationally. This could be because a higher line pre-tension is applied subsequent to installation or because environmental conditions have caused the lines to be loaded to such levels.

### 3. CALCULATION OF LINE TENSIONS

#### 3.1 *Maximum Line Tensions With EA maximum (Storm Stiffness)*

The maximum line tension is used to conservatively estimate the maximum loads in the windward line.

A static analysis is used to get the line tensions ( $T_s$ ) and the excursion ( $\chi'_s$ ) under mean environmental loads (i.e. current, wind, mean wave drift).

A low frequency tension analysis is used to obtain the significant second order motion ( $\chi'_2$ ).

A quasi-static analysis is used to obtain line tensions ( $T_{s+2}$ ) under static and low frequency forces (imposing an excursion of  $\chi'_s + \chi'_2$ ).

Dynamic analysis (frequency domain) is conducted to obtain the root mean square value of the wave frequency dynamic tensions in the lines ( $\sigma_{dyn}$ ).

The maximum tensions ( $T_{max}$ ) in the lines are obtained by combining the tensions as follows:

$$T_{max} = T_{s+2} + 3.72 \times \sigma_{dyn}$$

#### 3.2 *Minimum Line Tensions With EA maximum (Storm Stiffness)*

The maximum line tension is used to conservatively estimate the minimum loads in the leeward line.

Minimum line tensions were determined from the line dynamics module of the DMOOR-4.0 program. If a separate line dynamics program (such as ORCAFLEX) is used the link between DMOOR and ORCAFLEX analyses is the tension ( $T_{s+2}$ ) under static and low frequency forces. Platform fairlead excursions are then applied at the top of the line in the ORCAFLEX model in order to simulate these tension values ( $T_{s+2}$ ). The line dynamics program is then run (in the time domain) in order to obtain the minimum tension ( $T_{min}$ ) in the leeward line.

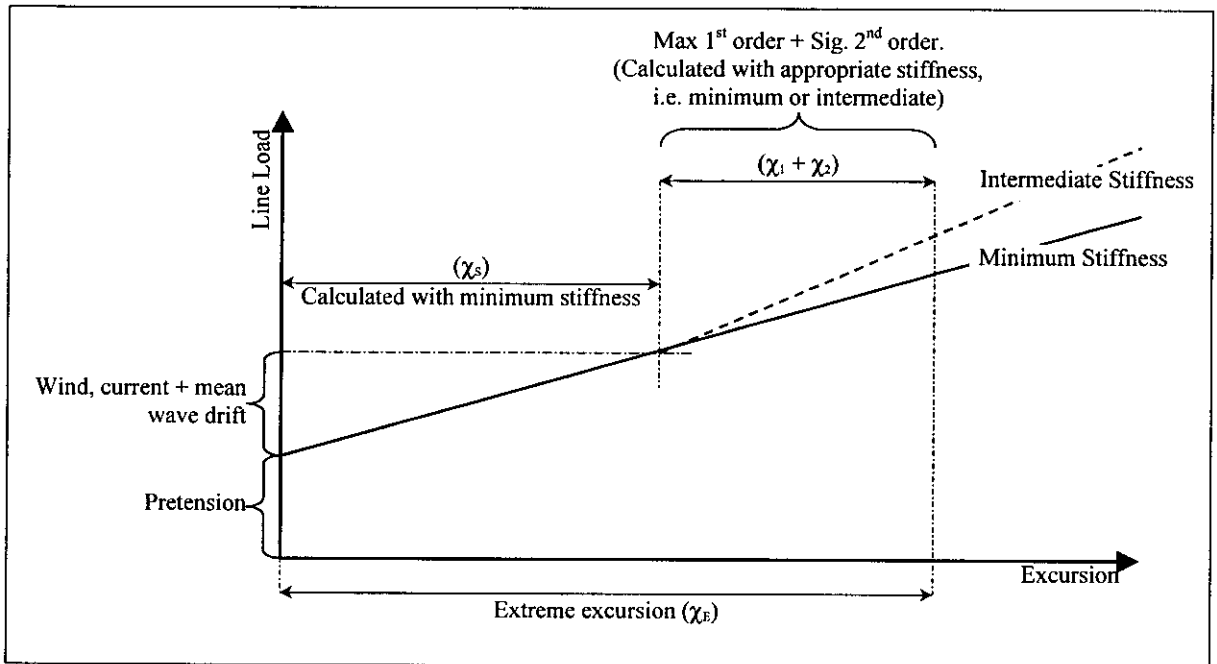


Figure 1: Calculation of Platform Excursions

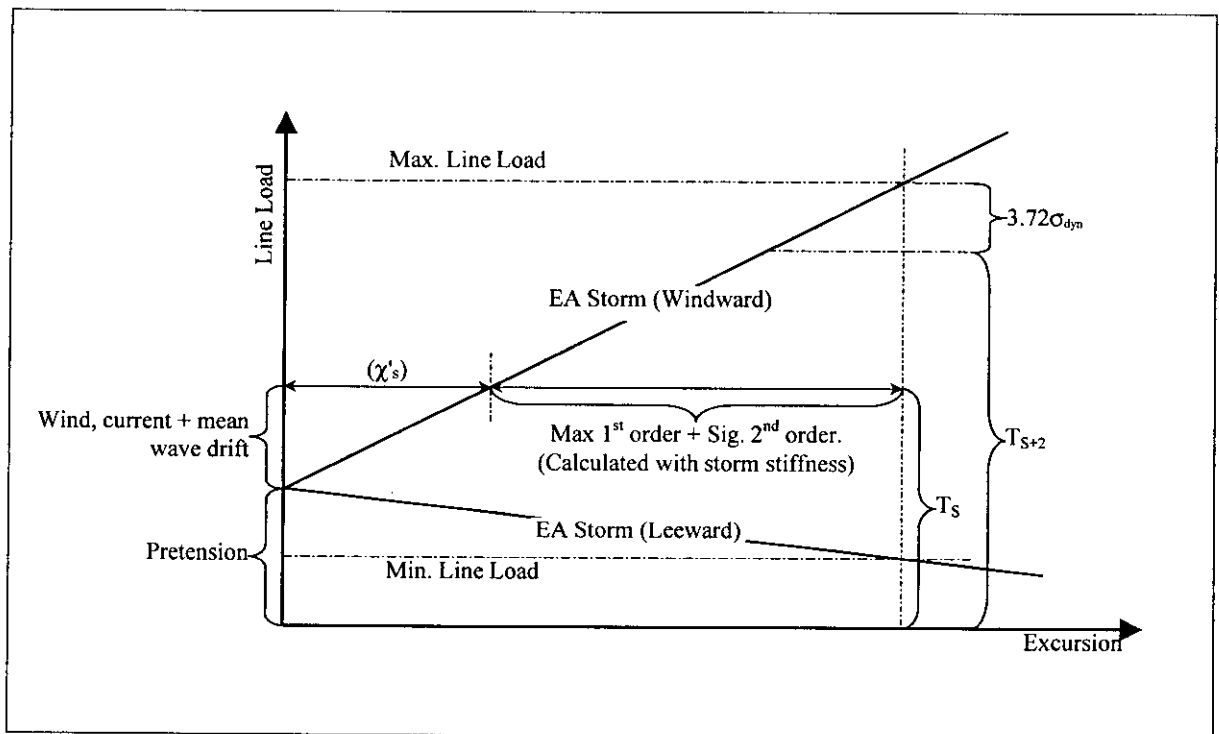


Figure 2: Calculation of Extreme Line Tensions

**Data Necessary to Complete the Mooring Analysis and References to DPD**

**(1 sheet)**

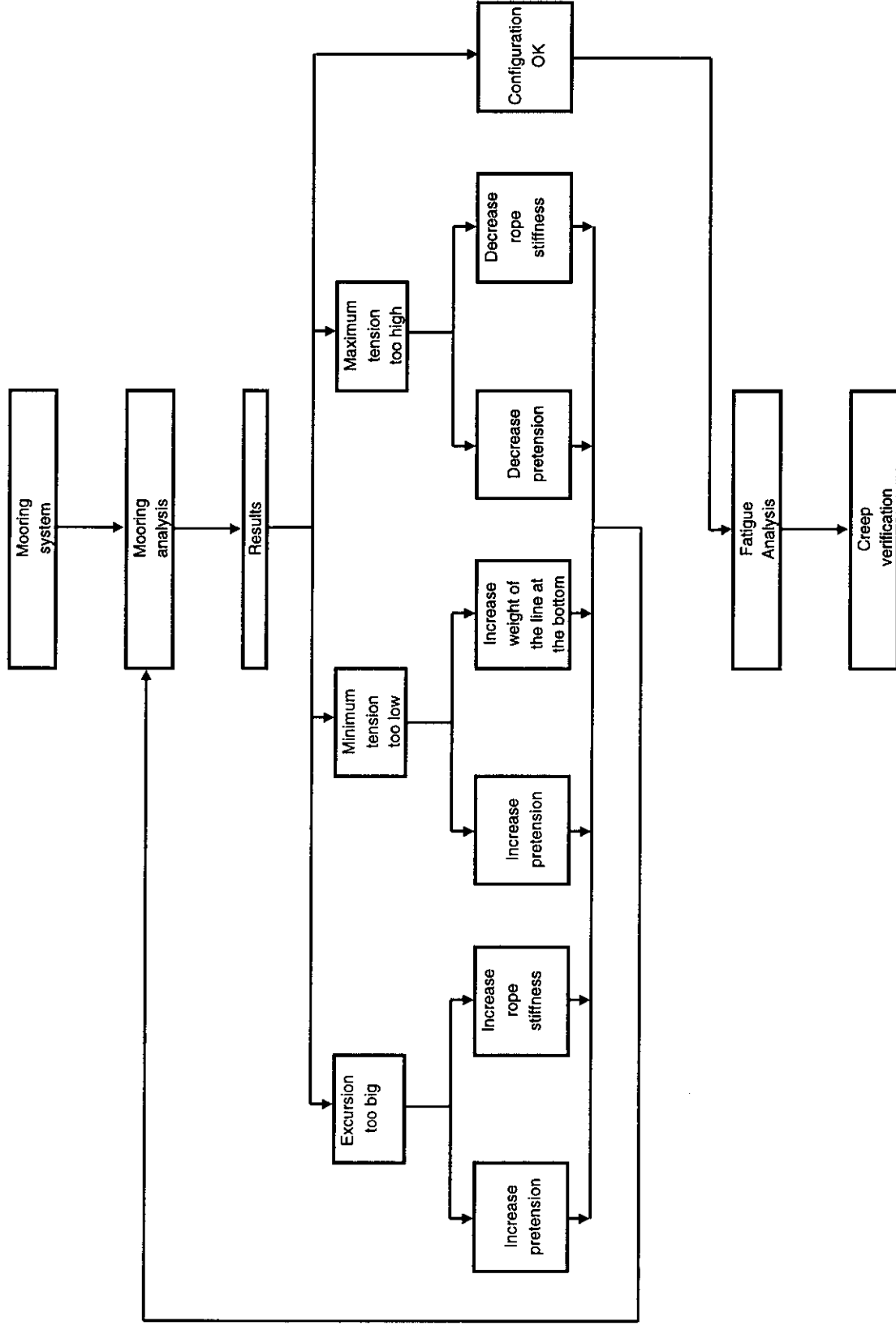
**Data necessary to complete the mooring analysis,  
and their reference in the DPD**

Data	Reference in EDG - DPD
<p><i>Site data, location</i>                      Environmental conditions (wind, wave, current)                      Water depth                      Seabed slope</p>	DPD 7.
<p><i>Platform data</i>                      Type of vessel                      Dimensions                      Displacement, mass                      Mass moment of inertia                      Added mass                      Damping                      Response Amplitude Operators (RAO's)                      Wave Drift Coefficients (QTF)                      Wind and current coefficients                      Turret and fairlead position</p>	DPD 7.
<p><i>Other</i>                      Risers data                      Thrusters</p>	?
<p><i>Mooring lines segments make-up</i>                      Fiber rope                          Diameter                          Dry and wet masses                          Stiffness                          Fatigue data                          Drag coefficient                          Friction coefficient                          Breaking load                      Other mooring line components</p>	DPD 5.2.2. DPD 5.2.2. DPD 5.3.3 DPD 5.5.2., DPD 8.2.9 DPD 8.3.4.3. DPD 8.3.4.4. DPD 6.
<p><i>Mooring system configuration</i>                      Number of lines                      Spread angle between lines                      Length of lines and segments                      Pretension                      Position of anchor</p>	DPD 8.

**Flowchart for the mooring line system design**

**(1 sheet)**

### Flowchart for the mooring line system design





**Data for Mooring Analyses in the Latest Configuration.**

**(1 sheet)**



**Worked example “a”**

**Turret Moored FPSO- Atlantic Margin**

**(46 sheets)**

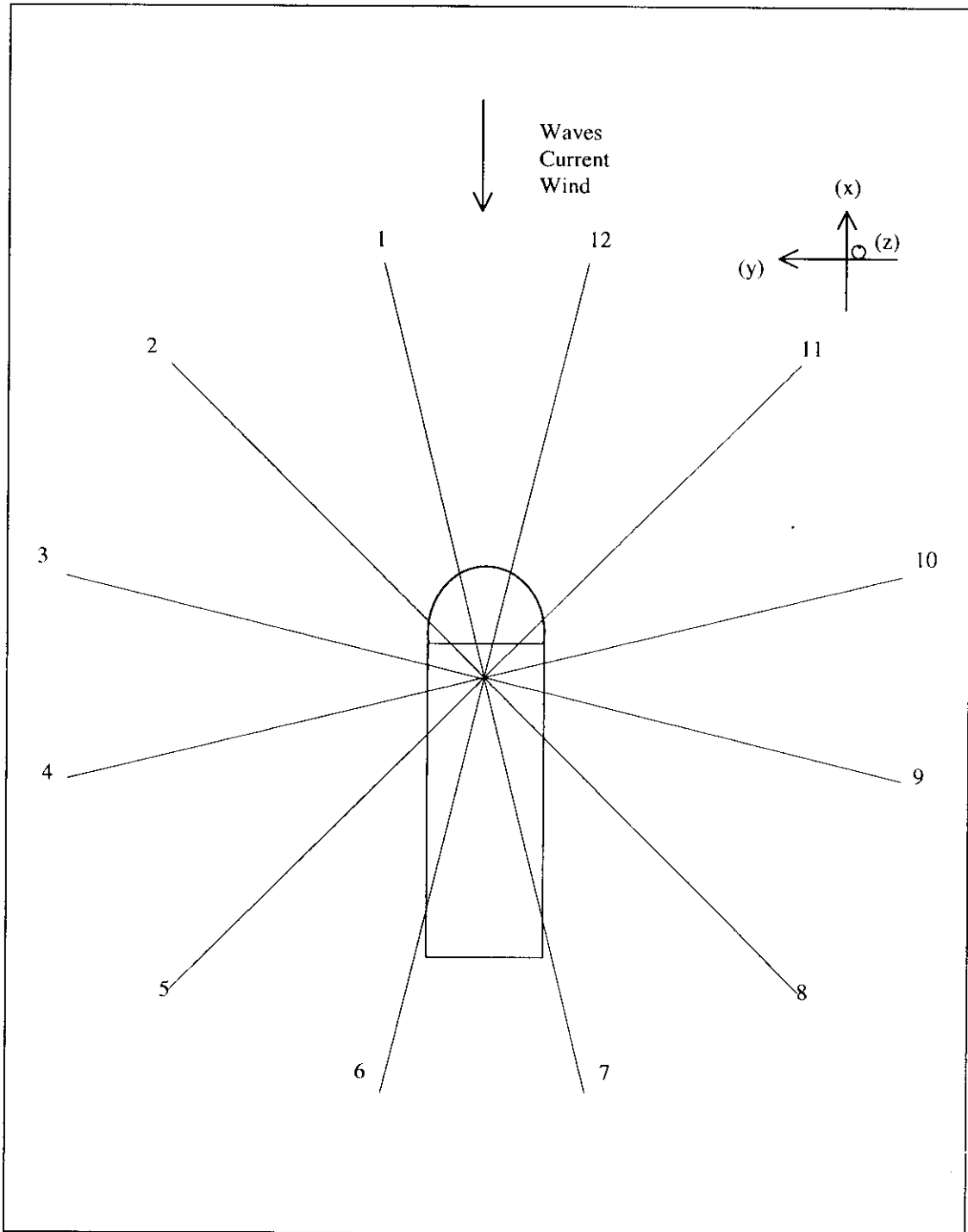
**Data necessary to complete the mooring analysis  
of an Atlantic Margin F.P.S.O.,  
their reference in the DPD, and results of the analysis.**

Reference in EDG - DPD	Data / Calculations	Results
DPD 7.	<p><i>Site data, location</i></p> <p>Location Environmental conditions environmental direction wind  wave  current  Water depth Seabed slope</p>	<p>Norwegian sea</p> <p>from F.P.S.O. bow</p> <p>Davenport spectrum Vw = 40 m/s</p> <p>Jonswap spectrum <math>\gamma = 3.3</math> Hs = 16.1 m Tp = 16.75 s Uniform Vc = 1.5 m/s 1 000 m 0 %</p>
DPD 7.	<p><i>Platform data</i></p> <p>Type of vessel Dimensions length breadth draft Displacement, mass Position of the COG COG forward aft perpendicular COG above keel Added mass surge sway yaw about COG Linear damping (vessel, mooring lines, risers) Surge (% of critical damping) Sway (% of critical damping) RAO's, QTF Wind and current coefficients  Turret turret centre aft of forward perpendicular turret diameter</p>	<p>Turret moored FPSO</p> <p>228.4 m 45 m 11.5 m 107,000 t 110.63 m 17.89 m 5,698 t 85,600 t 465x10<sup>6</sup> t.m<sup>2</sup>/rad 40 % 40 % RAOSC.xls and QTFSC.xls (appendix 1) 43.75 m 12 m</p>

	<p><b>Other</b> Risers data total load on risers in environmental direction</p>	2,600 kN
DPD 6.	<p><b>First mooring system configuration</b> Number of lines Spread angle between lines Length of lines from anchor to fairlead Number of segments in a line First segment (near the anchor) material breaking load length bar diameter dry mass added mass submerged weight stiffness normal drag coefficient tangential drag coefficient seabed friction coefficient Second segment material breaking load (BL) length diameter dry mass added mass submerged weight This is an unrealistically low value and was corrected later (see second step) stiffness normal drag coefficient tangential drag coefficient seabed friction coefficient Third segment Chain (K4 studlink) length Pretension  (see figure 1)</p>	<p>12 30 deg. 1,325 m 3 chain (K4 studlink) 14,715 kN 25 m 0.127 m 0.3532 t/m 0.0459 t/m 3.0145 kN/m 1.427x10<sup>6</sup> kN/m/m 2.5 0.5 1 fibre rope 14,715 kN 1,200 m 0.208 m 0.0349 t/m 0.0341 t/m 0.000854 kN/m variable from 8xBL to 35xBL 1.2 0.05 0 100 m Variable from 0.1xBL to 0.3xBL</p>
DPD 5.2.2. DPD 5.2.2. DPD 5.2.2. DPD 5.3.3 DPD 8.3.4.3. DPD 8.3.4.4. DPD 6.		
DPD 8.2.4.1. DPD 8.2.4.2.	<p><b>Results for this first configuration</b> Typical input files for DMOOR 4.0 are provided in Appendix 2  <b>Conclusion:</b> After few calculation with different dip angles, we saw that the line length is too small.</p>	<p>File EDG-SCH1.xls Max. tension too high Min. tension too low</p>

Figure 1:

**Schematic of mooring line layout for Atlantic Margin FPSO**



**FPSO**

Fibre rope : **Polyester** 1 200 m

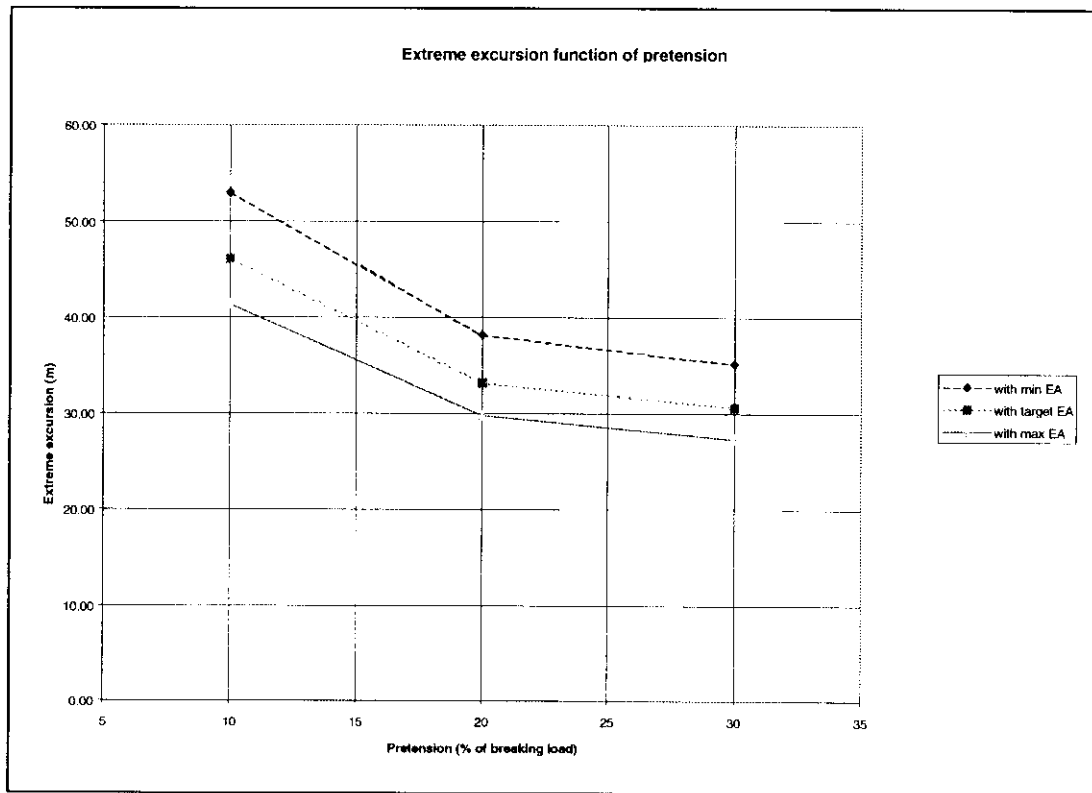
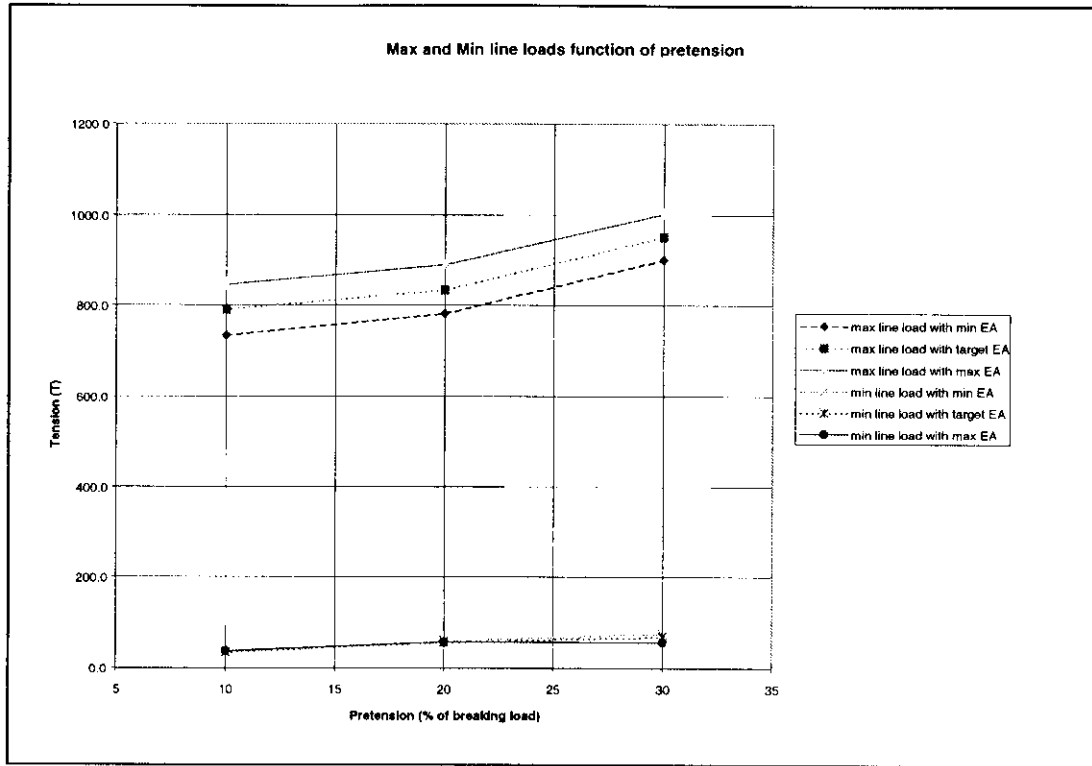
Breaking Load = 1 500 T  
Water depth = 1 000 m

Pretension		EA min	EA int	EA max	Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
10% BL	8 * BL	15 * BL	25 * BL	35 * BL					
	10 * BL	20 * BL	30 * BL	40 * BL	46.12	4.61	791.0	1.90	34.6
	12 * BL	25 * BL	35 * BL	45 * BL	41.33	4.13	846.6	1.77	36.9
20% BL	8 * BL	15 * BL	25 * BL	35 * BL	38.16	3.82	782.3	1.91	58.8
	10 * BL	20 * BL	30 * BL	40 * BL	33.20	3.32	835.9	1.79	57.6
	12 * BL	25 * BL	35 * BL	45 * BL	29.67	2.98	888.7	1.68	56.6
30% BL	8 * BL	15 * BL	25 * BL	35 * BL	35.18	3.52	901.8	1.66	74.6
	10 * BL	20 * BL	30 * BL	40 * BL	30.62	3.06	952.4	1.57	68.4
	12 * BL	25 * BL	35 * BL	45 * BL	27.34	2.73	1002.5	1.50	57.3

1 line damage

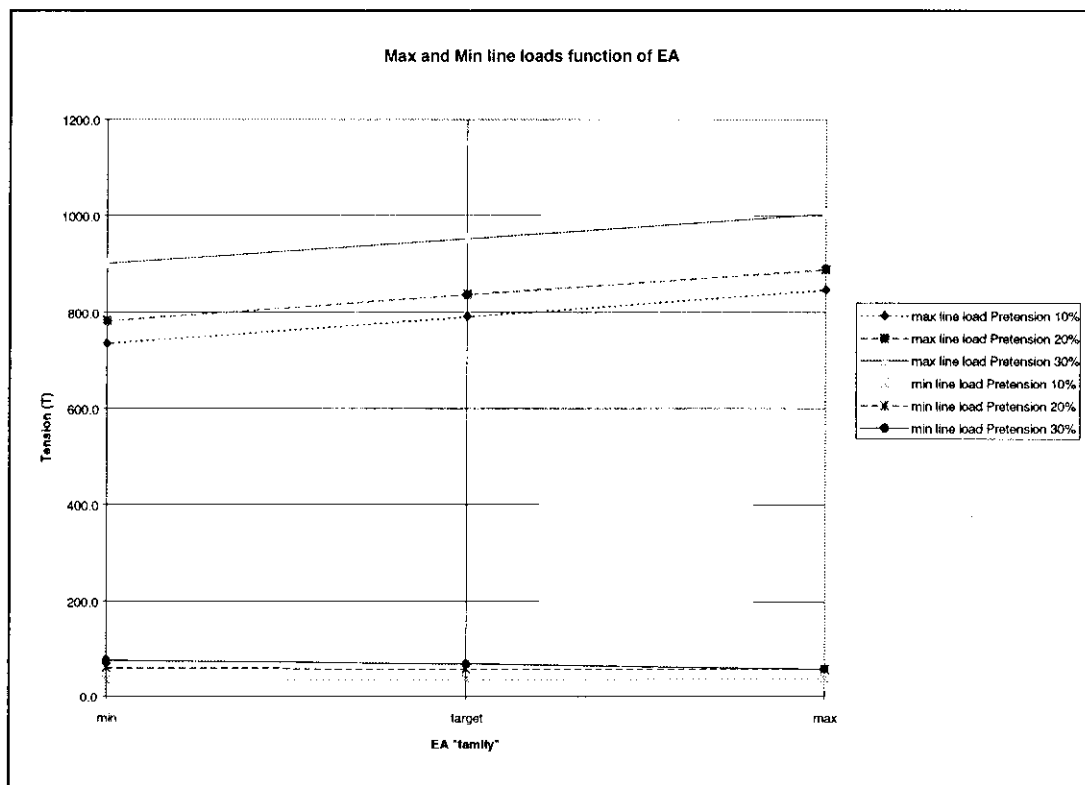
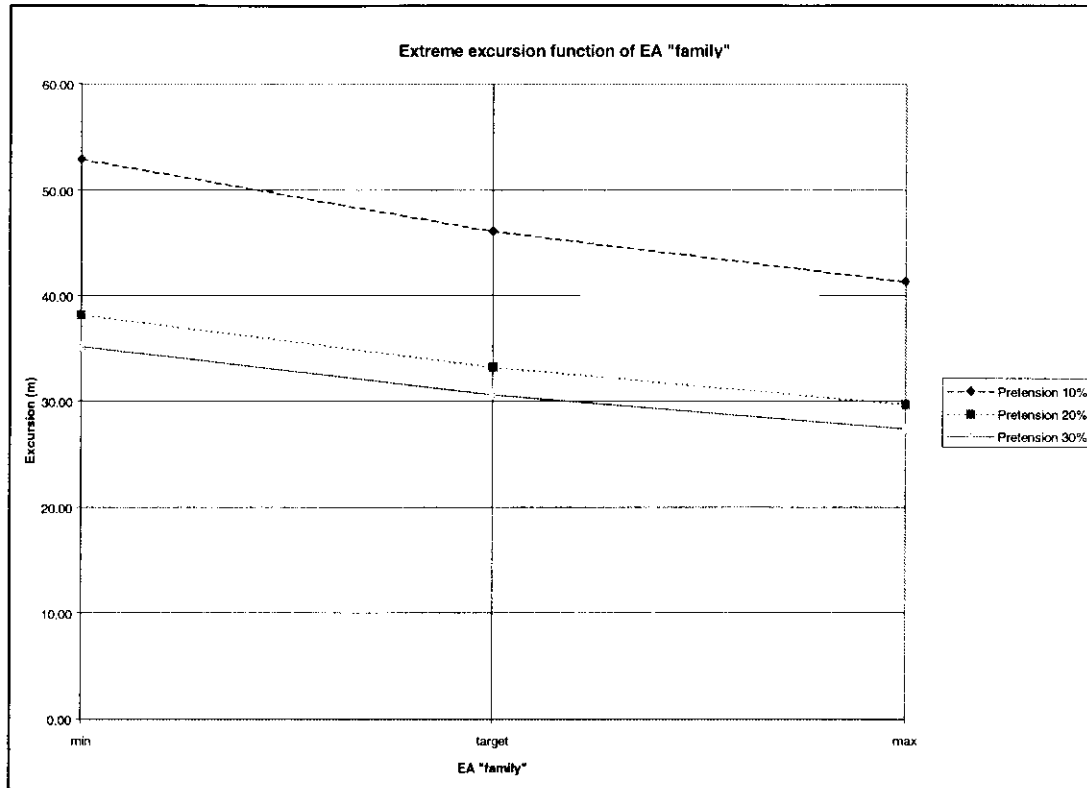
Line 12

Pretension		EA min	EA int	EA max	Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
10% BL	8 * BL	15 * BL	25 * BL	35 * BL					





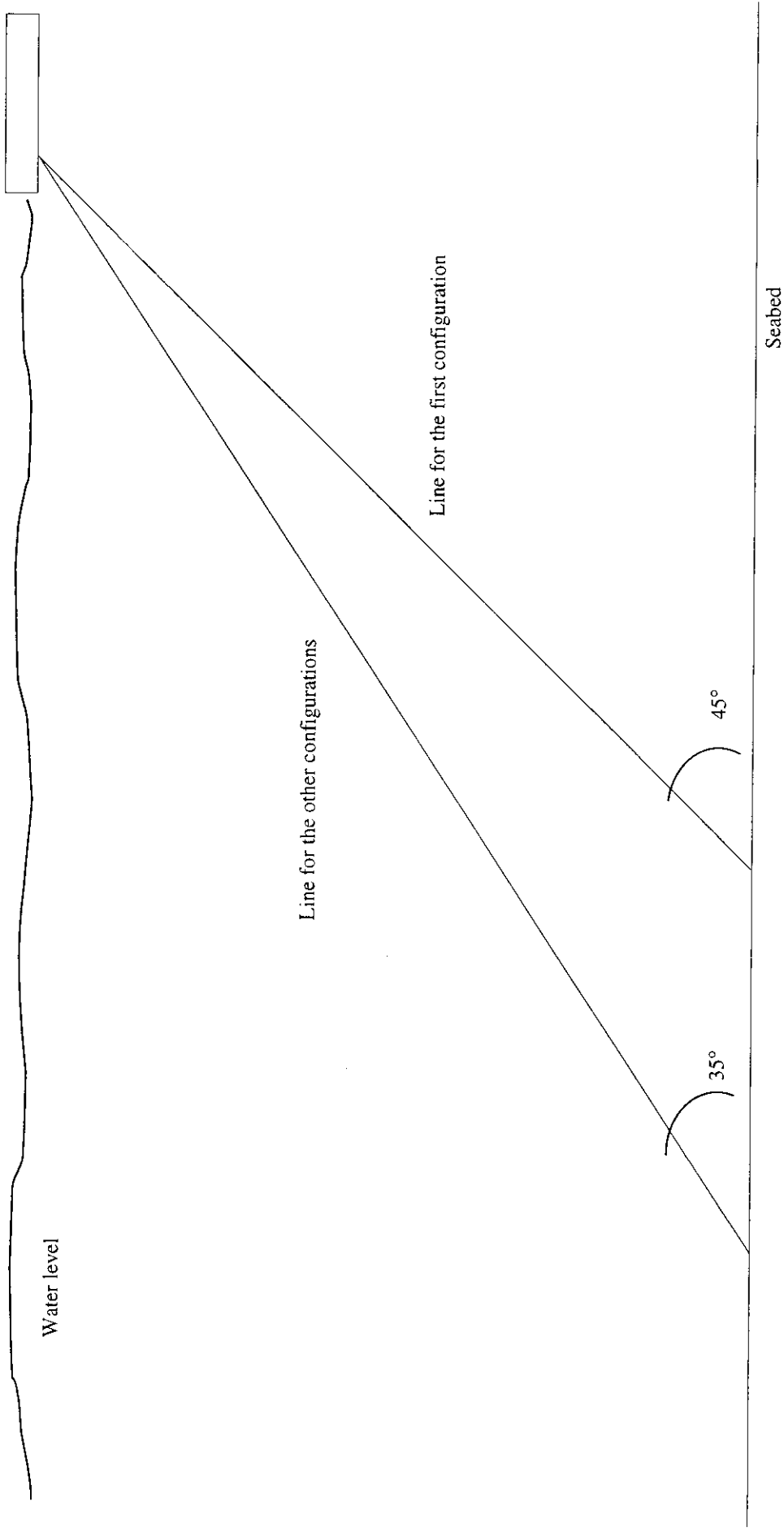
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	<p><b>Second mooring system configuration</b>                  The only thing that changes compared to the first configuration is the length of the second segment, the dip angle passing from 45 deg. to 35 deg.                  Length of lines                  Second segment length                  (see figure 2)</p>	<p>1,725 m                  1,600 m</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.                  DPD 5.2.2.</p>	<p><b>Results for this second configuration</b></p> <p><b>Conclusion:</b>                  The results are better than for the first configuration but still not acceptable. It was then noticed that the fibre ropes (segment 2) submerged weight had been set at an unrealistically low value. It was now corrected and the calculation re-run.</p>	<p>File EDG-SCH2.xls                  Min. tension too low</p>

Figure 2:

**Diagram showing line elevation for the different configuration**



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**FPSO**

Fibre rope : **Polyester** 1 600 m

Breaking Load = 1 500 T  
Water depth = 1 000 m

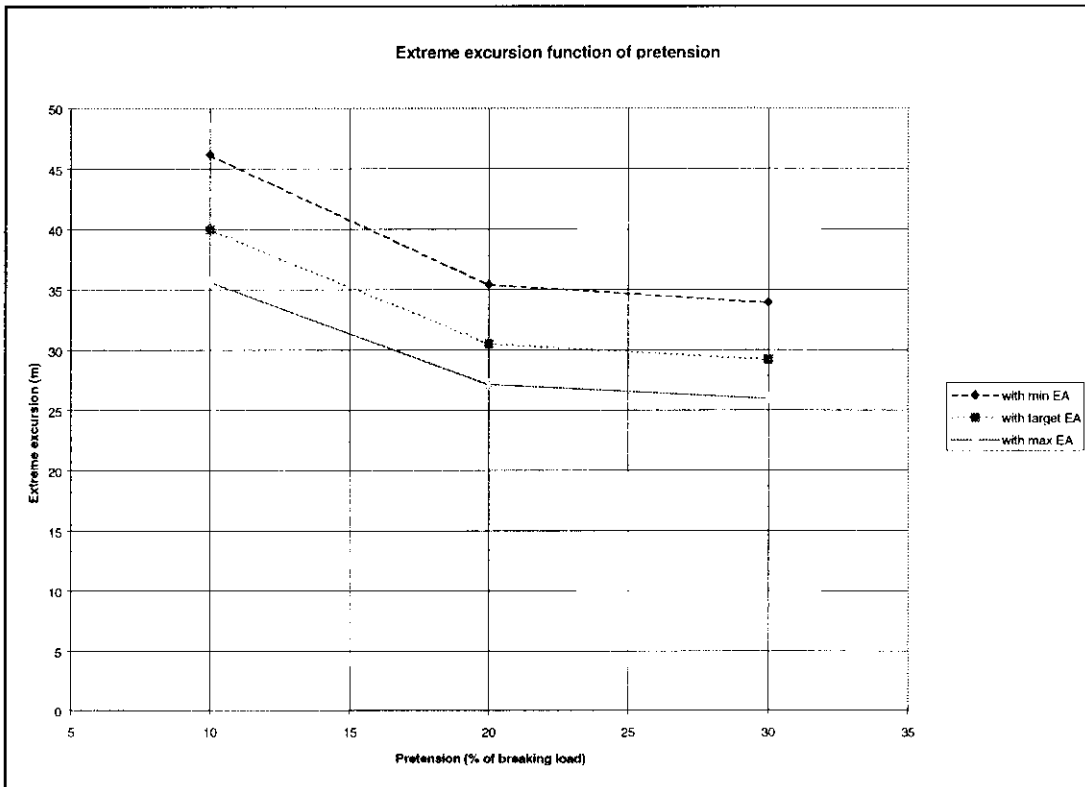
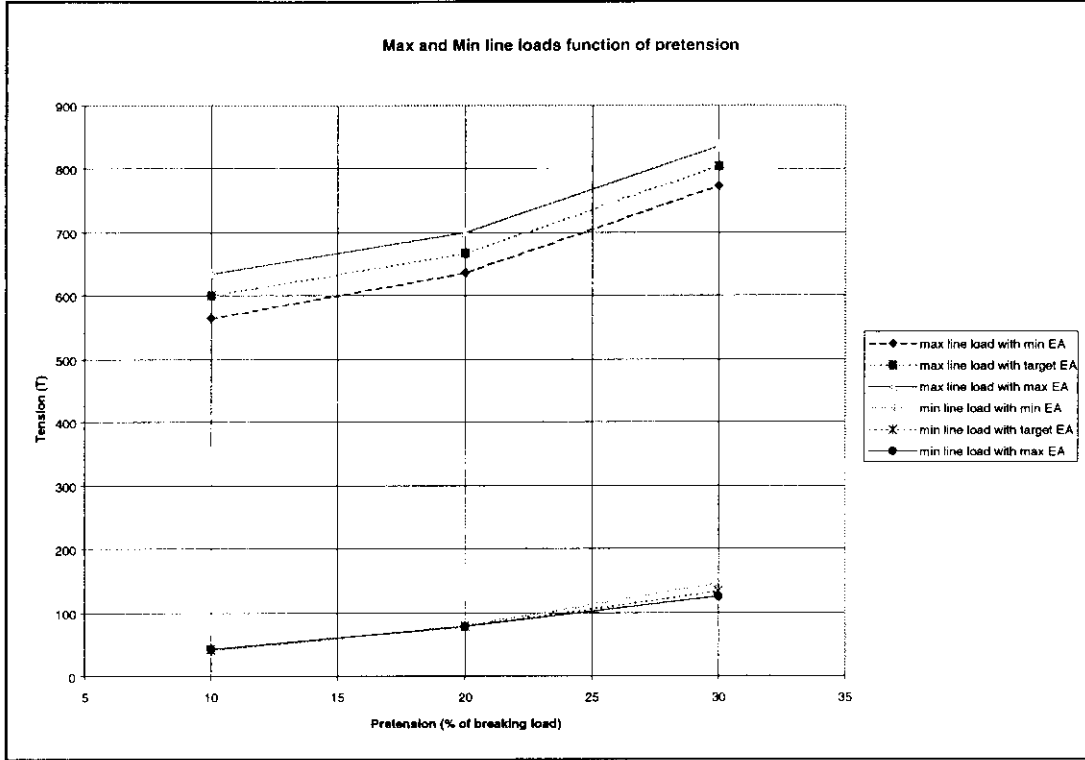
Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	46.17	4.62	564.9	2.65	40.3
	10 * BL	20 * BL	30 * BL	39.96	4.00	599.8	2.50	41.6
	12 * BL	25 * BL	35 * BL	35.65	3.57	635.4	2.36	42.3
20% BL	8 * BL	15 * BL	25 * BL	35.42	3.54	636.1	2.35	80.5
	10 * BL	20 * BL	30 * BL	30.53	3.05	667.90	2.24	78.2
	12 * BL	25 * BL	35 * BL	27.11	2.71	700.2	2.14	78.9
30% BL	8 * BL	15 * BL	25 * BL	33.93	2.29	773.10	1.94	146.6
	10 * BL	20 * BL	30 * BL	29.24	2.92	803.3	1.86	133.0
	12 * BL	25 * BL	35 * BL	25.95	2.60	834.2	1.79	125.4

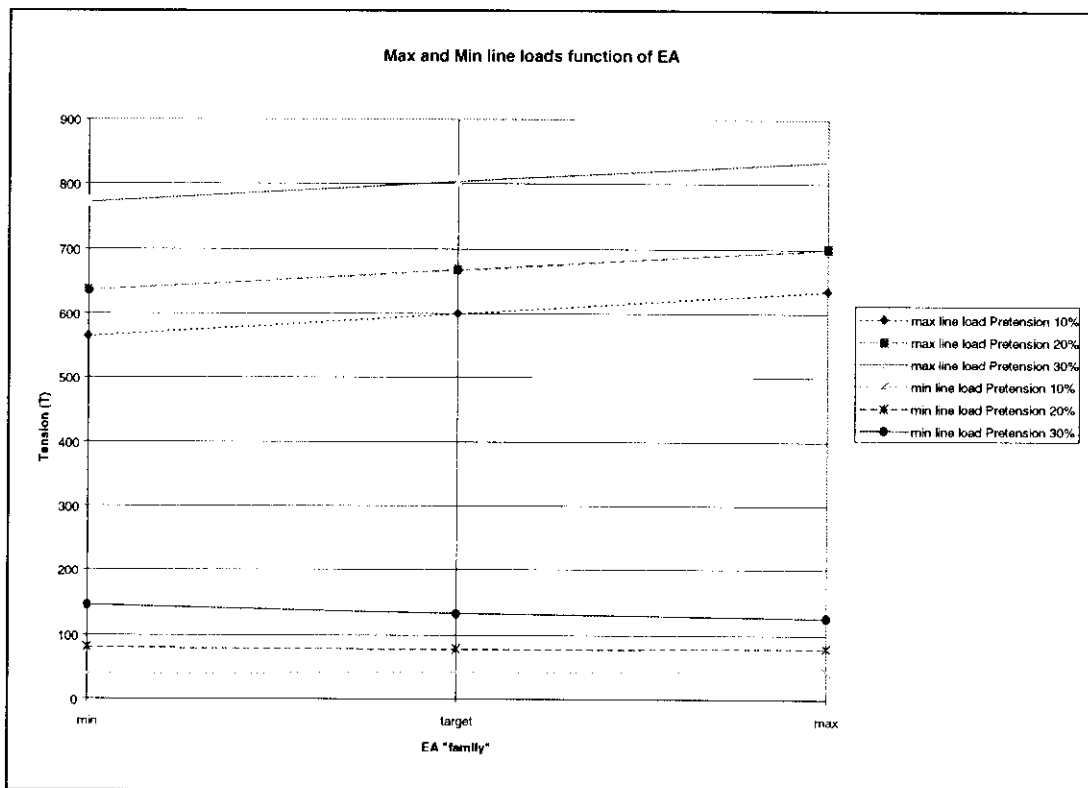
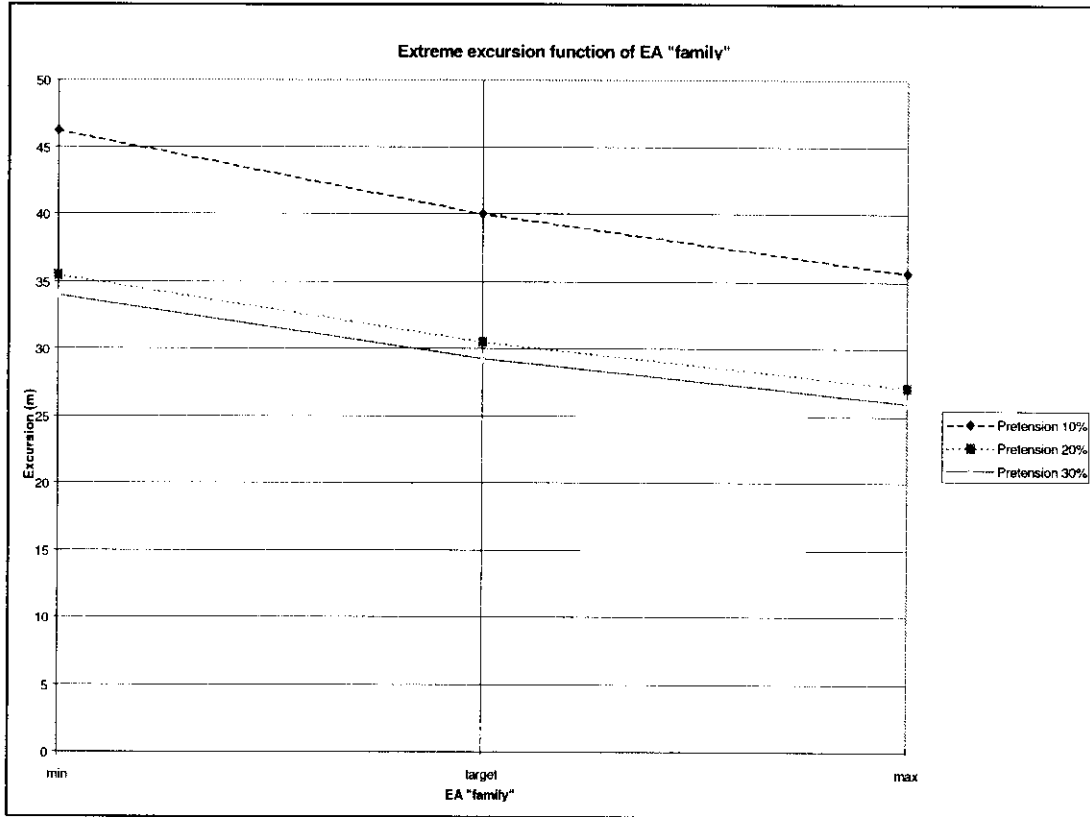
1 line damage

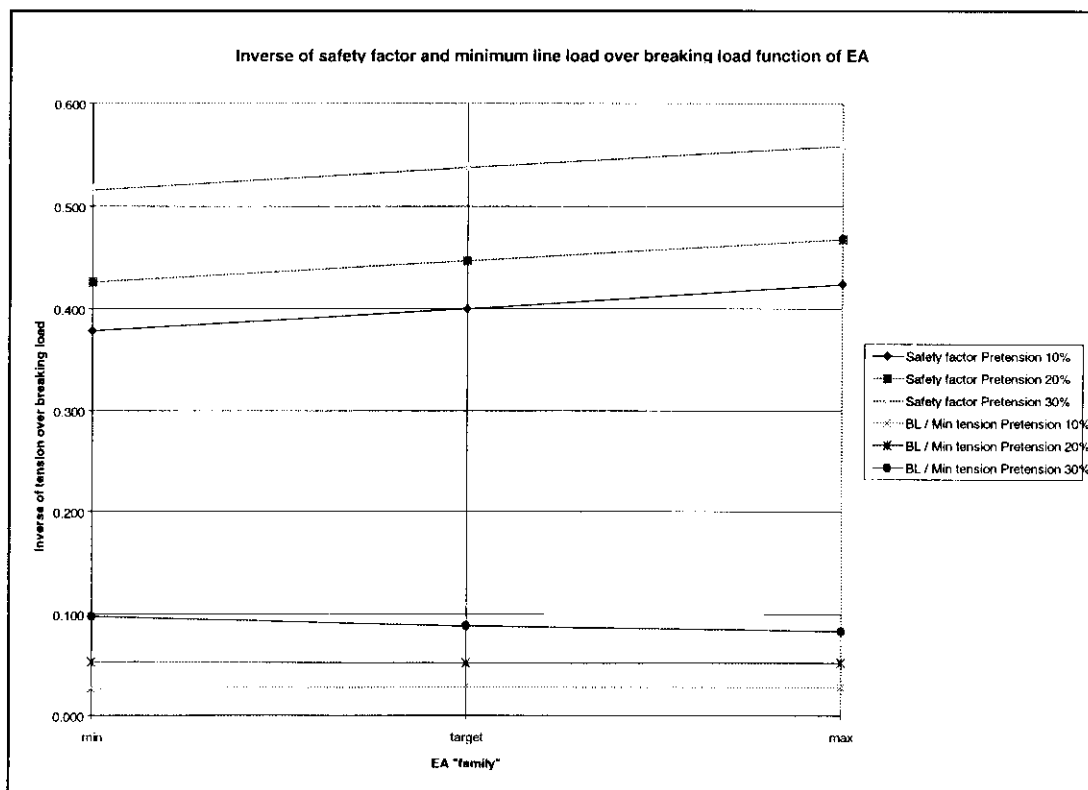
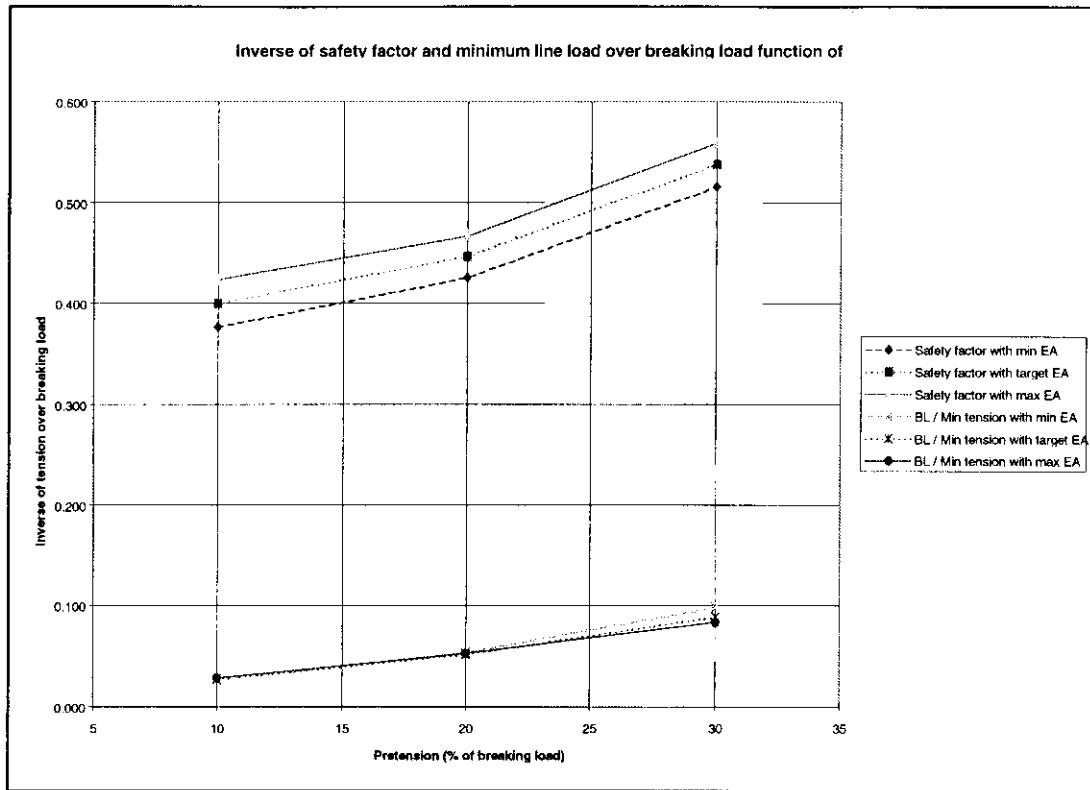
Line 12

Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	66.12	6.61	699.4	2.14	33.7

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<p>DPD 5.2.2.</p>	<p><b>Third mooring system configuration</b>                  The only thing that changes compared to the second configuration is the submerged weight of the second segment.                  Second segment submerged weight</p>	<p>0.868 kN/m</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results for this third configuration</b>   <b>Conclusion:</b>                  The configuration with pretension equals 0.3xBL and with the smaller family of stiffness seems to be suitable. But we want to demonstrate the accuracy of our minimum tension calculation method on DMOOR 4.0 with the program ORCAFLEX (as shown in the next stage of analysis).</p>	<p>File EDG-SCH3.xls</p>



**FPSO**

Fibre rope : **Polyester** 1 600 m

Breaking Load = 1 500 T  
Water depth = 1 000 m

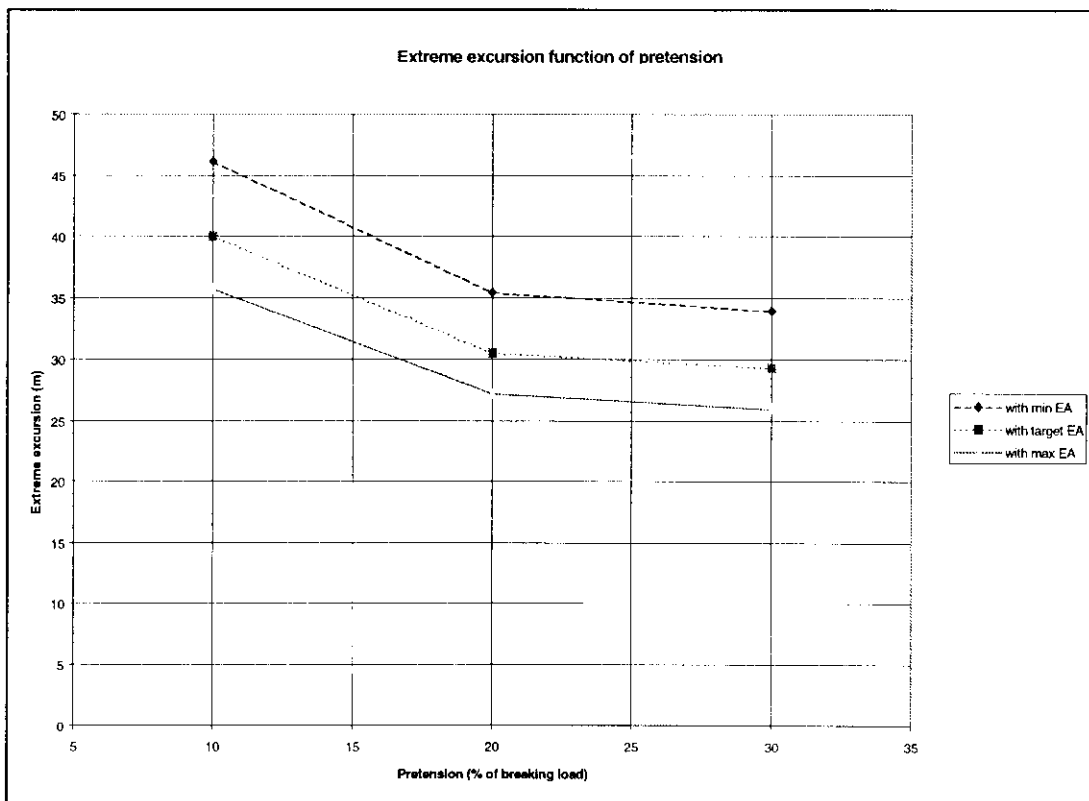
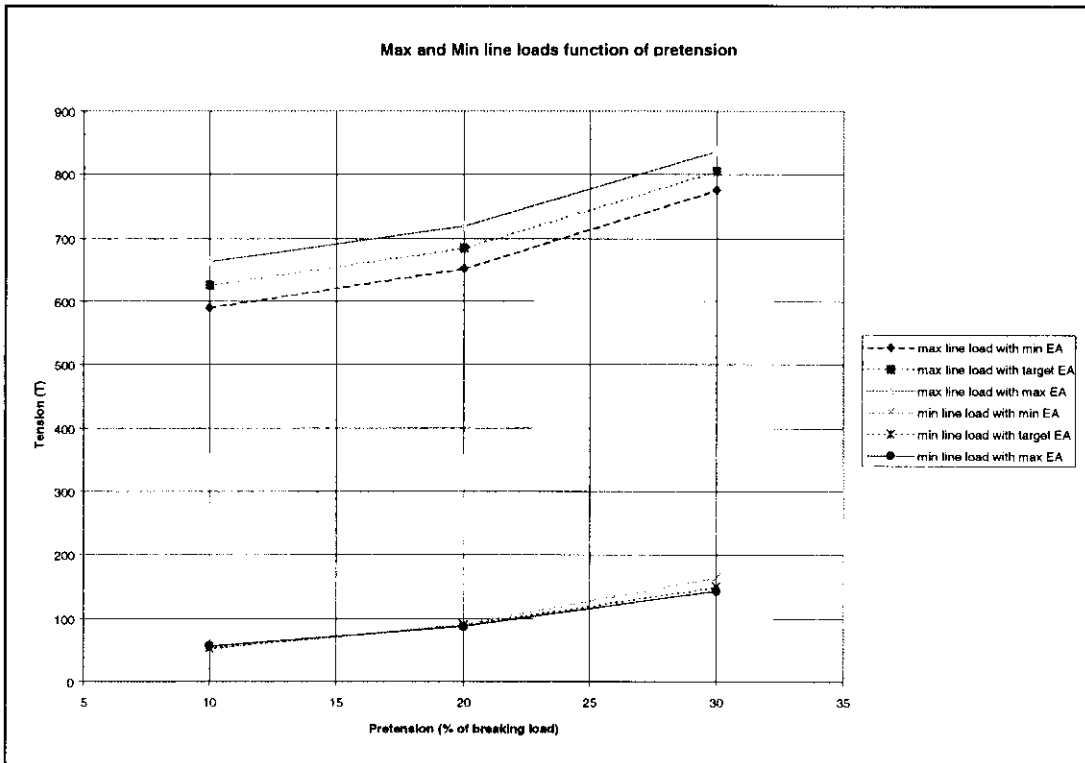
Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	46.17	4.62	590.3	2.54	52.8
	10 * BL	20 * BL	30 * BL	39.96	4.00	626.6	2.39	54.6
	12 * BL	25 * BL	35 * BL	35.65	3.57	663.1	2.26	56.5
20% BL	8 * BL	15 * BL	25 * BL	35.42	3.54	651.7	2.30	91.7
	10 * BL	20 * BL	30 * BL	30.53	3.05	684.4	2.19	89.2
	12 * BL	25 * BL	35 * BL	27.11	2.71	718.6	2.09	88.8
30% BL	8 * BL	15 * BL	25 * BL	33.93	2.29	775.40	1.93	165.0
	10 * BL	20 * BL	30 * BL	29.24	2.92	805.9	1.86	149.7
	12 * BL	25 * BL	35 * BL	25.95	2.60	836.6	1.79	142.9

Line 12

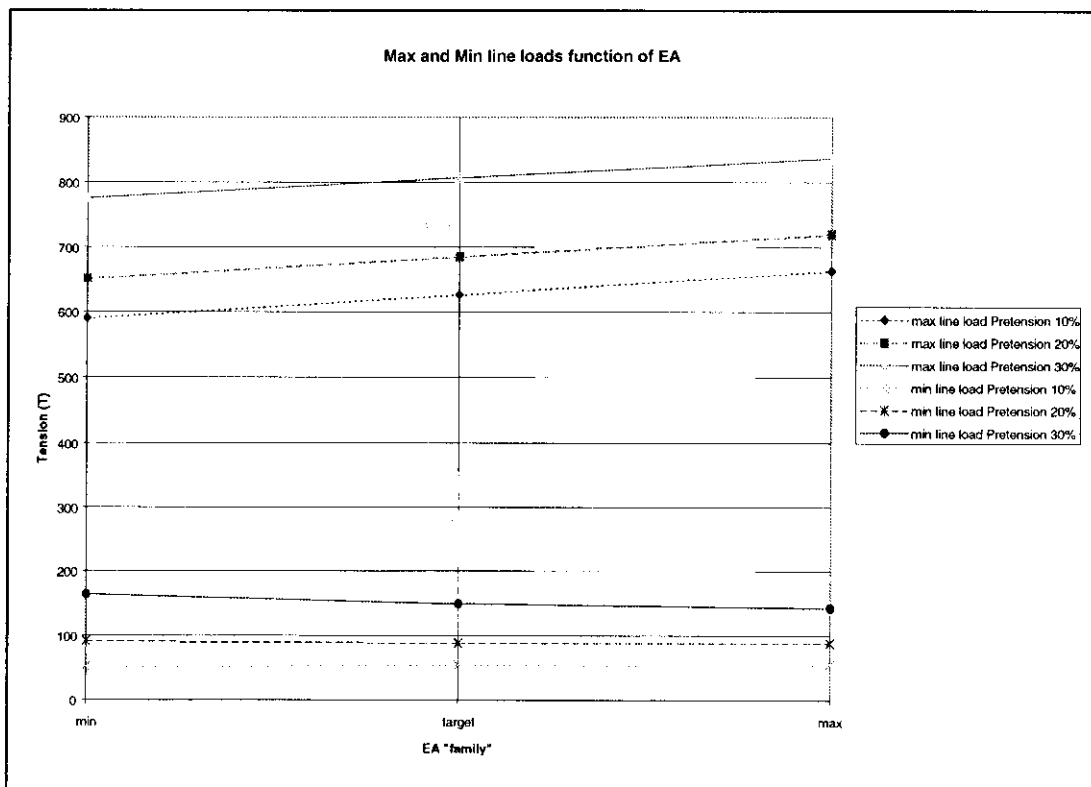
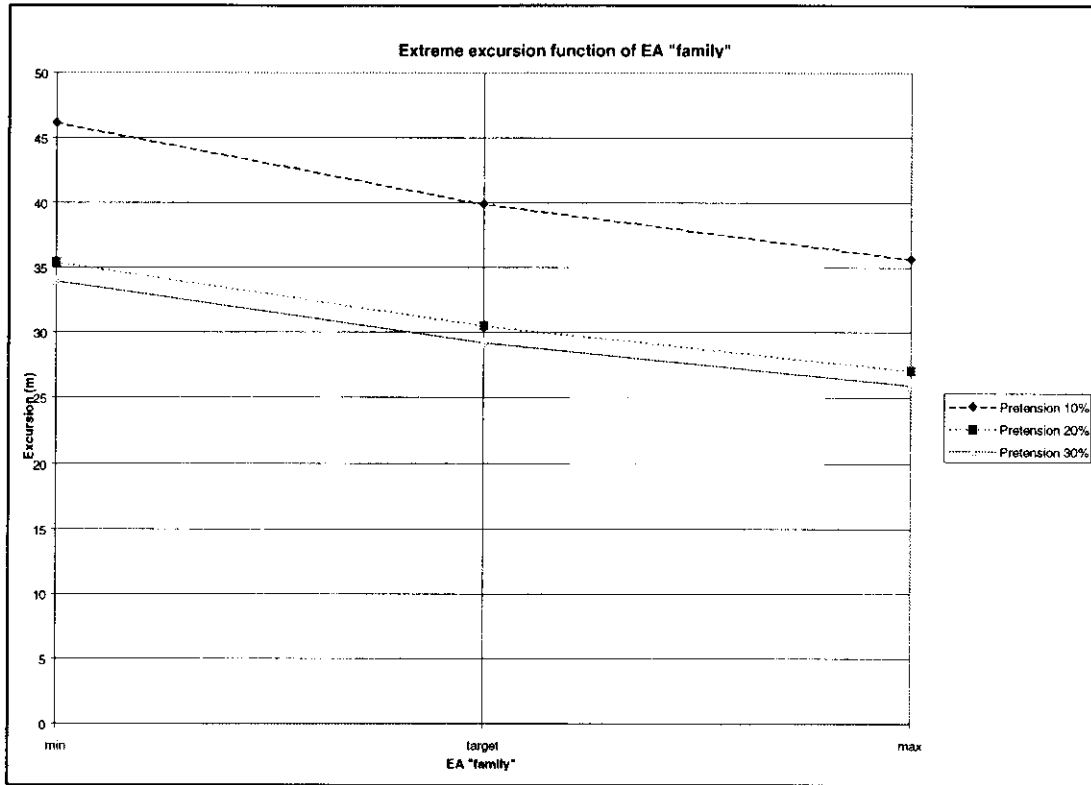
1 line damage

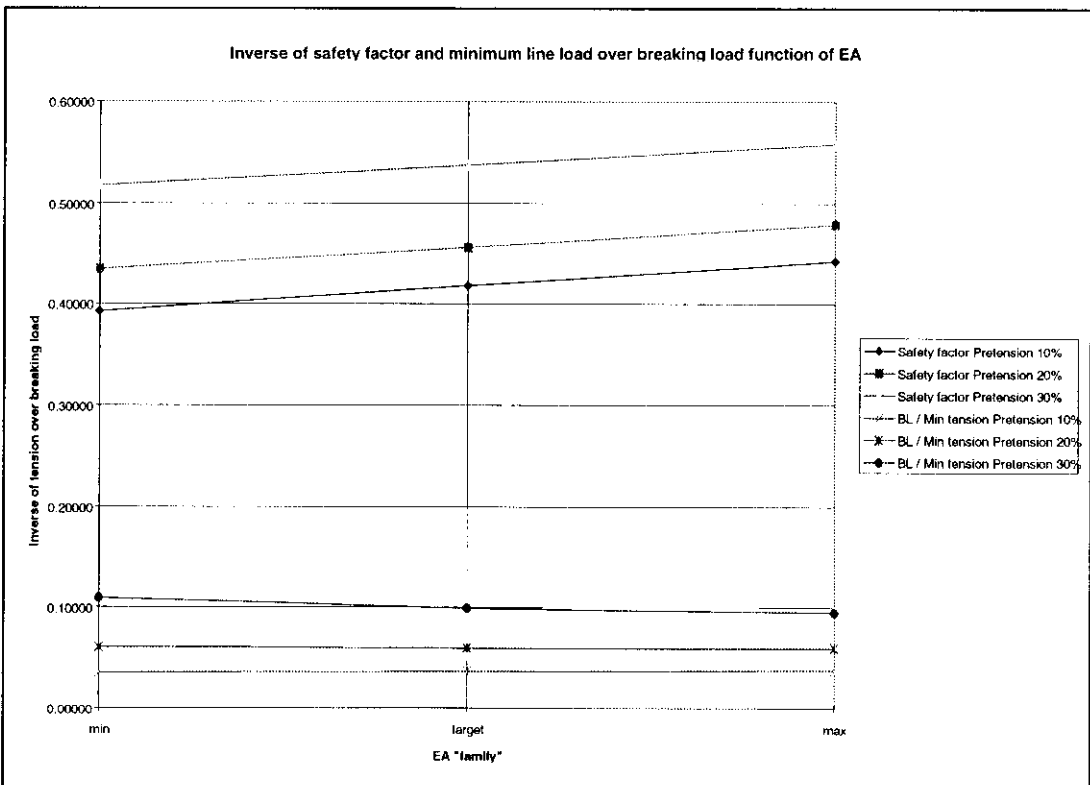
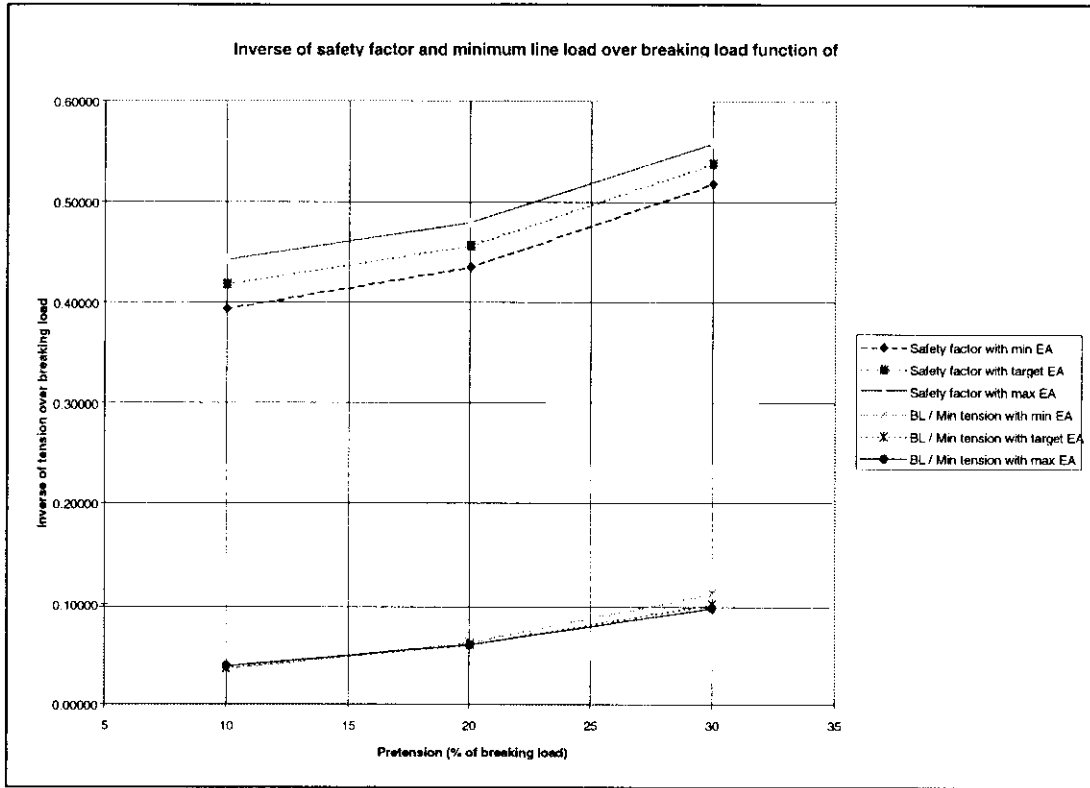
Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	66.12	6.61	730.8	2.05	44.2

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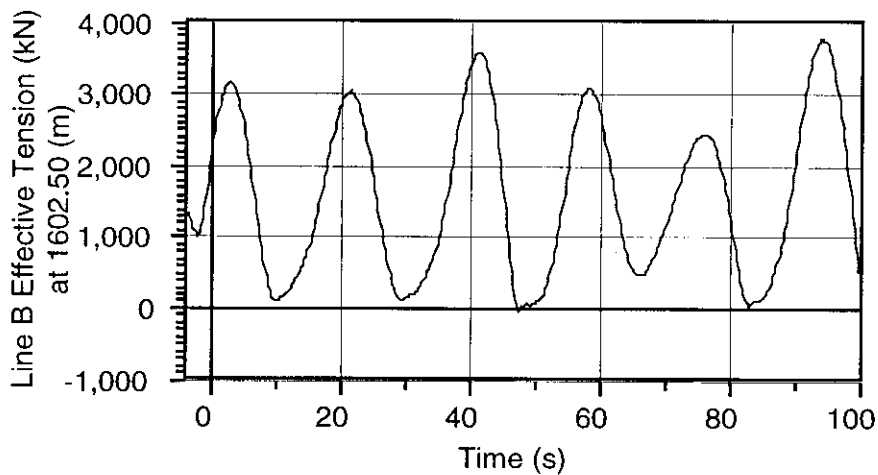
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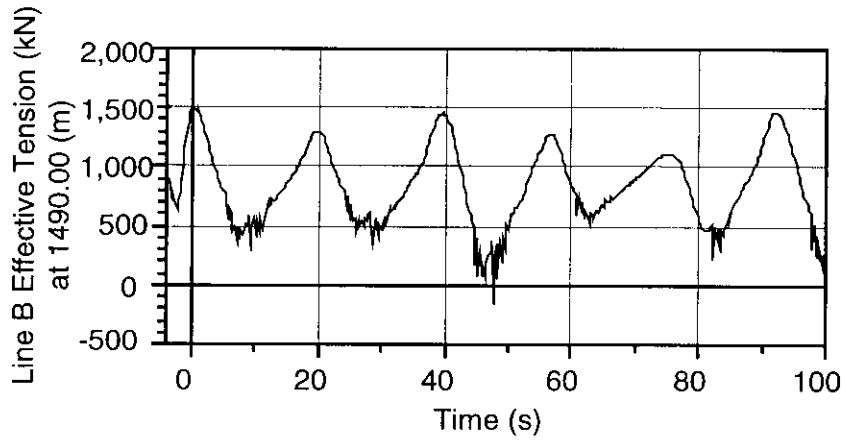


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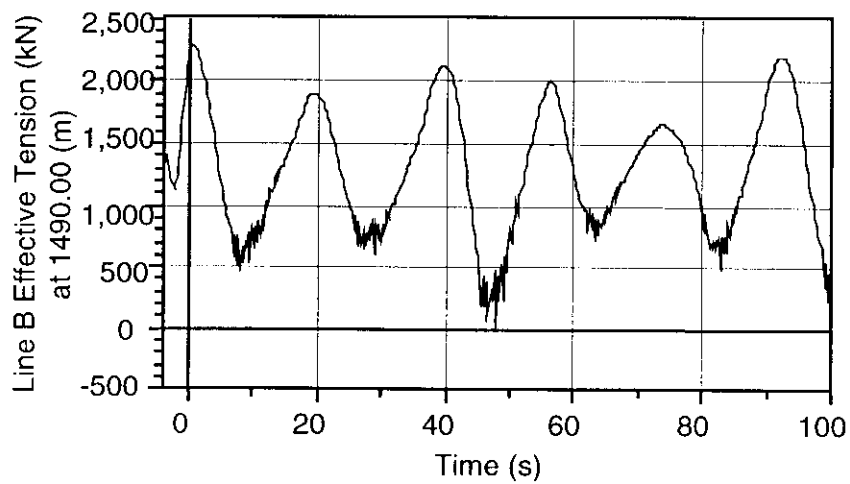
	<p><b>Detailed analysis of leeward line for third mooring system configuration</b>                  Second segment                  stiffness                  Pretension</p>	<p>20xBL                  0.2xBL</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results</b>                  DMOOR 4.0 prestudy                  Tension at fairlead (static + sig. second order motion)                  Line 12                  Line 6                  Max. tension                  Line 12                  ORCAFLEX                  Min tension                  Line 6</p> <p><b>Conclusion</b>                  The minimum tension in the fibre rope for the leeward line is negative. That proves that the method used for the calculation of minimum tensions with DMOOR 4.0 is not accurate, and that the mooring configuration is not suitable for fibre ropes.</p>	<p>5,055 kN                  1,575 kN                    6,713.9 kN                  File 100year0.sim                    -36.67 kN                  Min. tension negative</p>



	<p><b>Fourth mooring system configuration</b>                  Model on ORCAFLEX                  The weight and bar diameter of the chain at the bottom and at the top are increased; the length of the bottom segment is increased to 150 m and the length of the second segment is decreased to 1,375 m.                  First segment                      breaking load                      length                      bar diameter                      dry mass                      added mass                      submerged weight                      stiffness                      normal drag coefficient                      tangential drag coefficient                      friction coefficient                  Second segment                      length                      stiffness                  Third segment                      same as first segment                      length                  Pretension</p>	<p>19,816 kN                  150 m                  0.152 m                  0.5273 t/m                  0.0693 t/m                  5.1035 kN/m                  1.427x10<sup>6</sup> kN/m/m                  2.5                  0.5                  1                    1,375 m                  20xBL                    100 m                  0.2xBL</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results</b>                  DMOOR 4.0 prestudy                  Tension at fairlead (static + sig. second order motion)                      Line 12                      Line 6                  Max. tension                      Line 12                  ORCAFLEX                  Min tension                      Line 6    <b>Conclusion</b>                  The results are improved but the minimum tension still be too low. Seeing the results, we can notice that to make the bottom chain heavier improves the results.</p>	<p>5,058kN                  1,451 kN                    6,959.2 kN                  File 100year1.sim                    -160.50 kN</p>

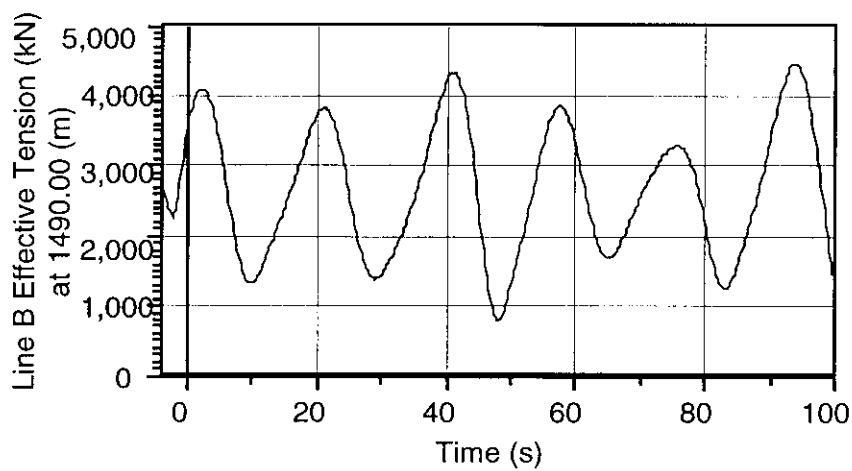


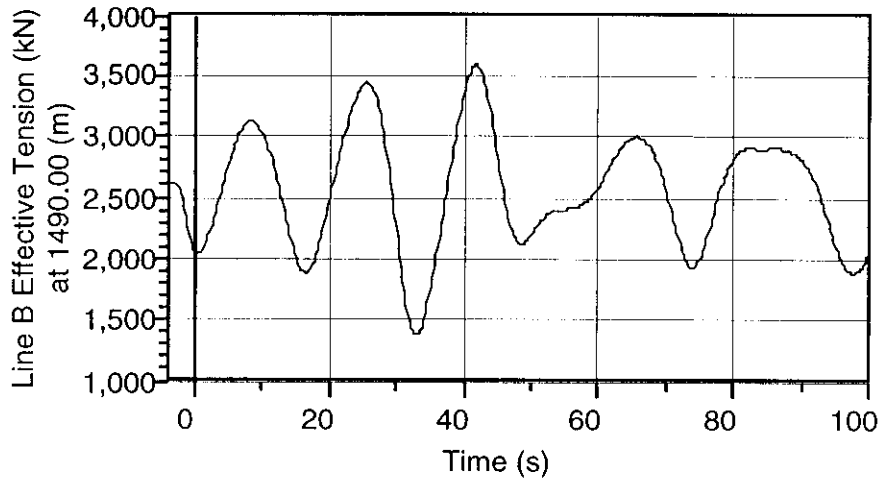
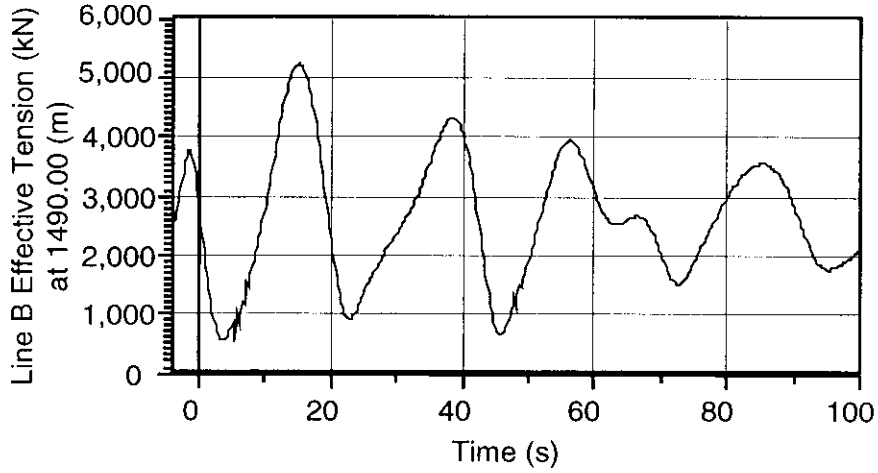
	<p><b>Fifth mooring system configuration</b></p> <p>The first segment is made heavier with a distributed clump weight system Ref: "Deepwater mooring - Searching for optimisation -", M.R. Piazza, Petrobras, A.T. Komura, Petrobras, C.J.M. Del Vecchio, Petrobras, Deep Offshore Technology, Rio De Janeiro, 1995.</p> <p>First segment</p> <ul style="list-style-type: none"> <li>breaking load 19,816 kN</li> <li>length 150 m</li> <li>bar diameter 0.304 m</li> <li>dry mass 1.0546 t/m</li> <li>added mass 0.1386 t/m</li> <li>submerged weight 10.207 kN/m</li> <li>stiffness <math>1.427 \times 10^6</math> kN/m/m</li> <li>normal drag coefficient 2.5</li> <li>tangential drag coefficient 0.5</li> <li>friction coefficient 1</li> </ul> <p>The other segments are unchanged.</p> <p>Pretension 0.2xBL</p>	
<p>DPD 8.2.4.1. DPD 8.2.4.2.</p>	<p><b>Results</b></p> <p>DMOOR 4.0 prestudy</p> <ul style="list-style-type: none"> <li>Tension at fairlead (static + sig.second order motion)</li> <li>Line 12 5,530 kN</li> <li>Line 6 1,843 kN</li> <li>Max. tension</li> <li>Line 12 7,535.1 kN</li> </ul> <p>ORCAFLEX (input file: appendix 3)</p> <ul style="list-style-type: none"> <li>File 100year2.sim</li> <li>Min tension</li> <li>Line 6 -38.31 kN</li> </ul> <p><b>Conclusion</b></p> <p>The results are better but they should be improved by increasing the pretension.</p>	





	<p><b>Sixth mooring system configuration</b> The only thing that changes compared to the fifth configuration is the pretension. Pretension</p>	<p>0.3xBL</p>
<p>DPD 8.2.4.1. DPD 8.2.4.2.</p>	<p><b>Results for this first configuration</b> DMOOR 4.0 prestudy Max excursion Tension at fairlead (static + sig. second order motion) Line 12 Line 6 Max. tension Line 12 ORCAFLEX  Min tension Line 6  <b>Conclusion:</b> This configuration seems suitable, apart for the minimum tension in the fibre rope which stays below 5% of the breaking load (3.5%).</p>	<p>34.81 m  6,723 kN 3,123 kN  8,559.9 kN Files 100year3.sim 100year4.sim 100year5.sim (different time origins)  511.21 kN</p>





A new analysis has been performed for the calculation of the number of cycles. For this run it was noticed that the dynamic analysis for leeward lines was possible except for 1 case) for the last configuration with DMOOR program. The analysis was performed with the 100-year and the 10 year environment, for different pretensions and stiffnesses. The results are presented in the following table:



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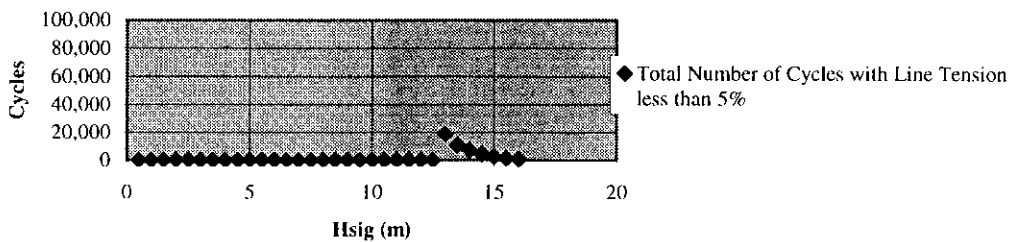
Results for the case with a pretension of 0.2xBL are very interesting because the excursion range and the maximum tensions meet the requirements of the API, and because we can see that the minimum tension in the rope goes from 1.88 to 6.83 % of the breaking strength for the 20xBL stiffness case. The 5% requirements is met between the two environments.

A statistical study is performed below to evaluate the number of cycles that the minimum tension goes below this limit of 5 per cent of the breaking load.

<p><b>Worked Example</b>  <b>Minimum Tension Cycles in Leeward Line</b>  <u><b>Explanation of Cumulative Cycle Table</b></u></p>									
<p><b>Introduction</b></p> <p>During the worked example for the Turret Moored FPSO Vessel (Atlantic Margin Conditions) tensions in the leeward line were found to drop below the minimum tension guideline limit (5% of break strength) recommended for Polyester ropes.</p> <p>These calculations describe a simple method of making a conservative estimate of the number of such low tension cycles accumulated during the (nominal) 100 year design life of the platform.</p> <p>It requires as a starting point a scatter diagram relating storms (in terms of significant wave height) to their probability of occurrence during the design 100 year exposure.</p>									
<p><b>Contents:</b></p>									
<p>Tabulation of cumulative cycles of leeward line tension below guidance limit</p>									
<p>Explanation of Tabulated values and method</p>									
<p>Interpolation of significant wave height resulting in leeward line tension below guideline limit.</p>									

A	B	C	D	E	F	G	H	I	J	K	L
Sea States		All Waves - Wave Occurances					Cumulative Occurance Probabilities				
		Vessel Heading									
Hs (m)	Tz (s)	0 deg	20 deg	45 deg	90 deg	Total	Cumulative Probability (Total Below)	Number of Associated 3-hour seastates	Number of Wave Cycles	Less than 5% Factor	Total Number of Cycles with Line Tension less than 5%
0.5	4.13	4.1E-05	0.00036	0.00038	0.00015	0.00093	1.000000	292,000.	315.4E+6	0	0
1	5.21	0.00172	0.01507	0.01593	0.00646	0.03918	0.999072	291,729.	315.1E+6	0	0
1.5	5.8	0.01666	0.0541	0.03866	0.01712	0.12653	0.959895	280,289.	302.7E+6	0	0
2	6.25	0.03193	0.07956	0.04406	0.01469	0.17022	0.833361	243,341.	262.8E+6	0	0
2.5	6.61	0.03507	0.07783	0.03595	0.01452	0.16337	0.663139	193,637.	209.1E+6	0	0
3	6.97	0.02882	0.06575	0.02435	0.00754	0.12645	0.499770	145,933.	157.6E+6	0	0
3.5	7.33	0.03133	0.05871	0.01583	0.00363	0.10951	0.373325	109,011.	117.7E+6	0	0
4	7.75	0.02066	0.0371	0.01215	0.00179	0.07171	0.263820	77,035.	83.2E+6	0	0
4.5	8.19	0.01765	0.02966	0.00552	0.00067	0.05351	0.192111	56,096.	60.6E+6	0	0
5	8.33	0.01461	0.02162	0.00311	7.2E-05	0.03941	0.138606	40,473.	43.7E+6	0	0
5.5	8.76	0.01129	0.01634	0.0011		0.02872	0.099193	28,964.	31.3E+6	0	0
6	8.99	0.00877	0.01023	0.00174		0.02074	0.070472	20,578.	22.2E+6	0	0
6.5	9.2	0.00519	0.00922	0.00032	0.00011	0.01484	0.049735	14,523.	15.7E+6	0	0
7	9.65	0.00441	0.00588	0.00027	0	0.01056	0.034895	10,189.	11.0E+6	0	0
7.5	9.74	0.00275	0.00437	0.00032	0	0.00745	0.024331	7,105.	7.7E+6	0	0
8	9.93	0.0023	0.00293			0.00523	0.016881	4,929.	5.3E+6	0	0
8.5	10.13	0.00109	0.00237	0.00018		0.00364	0.011655	3,403.	3.7E+6	0	0
9	10.37	0.0009	0.00181			0.00271	0.008011	2,339.	2.5E+6	0	0
9.5	10.65	0.00093	0.00099			0.00192	0.005306	1,549.	1.7E+6	0	0
10	10.92	0.00046	0.00133			0.00179	0.003386	989.	1.1E+6	0	0
10.5	11.2	0.00024	0.00053			0.00078	0.001596	466.	503.3E+3	0	0
11	11.48	5.8E-05	0.00018			0.00024	0.000820	239.	258.6E+3	0	0
11.5	11.73	3.9E-05	0.00016			0.0002	0.000584	171.	184.2E+3	0	0
12	12	2.7E-05	0.00015			0.00017	0.000386	113.	121.7E+3	0	0
12.5	12.25	1.7E-05	0.00014			0.00015	0.000213	62.	67.2E+3	0	0
13	12.49	1.2E-05	1.2E-05			2.4E-05	0.000059	17.	18.6E+3	1	18,606
13.5	12.73	5E-06	6E-06			1.1E-05	0.000035	10.	11.0E+3	1	11,038
14	12.96	5E-06	5E-06			0.00001	0.000024	7.	7.6E+3	1	7,569
14.5	13.19	3E-06	3E-06			6E-06	0.000014	4.	4.4E+3	1	4,415
15	13.43	2E-06	2E-06			4E-06	0.000008	2.	2.5E+3	1	2,523
15.5	13.66	1E-06	1E-06			2E-06	0.000004	1.	1.3E+3	1	1,261
16	13.86	1E-06	1E-06			2E-06	0.000002	1.	630.7E+0	1	631
Totals		0.237	0.4964	0.1999	0.0667	1					

Total Number of Cycles with Line Tension less than 5%



<p><b>Worked Example</b>  <b>Minimum Tension Cycles in Leeward Line</b>  <u>Explanation of Cumulative Cycle Table</u></p>											
<p><u>Basic Information</u></p> <p>A study for the loading directions on a turret moored vessel has produced the scatter diagram of wave occurrences shown in columns C to F for the wave height and period values given in columns A and B. The totals for all directions at each storm condition are given in column G.</p> <p>The maximum sea state shown in the table is Hsig = 16 metres which equates to the 100 year storm for the location.</p>											
<p><u>Cumulative Probability : Probabilities of Occurance</u></p> <p>The propability of a storm condition being reached or exceeded at a given sea state is given by the sumation presented in column H.</p> <p>For the lowest sea state the cumulative probability is 1.0; that is there is a certainty that this sea state will be experienced during the 100 year exposure.</p>											
<p><u>Number of 3-Hour Seastates</u></p> <p>During an exposure of 100 years there will be a total of <math>(100 \times 365 \times 24 / 3 = 292,000)</math> periods of 3-hour storms as statistically storms are considered to occur in 3-hour segments. Thus column I gives the probable number of 3-hour storm periods which will meet or exceed each given level of seastate.</p>											
<p><u>Number of Wave Cycles</u></p> <p>As an estimate one can assume that the average period of a wave is 10 seconds. Using this number there would be <math>(3 \times 60 \times 60 / 10 = 1080)</math> wave cycles in each 3 hour storm period. Column J multiplies the number of storms given in column I by 1080 to give the number of cumulative number of cycles for all sea states equal to or greater than the given level.</p>											
<p><u>Less than 5% Step Function</u></p> <p>Analysis of the mooring system shows that when Hs= 16.1 metres the minimum tension in the leaward line is 1.88% of line break strength. For Hs= 11.0 metres the minimum tension is 6.83% of break. The recommended guideline tension for polyester is 5% of break strength. By interpolation the storm state at which the minimum line tension dips to 5% is approximately 13 metres.</p> <p>Thus for storm states equal to or greater than Hsig= 13 metres each wave loading cycle has the potential of cycling the leaward line below the 5% guideline tension. A step function is applied in column K, set at 0 for sea states Hsig below 13 metres and 1 for Hsig equal to or greater than 13 metres.</p>											

<u>Number of Cycles resulting in line tension dips below 5%</u>											
<p>Column L gives the product of columns J and K and represents the cumulative number of cycles in which the leeward line tension may dip below the guideline tension of 5% break strength.</p> <p>Over an exposure of 100 years the upper bound on the number of cycles which can cause the leeward line tension to dip below the guideline tension (5% break strength) is 18,606. This is within than the guidance design limit of 100,000 cycles given in DPD Table 5.5.1.</p>											
<u>Conclusions</u>											
<p>Using a very conservative calculation methods in which it is assumed that <u>all</u> wave cycles for storms that exceed Hsig= 13 metres result in leeward line tensions dipping below the guideline limit of 5% break strength it has been estimated that there will only be 18,606 such cycles during an exposure of 100 years. This is very conservative as in large random storms many load cycles will not result in such low leeward line tensions.</p> <p>The number of estimated cycles is still within the guidance design limit of 100,000 cycles given by the Design Practice Document for Polyester and therefore is acceptable for design.</p>											



## **APPENDIX 1**

### **Response Amplitude Operators, Wave Drifts Coefficients Current and Wind Coefficients**

RAO's for the F.P.S.O. in the environmental direction

Frequency rad/s	Period s	Surge		Sway		Heave		Roll		Pitch		Yaw	
		Amp m/m	Phase deg	Amp m/m	Phase deg	Amp m/m	Phase deg	Amp deg/ deg/ m	Phase deg	Amp deg/ deg/ m	Phase deg	Amp deg/ deg/ m	
0.200	30.06	0.9468	-90.5	0	89.7	0.9582	3.3	0	-70.7	0.2493	90.5	0	178.2
0.251	25.03	0.8965	-90.4	0	88.8	0.9136	4.3	0	-51.9	0.353	90.8	0	177.9
0.314	20.01	0.7776	-90.5	0	90.0	0.7940	5.7	0	97.3	0.5226	91.2	0	178.3
0.349	18.00	0.6861	-90.5	0	90.3	0.6951	6.2	0	127.8	0.6134	91.6	0	177.8
0.393	15.99	0.5468	-90.3	0	90.4	0.5396	5.4	0	171.5	0.7091	92.4	0	177.2
0.419	15.00	0.4527	-89.9	0	90.7	0.4370	3.4	0	-158.2	0.7469	93.2	0	176.8
0.433	14.51	0.3996	-89.5	0	91.1	0.3811	1.4	0	-143.5	0.7589	93.7	0	176.6
0.449	13.99	0.3372	-89.0	0	91.8	0.3185	-2.0	0	-129.0	0.7627	94.4	0	176.4
0.465	13.51	0.2741	-88.4	0	93.0	0.2592	-7.4	0	-116.8	0.7558	95.2	0	176.1
0.524	11.99	0.06	-84.2	0	111.2	0.1267	-61.9	0	-81.3	0.6125	97.2	0	175.8
0.546	11.51	0.0033	15.8	0	141.2	0.1338	-88.9	0	-68.9	0.5163	96.1	0	176.4
0.571	11.00	0.0511	88.4	0	-160.5	0.1587	-107.9	0	-54.0	0.3941	91.3	0	178.2
0.598	10.51	0.0817	87.9	0	-131.6	0.1796	-118.3	0	-36.3	0.2731	76.4	0	-176.8
0.628	10.01	0.0883	84.0	0	-119.4	0.1792	-124.3	0	-13.8	0.2211	42.7	0	-161.5
0.698	9.00	0.0469	35.5	0	-101.5	0.0942	-148.5	0	54.1	0.2534	14.3	0	-48.9
0.785	8.00	0.0514	-67.7	0	6.8	0.0552	142.8	0	137.5	0.0797	-20.2	0	-16.7
0.898	7.00	0.0285	-174.0	0	74.7	0.0380	9.7	0	-108.4	0.0591	-155.5	0	129.6
1.047	6.00	0.0169	-2.4	0	-125.8	0.0095	-164.5	0	44.5	0.0165	47.7	0	-49.2
1.257	5.00	0.0085	26.8	0	-120.2	0.0024	-143.7	0	4.6	0.0076	60.6	0	161.1
1.600	4.00	0.0046	128.8	0	-21.4	0.0011	-125.7	0	147.4	0.0006	-33.2	0	132.5

**QTF for the FPSO  
in the environmental direction**

Frequency rad/s	Fx kN/m <sup>2</sup>	Fy kN/m <sup>2</sup>	Mz kN/m
0.10	0.01	0	0
0.15	0.04	0	0
0.20	0.08	0	0
0.25	0.17	0	0
0.30	0.15	0	0
0.35	-0.49	0	0
0.40	-3.45	0	0
0.45	-18.12	0	0
0.50	-69.86	0	0
0.55	-129.12	0	0
0.60	-138.88	0	0
0.65	-135.56	0	0
0.70	-136.27	0	0
0.75	-104.84	0	0
0.80	-96.10	0	0
0.85	-101.71	0	0
0.90	-96.23	0	0
0.95	-92.93	0	0
1.00	-94.29	0	0

**Wind coefficient  
in the environmental direction**

$F_x/V_w^2 = -1.05 \text{ kN} \cdot (\text{s/m})^2$ $F_y/V_w^2 = 0.122 \text{ kN} \cdot (\text{s/m})^2$
--

**Current coefficient  
in the environmental direction**

$F_x/V_c^2 = -107.12 \text{ kN} \cdot (\text{s/m})^2$ $F_y/V_c^2 = 8.39 \text{ kN} \cdot (\text{s/m})^2$
---

**APPENDIX 2**

**DMOOR 4.0**  
**Input Files**  
**For the last configuration**

```

*****START OF DETER.INP *****
#INPUT NO.1: TITLE DESCRIPTION
FPSO
#INPUT NO.2: NL,NJ,NI,NT,IANAL; IANAL = 1 ,FOR FULL DYNAMIC ANALYSIS
1 1 1 1 1
#INPUT NO.3: IIT; INNIT = 1 ,ALL DATA IN METRIC UNITS
1
#INPUT NO.4: FRQ1,FRQ2
0.2 1.6
#INPUT NO.5: (ANGI(I),I=1,NI) ... MOORING LINE SPREAD ANGLE
0.
#INPUT NO.6: (ANGJ(J),J=1,NJ) ... ENV HEADING (TO) FROM BOW C.C.W.
180.0
#INPUT NO.7: (LTYP(I),I=1,NI) ... LINE TYPES IF NI>1
#INPUT NO.8: (SEA(L),WINDY(L),CURRY(L),L=1,NL)
16.1 40.00 1.5
#INPUT NO.9: ISPEC,PARAM; ISPEC = 4, JONSWOP SPECTRUM
4 3.3
#INPUT NO.10: KSPEC
0
#INPUT NO.11: (XSPECT(JG),JG=1,NL) ... PEAK PERIOD OF WAVE SPECTRUM
16.75
#INPUT NO.13: IWSPEC,WPAR1,WPAR2 IWSPEC = 3 , JONSWAP SPECTRUM
# WPAR1 = 1200., WIND DYNAMICS IS CONSIDERED, USE 1-HOUR
3 1200. 0.
#INPUT NO.14: NCOEFF = THE NUMBER OF DISTINCT WIND FORCE COEFF.
1
#INPUT NO.15: (ICOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.16: (WIND(J),J=1,NCOEFF) ... WIND FORCE COEFF. PER VELOCITY**2
1050.0
#INPUT NO.17: NCOEF1 = THE NUMBER OF DISTINCT CURRENT FORCE COEFF.
1
#INPUT NO.18: (JCOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.19: (CURR(J),J=1,NCOEF1) ... CURRENT FORCE COEFFICIENTS
107122.0
#INPUT NO.20: NCOEF2 = THE NUMBER OF DISTINCT WAVE DRIFT FORCE COEFF.
1
#INPUT NO.21: (KCOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.22: ((DRIFT(I,J),J=1,NF),I=1,NCOEF2)
170 150 490 3450 19120 69860 129120 138880 135560 136270
104840 96100 101710 96230 92930 94290 0 0 0 0
0 0 0 0 0
#INPUT NO.23: ITCODE,LPTS,MAXSEG ... IF ITCODE = 0, THEN TENSION OUTPUT
# AT FAIRLEAD & SKIP INPUT NO.24
0 0 0
#INPUT NO.24: (IOP (JG,JGG), JGG = 1, MAXSEG));OUTPUT FOR ALL SEGMENTS
#INPUT NO.25: IFINC = 1 , USE 25 FREQUENCIES IN FREQ. DOMAIN DYNAMICS
1
***** END OF DETER.INP *****

```

```

*****START OF STEADY.INP*****
# FPSO
#INPUT NO.1: ITLP,ICURR
0,2
#ICURR=1, NO CURRENT(ACTING ON MOORING LINES & BUOYS IF ANY)
#INPUT NO.2: NO. OF STEPS FOR STEPPED CURRENT PROFILE
#INPUT NO.3: DEPTH OF STEPS FOR STEPPED CURRENT PROFILE
#INPUT NO.4: RATIOS OF SURFACE CURRENT SPEED FOR STEPPED CURRENT
PROFILE
#INPUT NO 5: N2, N3, NUMBER OF LINES & NUMBER OF LINE TYPES
12,1
#INPUT NO.6: (ANGI(I),I= 1,N2) ... SPREAD ANGLES OF ALL LINES (CCW FR BOW)
#MOORING PLAN (SEE INPUT NO.12)
345.,315.,285.,255.,225.,195.,165.,135.,105.,75.,45.,15.
#INPUT NO.7: (LTYP(I),I= 1,N2) ... LINE TYPES OF ALL LINE
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
#INPUT NO.8: NSEG, NBUOY, NTOT
3 0 48
#INPUT NO.9:
RLENG,RMASS,AMASS,WEIGHT,DIA,EA,TBREAK,ANMSE,CD,CDT,FRICTN
150. 1054.6 138.6 10207 0.304 1.427E9 2.02E7 10 2.5 0.50 1.00
1375. 34.91 34.05 86.8 0.208 4.410E8 1.50E7 30 1.2 0.05 0.00
100. 527.3 69.29 5103.5 0.152 1.427E9 2.02E7 8 2.5 0.50 1.00
#INPUT NO.10:BUOY PROPERTIES
#INPUT NO.11:DEPTH,SLOPE,CURREF
1000 0.0 1.5
#INPUT NO.12: XO(L), YO(L), ZO(L), DPRE(L) ... FAIRLEAD COORDINATES
#MOORING PLAN (LINE ANGLES 345,315,285,255,225,195,165,135,105,75,45,15)
77.21, -1.81, -17.89, 4414500.
75.40, -4.95, -17.89, 4414500.
72.26, -6.76, -17.89, 4414500.
68.64, -6.76, -17.89, 4414500.
65.50, -4.95, -17.89, 4414500.
63.69, -1.81, -17.89, 4414500.
63.69, 1.81, -17.89, 4414500.
65.50, 4.95, -17.89, 4414500.
68.64, 6.76, -17.89, 4414500.
72.86, 6.76, -17.89, 4414500.
75.40, 4.95, -17.89, 4414500.
77.21, 1.81, -17.89, 4414500.
***** END OF STEADY.INP *****

```

\*\*\*\*\*FILE3.DAT\*\*\*\*\*

FPSO

1 20

180 deg wrt bow

0.20	30.06	0.9468	-90.50	0.00	89.70	0.9582	3.30	0.00	-70.70	0.2493	90.50	0.00	178.20
0.251	25.03	0.8965	-90.4	0.00	88.80	0.9136	4.30	0.00	-51.90	0.3530	90.80	0.00	177.90
0.314	20.01	0.7776	-90.50	0.00	90.00	0.7940	5.70	0.00	97.30	0.5226	91.20	0.00	178.30
0.349	18.0	0.6861	-90.50	0.00	90.30	0.6951	6.20	0.00	127.80	0.6134	91.60	0.00	177.80
0.393	15.99	0.5468	-90.30	0.0	90.40	0.5396	5.40	0.00	171.50	0.7091	92.40	0.00	177.20
0.419	15.0	0.4527	-89.90	0.0	90.70	0.4370	3.40	0.00	-158.20	0.7469	93.20	0.00	176.80
0.433	14.51	0.3996	-89.50	0.0	91.10	0.3811	1.40	0.0	-143.50	0.7589	93.70	0.00	176.60
0.449	13.99	0.3372	-89.00	0.0	91.80	0.3185	-2.00	0.0	-129.00	0.7627	94.40	0.00	176.40
0.465	13.51	0.2741	-88.40	0.08	93.0	0.2592	-7.40	0.0	-116.80	0.7558	95.20	0.00	176.10
0.524	11.99	0.060	-84.20	0.00	111.20	0.1267	-61.90	0.0	-81.30	0.6125	97.20	0.0	175.80
0.546	11.51	0.0033	15.80	0.0	141.20	0.1338	-88.90	0.0	-68.90	0.5163	96.10	0.0	176.40
0.571	11.00	0.0511	88.40	0.0	-160.5	0.1587	-107.90	0.0	-54.00	0.3941	91.30	0.0	178.20
0.598	10.51	0.0817	87.90	0.0	-131.60	0.1796	-118.3	0.0	-36.30	0.2731	76.4	0.0	-176.80
0.628	10.01	0.0883	84.0	0.0	-119.40	0.1792	-124.30	0.0	-13.80	0.2211	42.70	0.0	-161.5
0.698	9.00	0.0469	35.50	0.00	-101.50	0.0942	-148.50	0.0	54.10	0.2534	14.30	0.0	-48.90
0.785	8.00	0.0514	-67.70	0.00	6.80	0.0552	142.80	0.00	137.50	0.0797	-20.20	0.0	-16.70
0.898	7.00	0.0285	-174.00	0.00	74.70	0.0380	9.70	0.0	-108.40	0.0591	-155.50	0.0	129.60
1.047	6.00	0.0169	-2.40	0.00	-125.80	0.0095	-164.50	0.0	44.50	0.0165	47.70	0.0	-49.20
1.257	5.00	0.0085	26.80	0.00	-120.20	0.0024	-143.70	0.0	4.60	0.0076	60.60	0.0	161.10
1.600	4.0	0.0046	128.80	0.0	-21.40	0.0011	-125.70	0.0	147.40	0.0006	-33.20	0.0	132.50

\*\*\*\*\* End of FILE3.DAT\*\*\*\*\*

```

# *****LOWFRQ.INP*****
#INPUT 1: ICODE=0 , AN ORIGINAL RUN ABOUT THE STATIC OFFSET
0
#INPUT 2: NMASS, NDAMP
#      NUMBER OF DISTINCT ADDED MASS AND DAMPING RATIO
1,1
#INPUT 3 : ADDED MASS ID NUMBER
1
#INPUT 4 : ADDED MASS (KG)
5697600
#INPUT 5 : DAMPING RATIO ID NUMBER
1
#INPUT 6 : DAMPING RATIO
0.47
#INPUT 7 : TOTAL VESSEL MASS (KG)
107000000
# *****End of LOWFRQ.INP*****

```

```

# *****WAVFRQ.INP*****
#INPUT NO.1: KDATA = 0, READ INPUTS 4 & 5 FOR THE MOTION RAO TABLE.
#      .NE. 0, READ THE DATA FROM FILE1.DAT.
0
#INPUT NO.2: NHD, NFRE ... NUMBERS OF WAVE HEADINGS & FREQUENCIES OF
THE
#      MOTION RAO DATA,WHICH MUST BE STORED IN FILE3.DAT.
1 20
#INPUT NO.3: (LYNCO(J), J = 1,NJ) ... CODE MATRIX FOR THE DEFINED
#      ENVIR. DIRECTIONS CORRESPONDING
#      TO THE HEADINGS OF MOTION RAO DATA.
#      NO.2 HEADING (OBLIQUE) IS SELECTED HERE .....1
1
#INPUT NO.4: NM = THE NUMBER OF DISTINCT FAIRLEAD MOTION RAO TABLES.
1
#INPUT NO.5: ((IA(J,I), I = 1,NI), J = 1,NJ)
#      IA(J,I) = THE ID NO. OF DISTINCT FAIRLEAD MOTION RAO TABLES.
1
# *****End of WAVFRQ.INP*****

```



**APPENDIX 3**

**ORCAFLEX**  
**Input Files**  
**For the last configuration**

Title:

OrcaFlex Example Data

Units:

System	Length	Mass	Force	Time	g (m/s <sup>2</sup> )
SI	m	te	kN	s	9.807

Statics

Buoys included in Static Analysis:

All

Convergence:

Max Iterations	Tolerance	Min Damping	Mag. Of Std. Error	Mag. Of Std. Change
30	0.0001	1.000	2.500	0.070

Dynamics

Stages:

1

Stage Number	Duration (s)
0	4.000
1	100.000

Time Steps (s)		No. of Log Samples
Inner	Outer	
0.00010	0.0500	400

Target Damping (% Critical)
10.0000

Sea:

Surface Z (m)	Depth (m)	Density (t/m <sup>3</sup> )
0.000	1000.000	1.024

Sea Bed:

Slope (deg)	Direction (deg)	Stiffness (kN/m/m <sup>2</sup> )	Damping (% Critical)
0.000	0.000	100.000	100.000

Waves:

Direction (deg)	Height (m)	Period (s)	Simulation Time Origin (s)	Wave Type
180.000	16.10	16.750	8500.000	JONSWAP

Current

Current:

Speed (m/s)	Direction (deg)	Ramp during build-up
1.500	180.000	<input type="checkbox"/>

Current Profile:

2

Level Number	Depth (m)	Factor	Rotation (deg)
1	0.000	1.000	0.000
2	1000.000	1.000	0.000

Random Waves

Data

Number of Components:

50

Parameters:

Gamma		Alpha	Sigma1	Sigma2	fm
Auto	Value				
No	3.300	0.0040	0.070	0.090	0.046

Name:  Included in Static Analysis:  Dynamics:

Initial Position:

Position (m)			Orientation (deg)		
X	Y	Z	Heel	Trim	Heading
0.00	0.00	0.00	0.0	0.0	0.0

RAOs

Periods:

Period (s)	Surge		Sway		Heave		Roll		Pitch		Yaw	
	Ampl. (m/m)	Phase (deg)	Ampl. (m/m)	Phase (deg)	Ampl. (m/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)
4.0	0.005	129	0.000	-21	0.001	-126	0.000	147	0.006	-33	0.000	132.5
8.0	0.050	-68	0.000	6.8	0.055	143	0.000	138	0.080	-20	0.000	-16.7
10.0	0.088	84	0.000	-119	0.179	-124	0.000	-14	0.221	43	0.000	-162
13.5	0.274	-88	0.000	93	0.259	-7.4	0.000	-117	0.756	95	0.000	176.1
15.0	0.453	-90	0.000	91	0.437	3.4	0.000	-158	0.747	93	0.000	176.8
16.0	0.547	-90	0.000	90	0.540	5.4	0.000	172	0.709	92	0.000	177.2
18.0	0.686	-90	0.000	90	0.695	6.2	0.000	-71	0.613	92	0.000	178.2
20.0	0.778	-90	0.000	90	0.794	5.7	0.000	-71	0.523	91	0.000	178.2
30.1	0.950	-90	0.000	90	0.960	3.3	0.000	-71	0.250	90	0.000	178.2
Infinity	0.950	-90	0.000	90	0.960	3.3	0.000	-71	0.250	90	0.000	178.2

Slow Drift

Period (s)	Surge		Sway		Heave		Roll		Pitch		Yaw	
	Ampl. (m)	Phase (deg)	Ampl. (m)	Phase (deg)	Ampl. (m)	Phase (deg)	Ampl. (deg)	Phase (deg)	Ampl. (deg)	Phase (deg)	Ampl. (deg)	Phase (deg)
100.0	0.000	90	0.000	90	0.000	90	0.000	90	0.000	90	0.000	90.0

Steady Motion

Stage Number	Duration (s)	Velocity		Rate of Turn
		Mode	Value	
0	4.000	Constant Velocity	0.000	0.000
1	100.000	Constant Velocity	0.000	0.000

Applied Load

Force (kN)			Moment (kN.m)		
X	Y	Z	Roll	Pitch	Yaw
0.0	0.0	-	-	-	0.0

Multiple Statics

Azimuths:

From (deg)	To (deg)	Number of steps
0.00	-	0

Offsets:

From (m)	To (m)	Number of steps
0.00	-	0

Drawing




Vertices: 9

No.	x	y	z
1	110.000	20.000	-17.890
2	117.000	20.000	10.000
3	-110.000	20.000	-17.890
4	-110.000	20.000	10.000
5	-110.000	-20.000	10.000
6	-110.000	-20.000	10.000
7	117.000	-20.000	10.000
8	110.000	-20.000	-17.890
9	-110.000	-20.000	-17.890

Edges: 12

No.	From	To
1	3	1
2	1	2
3	1	8
4	8	7
5	7	2
6	3	4
7	4	2
8	3	9
9	9	6
10	6	4
11	6	7
12	9	8

Geometry, Mass, Drawing

	Name	Diameters		Unit Mass (te/m)	Width	Pen Style	Colour
		Outer (m)	Inner (m)				
1	chain	0.560	0.000	1.054	2	---	
2	fibre	0.208	0.000	0.034	2	---	
3	LType A	0.280	0.000	0.527	2	---	

Tension, Bending, Contact

	Name	Stiffnesses			Limit Compression	Maximum Tension (kN)	Minimum Radius (m)
		Axial (kN)	Bending (kN.m^2)	Contact (kN/m)			
1	chain	1.427E6	0.000	0.000	No	~	~
2	fibre	441.45E3	0.000	0.000	No	~	~
3	LType A	1.427E6	0.000	0.000	No	~	~

Hydrodynamics

	Name	Drag Coefficients		Added Mass Coefficients	
		Normal	Axial	Normal	Axial
1	chain	1.180	0.500	1.000	0.000
2	fibre	1.200	0.050	1.000	0.000
3	LType A	1.180	0.500	1.000	0.000

Friction

	Name	Friction Coefficients		Bias Power
		Normal	Axial	
1	chain	1.000	~	1.000
2	fibre	1.000	~	1.000
3	LType A	1.000	~	1.000

Stress

	Name	Stress Diameters (m)	
		Outer	Inner
1	chain	~	~
2	fibre	~	~
3	LType A	~	~

Geometry, Mass

	Name	Mass (te)	Volume (m <sup>3</sup> )	Height (m)	Offset (m)
1	CType A	0.1000	0.2000	0.2000	0.0000

Drag

	Name	Drag Areas (m <sup>2</sup> )			Drag Coefficients		
		x	y	z	x	y	z
1	CType A	0.600	0.600	0.600	1.100	1.100	1.100

Added Mass

	Name	Added Mass Coefficients		
		x	y	z
1	CType A	1.000	1.000	1.000

Name:

Total Line Length = 1625.00 m

Connections:

Object	Object Relative Position (m)			No Moment Direction (deg)		Gamma (deg)	Stiffness (kN.m/deg)	Release at Start of Stage
	x	y	z	Azimuth	Declination			
Vessel A	76.450	0.000	-17.89	0.000	0.000	0.000	0.000	-
Anchored	1396.2	0.000	0.000	0.000	0.000	0.000	0.000	-

Statics:

Statics Method	Full Statics	Pre-Tension (kN)	Lay Azimuth (deg)	
Catenary	No	~	180.00	Set

Contents:

Density (te/m^3)	Pressure (kN/m^2)	Flow Rate (te/s)
1.000	~	0.00

Structure

Sections:

Clumps:

No.	Line Type	Length (m)	No. of Segments	Clash Check
1	LType A	100.000	5	No
2	fibre	1375.00	50	No
3	chain	150.000	5	No

Catenary Convergence

Max Iterations	Delta	Tolerance	Min Damping	Shooting Factor	BackTrack Factor	Mag. Of Std. Error	Mag. Of Std. Change
100	-5E-9	50E-9	1.000	1.500	2.000	0.200	0.600



Name:

Line B

Total Line Length = 1625.00 m

Connections:

Object	Object Relative Position (m)			No Moment Azimuth	Direction (deg)		Gamma (deg)	Stiffness (kN.m/deg)	Release at Start of Stage
	x	y	z		Declination				
Vessel A	64.450	0.000	-17.89	0.000	0.000	0.000	0.000	0.000	-
Anchored	-1237	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-

Statics:

Statics Method	Full Statics	Pre-Tension (kN)	Lay Azimuth (deg)	
Catenary	No	-	180.00	Set

Contents:

Density (te/m^3)	Pressure (kN/m^2)	Flow Rate (te/s)
1.000	-	0.00

Structure

Sections:

3

Clumps:

0

No.	Line Type	Length (m)	No. of Segments	Clash Check
1	LType A	100.000	5	No
2	fibre	1375.00	50	No
3	chain	150.000	5	No

Catenary Convergence

Max Iterations	Delta	Tolerance	Min Damping	Shooting Factor	BackTrack Factor	Mag. Of Std. Error	Mag. Of Std. Change
100	-5E-9	50E-9	1.000	1.500	2.000	0.200	0.600

**Sensitivity Study (1):**

**increase of the diameter (and strength & stiffness) of the Fibre Rope**

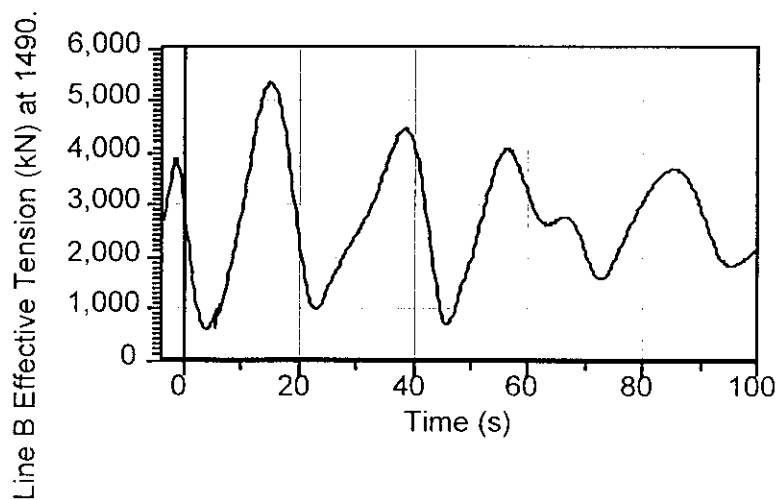
**(5 sheets)**

### Sensitivity study for the FPSO Effects of an increase of the diameter of the Fibre Rope

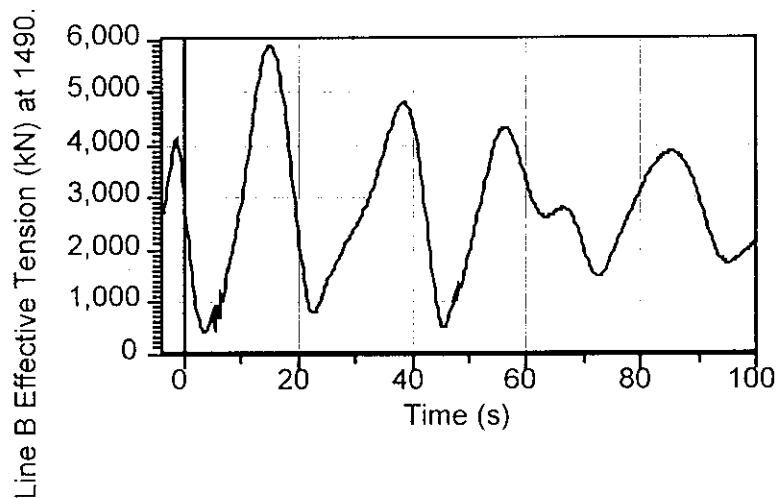
This analysis has been done to clarify the paragraph 2 of the DPD-8.2.4.1. in accordance to the minutes of the last meeting (see p11). In conclusion of this analysis and as recommended in the minutes, this paragraph should be deleted.

Data	Reference in EDG - DPD
------	------------------------------

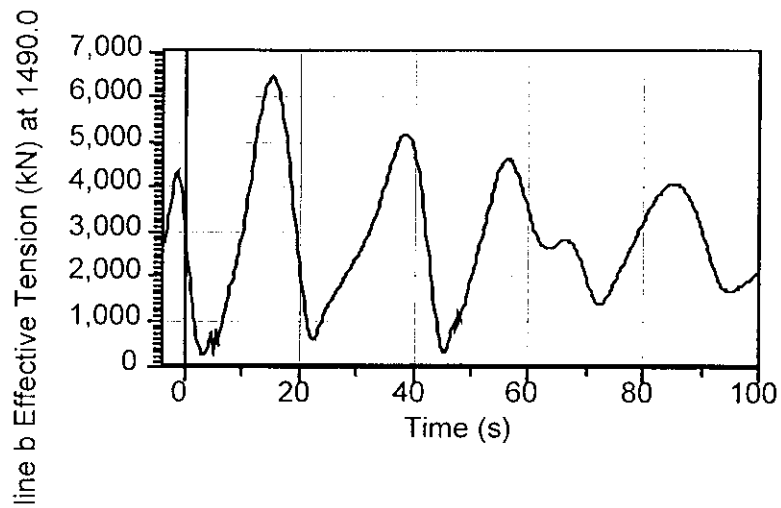
<i>Sixth mooring configuration (file data-sch.doc)</i>	
<p><b>Results</b></p> <p>DMOOR4.0 prestudy</p> <p style="padding-left: 20px;">Tension at fairlead (static + sig. second order motion)</p> <p style="padding-left: 40px;">Line 12</p> <p style="padding-left: 40px;">Line 6</p> <p style="padding-left: 20px;">Max. tension</p> <p style="padding-left: 40px;">Line 12</p> <p>ORCAFLEX</p> <p style="padding-left: 20px;">Min tension</p> <p style="padding-left: 40px;">Line 6</p>	<p>6,723 kN</p> <p>3,123 kN</p> <p>8,860 kN</p> <p>sen1.sim</p> <p>590 kN</p>



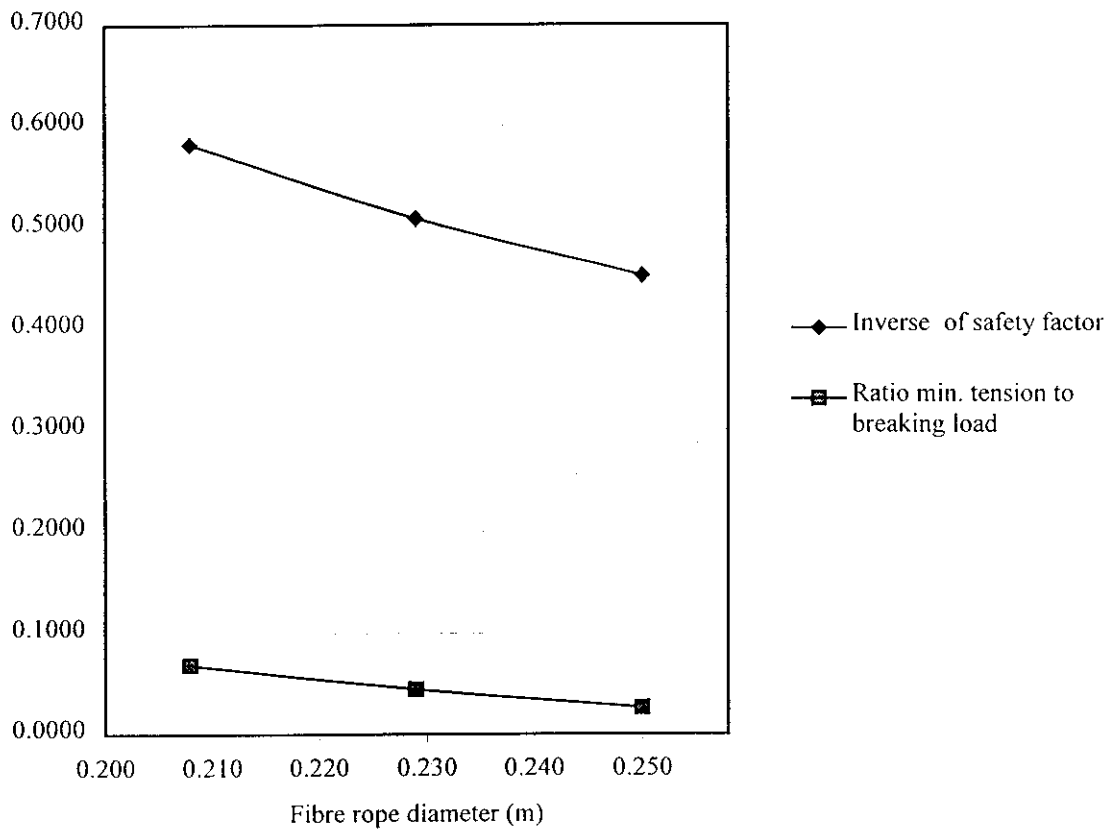
<p><b>Seventh mooring system configuration</b>                  The diameter of the rope is increased of 10% compared to the sixth configuration.                  Second segment                  material                  breaking load (BL)                  length                  diameter                  dry mass                  added mass                  submerged weight                  stiffness                  normal drag coefficient                  tangential drag coefficient                  seabed friction coefficient</p>	<p>fibre rope                  17,805 kN                  1,375 m                  0.229 m                  0.0423 t/m                  0.0413 t/m                  1.052 kN/m  <math>5.336 \times 10^5</math> kN/m/m                  1.2                  0.05                  0</p>
<p><b>Results</b>                  DMOOR4.0 prestudy                  Tension at fairlead (static + sig. second order motion)                  Line 12                  Line 6                  Max. tension                  Line 12                  ORCAFLEX                  Min tension                  Line 6</p>	<p>6,855 kN                  3,150 kN                  9,060 kN                  sen2.sim                  406 kN</p>

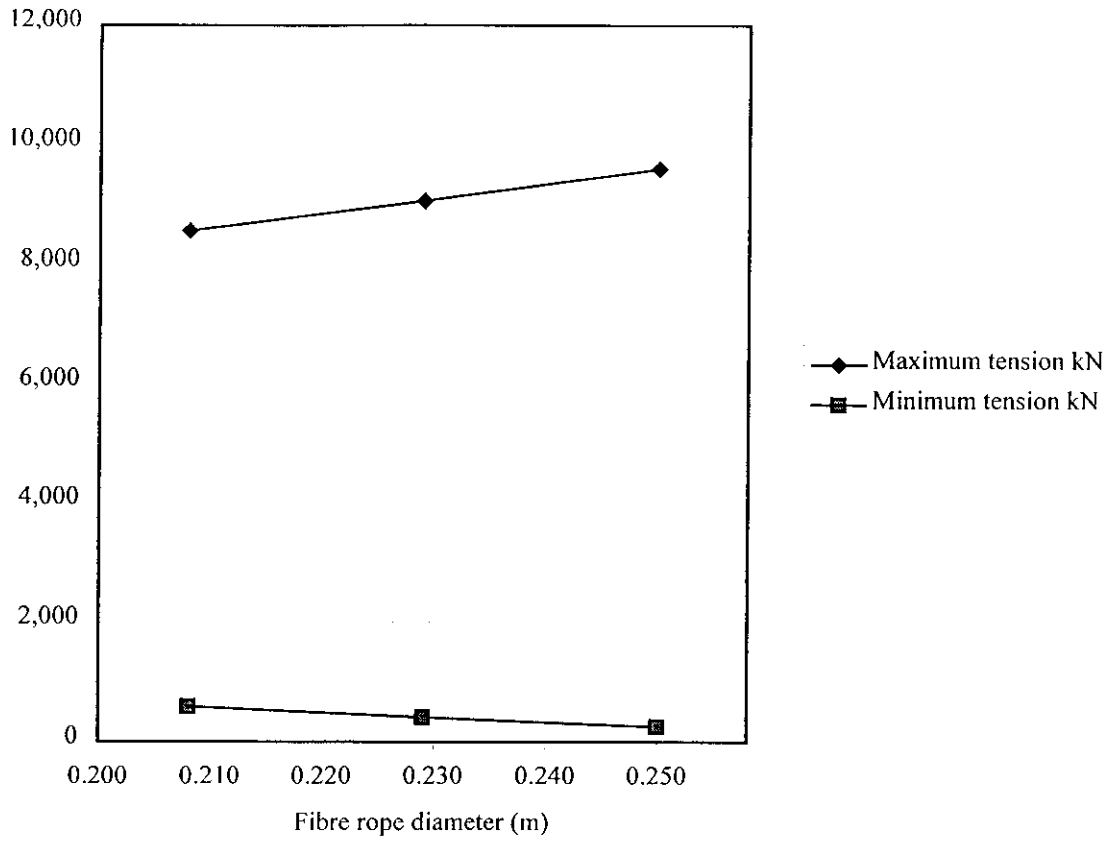


<p><b>Height mooring system configuration</b>                  The diameter of the rope is increased of 20% compared to the sixth configuration.                  Second segment                      material                      breaking load (BL)                      length                      diameter                      dry mass                      added mass                      submerged weight                      stiffness                      normal drag coefficient                      tangential drag coefficient                      seabed friction coefficient</p>	<p>    fibre rope                  21,190 kN                  1,375 m                  0.250 m                  0.0504 t/m                  0.0492 t/m                  1.254 kN/m                  6.350x10<sup>5</sup> kN/m/m                  1.2                  0.05                  0</p>
<p><b>Results</b>                  DMOOR4.0 prestudy                  Tension at fairlead (static + sig. second order motion)                      Line 12                      Line 6                  Max. tension                      Line 12                  ORCAFLEX                  Min tension                      Line 6</p>	<p>    6,985 kN                  3,178 kN                    9,585 kN                  sen3.sim                    253 kN</p>



Fibre rope diameter m	Breaking load kN	Maximum tension kN	Safety factor	Inverse of safety factor	Minimum tension kN	Ratio min. tension to breaking load
0.208	14,715	8,560	1.7190	0.5817	590	0.0689
0.229	17,805	9,060	1.9652	0.5088	406	0.0448
0.250	21,190	9,585	2.2107	0.4523	253	0.0264





**Sensitivity Study (2):**

**increase of the normal drag coefficient of the Fibre Rope**

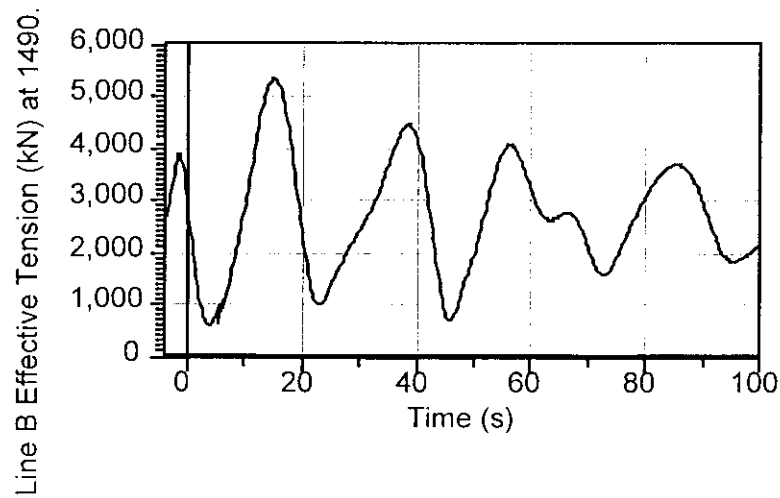
**(5 sheets)**



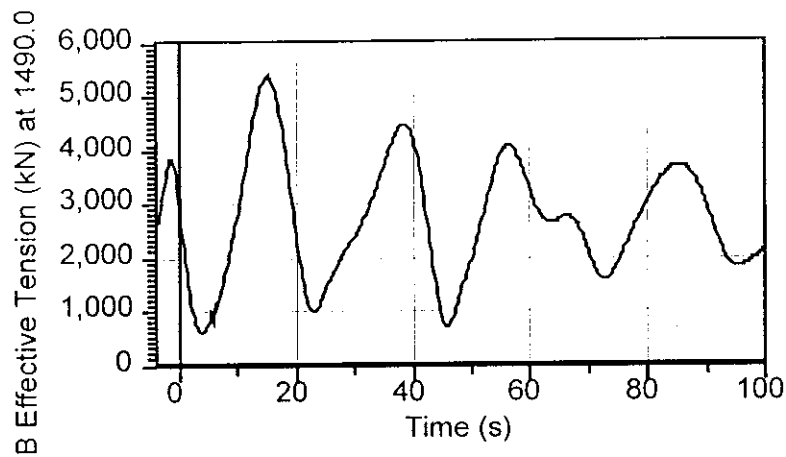
### Sensitivity study for the FPSO Effects of an increase of the normal Drag coefficient of the Fibre Rope

This analysis has been done to illustrate the DPD-8.3.4.3. as recommended in the minutes of the last meeting (see page 13).

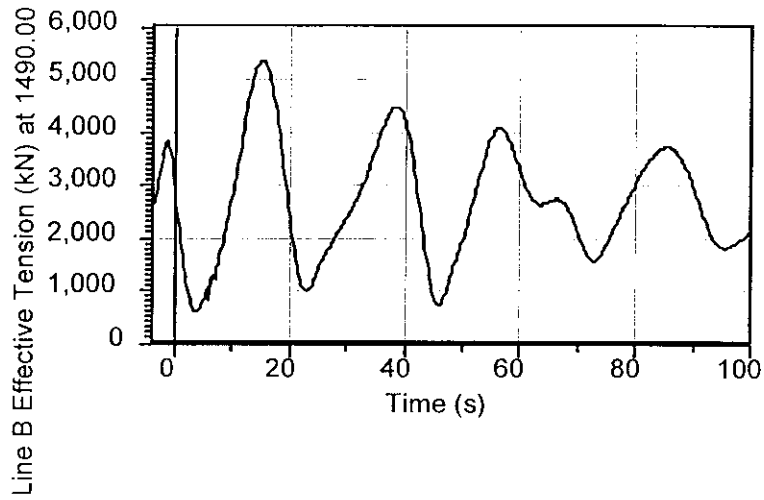
Data	Reference in EDG - DPD
<i>Sixth mooring configuration (file data-sch.doc)</i>	
<b>Results</b> DMOOR4.0 prestudy Maximum excursion Tension at fairlead (static + sig. second order motion) Line 12 Line 6 Max. tension Line 12 ORCAFLEX Min tension Line 6	34.81 m  6,723 kN 3,123 kN  8,860 kN sen1.sim  590 kN



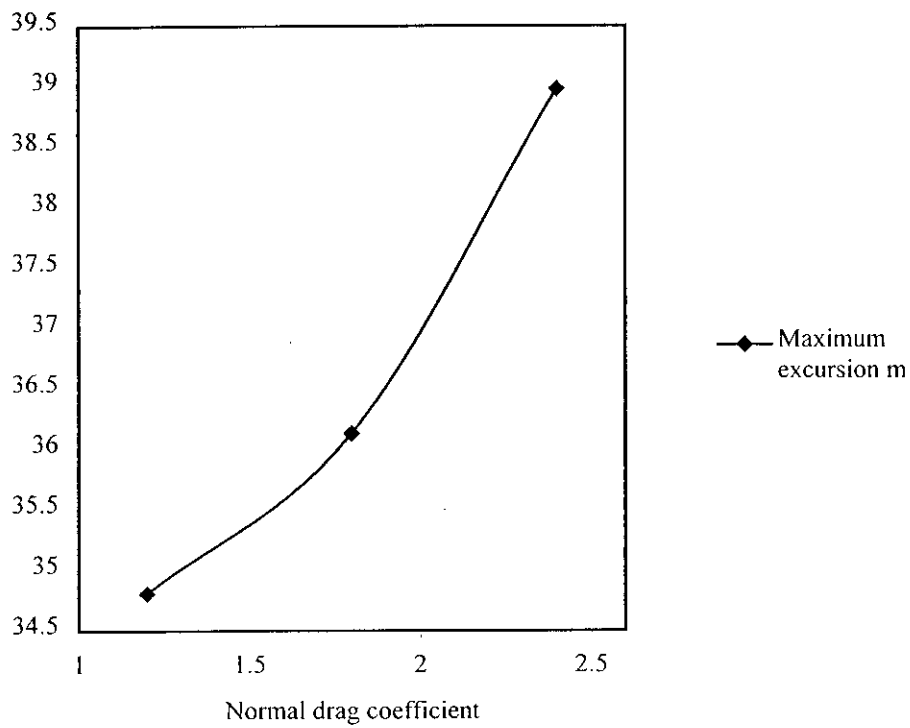
<p><b>Seventh mooring system configuration</b>                  The normal drag coefficient of the rope is increased.                  Second segment                  material                  normal drag coefficient</p>	<p>fibre rope                  1.8</p>
<p><b>Results</b>                  DMOOR4.0 prestudy                  Maximum excursion                  Tension at fairlead (static + sig. second order motion)                      Line 12                      Line 6                  Max. tension                      Line 12                  ORCAFLEX                  Min tension                      Line 6</p>	<p>36.13 m                  6,972 kN                  3,276kN                  8,823 kN                  sen12.sim                  595 kN</p>

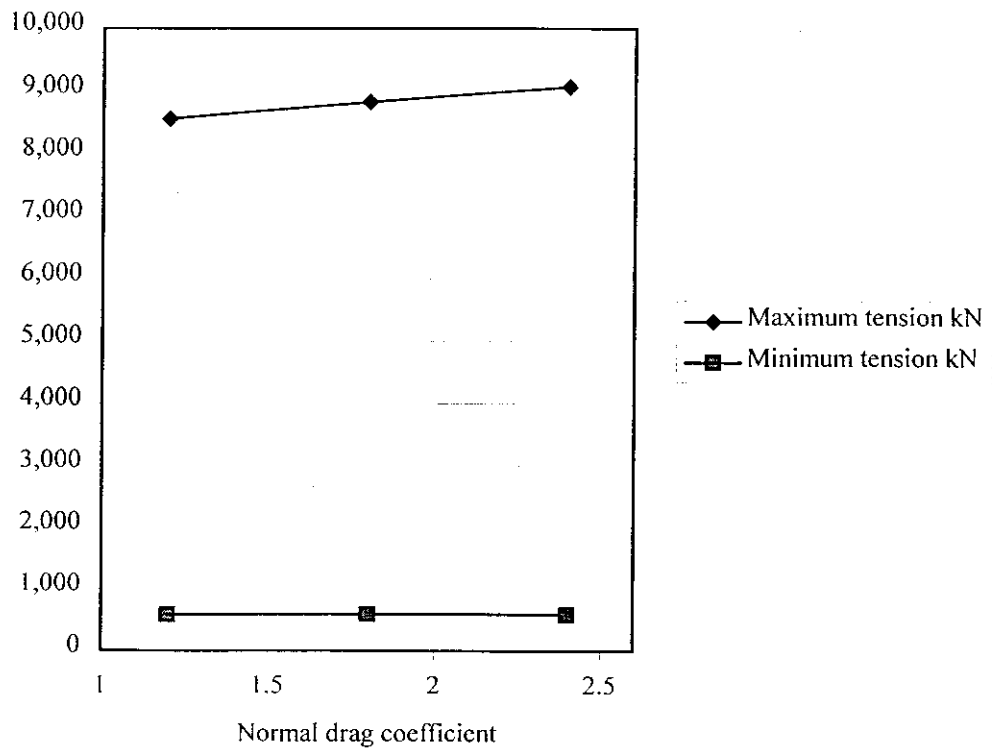
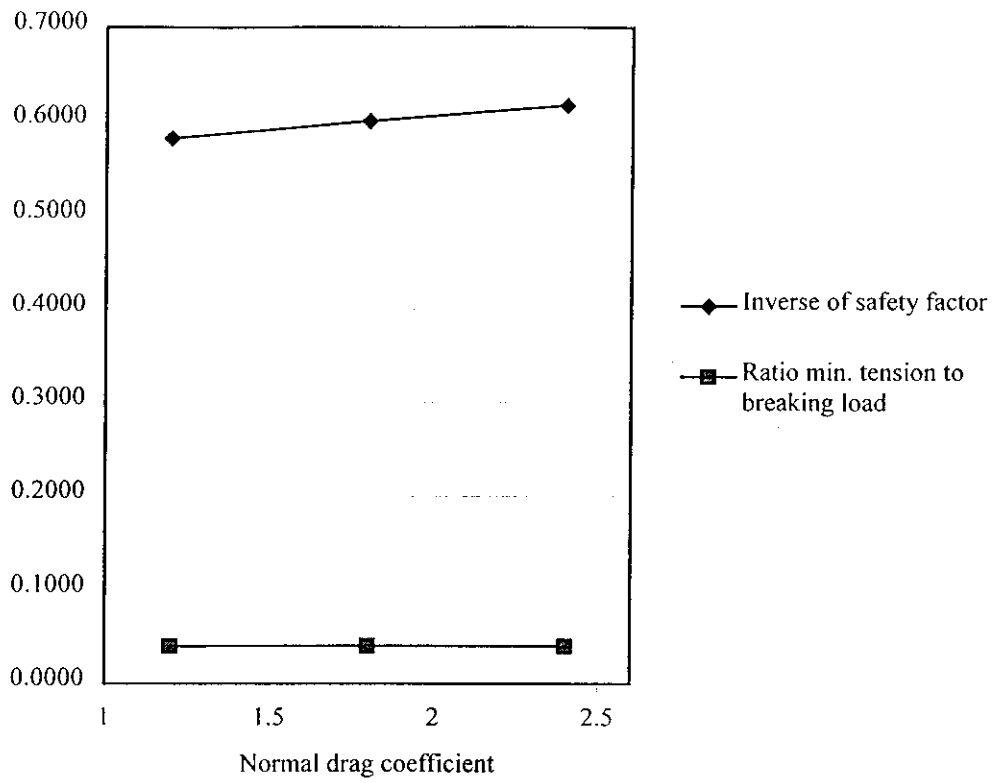


<p><b>Height mooring system configuration</b>                  The normal drag coefficient of the rope is increased.                  Second segment                  material                  normal drag coefficient</p>	<p>fibre rope                  2.4</p>
<p><b>Results</b>                  DMOOR4.0 prestudy                  Maximum excursion                  Tension at fairlead (static + sig. second order motion)                  Line 12                  Line 6                  Max. tension                  Line 12                  ORCAFLEX                  Min tension                  Line 6</p>	<p>38.98 m                  7,204 kN                  3,071 kN                  9,069kN                  sen13.sim                  594 kN</p>



Fibre rope normal drag coef.	Maximum excursion m	Maximum tension kN	Inverse of safety factor	Minimum tension kN	Ratio min. tension to breaking load
1.2	34.81	8,560	0.5817	590	0.0401
1.8	36.13	8,823	0.5996	595	0.0404





**Fatigue analysis**

**(10 sheets)**

## Fatigue analysis for the Atlantic margin FPSO.

The fatigue analyses is completed following the EDG and therefore the API RP 2SK. Tension responses in short-term seastates were predicted and used to compute the fatigue damage. The computed fatigue in each seastate was then combined to predict the total fatigue damage and fatigue life of the mooring lines taking into account the probabilities of occurrence of the seastates.

The following analysis is just an illustration for the EDG and follows the steps described in it. Major assumptions have been done to make the analysis easier, therefore the results are not really accurate, but the method used is the right one.

### 1- Scope of work

The scope of work of the mooring line analysis can be summarised as follows:

- Develop environmental model
  - The model includes:
    - The short terms seastates characterised by the significant wave height and zero crossing period
    - Associated wind and current speeds
    - The probabilities of occurrence of each short term seastate
- Dynamic analysis
  - For each environmental direction, mooring line dynamic analyses are performed for about 7 selected seastates to develop the tension response model as function of the significant wave height and zero crossing period.
  - The tension response models are then used to predict line tensions of all the seastates of interest.
- Predict mooring fatigue life
  - The long-term fatigue damage of moorings lines are computed in accordance with the procedures recommended by API RP 2SK.

In our case, we will not take into account the different seastate directions. We will assume that all seastates come from the bow of the vessel (0° heading). We will analyse the line number 12 as it has been identified as the most heavily loaded line for a weather heading of 0°.

Moreover, this analysis is carried out in a very **conservative** way; indeed, as we assume all the seastates coming from 0° heading, the tensions in the line 12 will be overestimated for all the other directions (20°, 45° and 90°). Therefore, the total fatigue life will be underestimated.

### 2- Environmental data

The table of wave occurrences for the FPSO location can be seen in the excel spreadsheet *fat2-sc2.xls* (appendix 1). The waves are modelled using the Jonswap spectrum, and the duration of a storm is assumed to be 3 hours.

### 3- Vessel and mooring system

The vessel is the FPSO described in the file *data-sch.doc* and the mooring system is the one corresponding to the last configuration in this same file.

### 4- Analysis

In the mooring analysis, the static loads for each short-term seastate are computed using the force coefficients. The RMS value of both low frequency tensions and wave frequency dynamic tension are computed directly from the program DMOOR.

The fatigue analysis requires the long-term tension responses, i.e. line tensions for every possible combination of significant wave height and zero crossing period. There are hundreds of such combinations and it is impractical to compute line tensions using the dynamic analysis method for all the individual seastates.

A method has been adopted to simplified the process of line tension prediction. For the wave heading, 7 seastates (table 1) which cover the whole range of wave height and period variations are selected and mooring analyses were conducted to compute the tension responses for the selected seastates (table 2). The RMS values have been computed using the **storm stiffness** for the fibre ropes. Regression analyses were then carried out to fit the RMS tensions as a function of the wave height and period using the following formula:

$$\sigma_t = a \times H_s^b / T_z^c$$

where  $\sigma_t$  is the RMS line tension,  $H_s$  is the significant wave height,  $T_z$  is the zero crossing period and a, b and c are coefficients which were determined through the regression analysis to produce the best fit (tables 3 and 4).

Table 1:

Seastate	Hs m	Tz s	Vw m/s	Vc m/s
1	2	6	14	0.9
2	8	8	24	1.2
3	8	10	24	1.2
4	8	12	24	1.2
5	18	12	40	1.7
6	18	15	40	1.7
7	18	17	40	1.7

Table 2:

Seastate	1st order RMS value N	2nd order RMS value N
1	12,698	15,899
2	147,189	379,666
3	188,309	271,343
4	197,876	144,240
5	464,091	897,800
6	656,880	429,287
7	739,885	298,909

Table 3:

1st order			
c	b	Log a	
-0.7436134	1.6311818	-0.9576120	Hs<8m
-1.0107268	1.0461084	-0.6947730	Hs>8m



Table 4:

2nd order	c	b	Log a	
	2.3544669	2.8198527	1.1929719	Hs<8m
	2.7074258	2.1319573	2.1650763	Hs>8m

The fatigue damage in a particular seastate is calculated using Equation 7.9 of API RP 2SK assuming Rayleigh distribution of tension peaks. The total fatigue damage is predicted taking into account the probability of occurrence of each sea state.

Fatigue damage due to first order wave frequency effect and second order low frequency effect is computed independently and added to derive the total fatigue damage. Since the first order load is the dominant effect in this case, this method is acceptable according to API RP 2SK [Ref. 4].

As the fatigue behaviour of fibre ropes is not really known but is better than the one for spiral strand ropes, the T-N curves used for the analysis are the **T-N curves of spiral strand ropes** as notified in DPD-8.2.9. The T-N curve recommended by API RP 2SK has the following form:

$$NR^m = K$$

where R is the ratio of tension range to the reference breaking strength, N is number of cycles to failure, M is the slope of the T-N curve and K is the intercept point of the T-N curve.

The following values of M and K were specified by API and used in the present fatigue analysis:

	M	K
Spiral strand rope	5.05	$10^{3.25-3.43 Lm}$

where Lm = Ratio of mean load to CBS (Catalog Breaking Strength)

The fatigue damaged of the mooring line in any particular short-term seastate was calculated according to the following formula recommended by API:

$$D = N_w(\sqrt{2}R_{wms})^M \times \Gamma(1+M/2)/K + N_L(\sqrt{2}R_{Lms})^M \times \Gamma(1+M/2)/K$$

where D is the annual fatigue damage from wave frequency and low frequency tensions,  $N_w$  is the number of wave frequency tension cycles per year,  $N_L$  is the number of low frequency tension cycles per year,  $R_{wms}$  is the wave frequency rms tension and  $R_{Lms}$  is the low frequency rms tension.

The complete fatigue analysis is presented in Appendix 1. The computed fatigue damage has been combined according to their probabilities of occurrence.

The above calculation gives a total fatigue life of **2280 years** (fatigue life = 1/fatigue damage). It is noted that the safety factor of 3.0 specified in the API has not been incorporated into the calculation, i.e. the service life of the mooring system should be less than **760 years**, which is quite realistic.

As the fibre rope fatigue behaviour is better than chain or spiral strand rope one, it will be necessary to complete a fatigue analysis for the other line components to get the final fatigue and service lives.

**Appendix 1**  
**Excel Spreadsheets**

**Tension Fatigue Spreadsheet - Design Life Fiber Rope T-N Curve**

**Wave Occurrences**

By TZV 15/04/98

All numerical variables to be changed by the user are underlined and in italic.

ALL WAVES - Wave Occurrences						
Hs [m]	Tz [s]	Vessel Heading				TOTAL
		0 deg	20 deg	45 deg	90 deg	
0.5	4.13	0.000041	0.000357	0.000377	0.000153	0.000928
1	5.21	0.001722	0.015068	0.015929	0.006458	0.039177
1.5	5.8	0.016657	0.054098	0.038663	0.017116	0.126534
2	6.25	0.031925	0.079556	0.044056	0.014685	0.170222
2.5	6.61	0.035065	0.077832	0.035953	0.014519	0.163369
3	6.97	0.028817	0.065748	0.024345	0.007535	0.126445
3.5	7.33	0.031334	0.058709	0.015828	0.003634	0.109505
4	7.75	0.020662	0.037102	0.012154	0.001791	0.071709
4.5	8.19	0.017651	0.029664	0.005516	0.000674	0.053505
5	8.33	0.014608	0.021623	0.00311	0.000072	0.039413
5.5	8.76	0.011286	0.01634	0.001095		0.028721
6	8.99	0.00877	0.010231	0.001736		0.020737
6.5	9.2	0.005194	0.009222	0.000318	0.000106	0.014840
7	9.65	0.004413	0.005884	0.000267	0	0.010564
7.5	9.74	0.002753	0.004373	0.000324	0	0.007450
8	9.93	0.002299	0.002927			0.005226
8.5	10.13	0.001093	0.002369	0.000182		0.003644
9	10.37	0.000897	0.001808			0.002705
9.5	10.65	0.000927	0.000993			0.001920
10	10.92	0.000464	0.001326			0.001790
10.5	11.2	0.000244	0.000532			0.000776
11	11.48	0.000058	0.000178			0.000236
11.5	11.73	0.000039	0.000159			0.000198
12	12	0.000027	0.000146			0.000173
12.5	12.25	0.000017	0.000137			0.000154
13	12.49	0.000012	0.000012			0.000024
13.5	12.73	0.000005	0.000006			0.000011
14	12.96	0.000005	0.000005			0.000010
14.5	13.19	0.000003	0.000003			0.000006
15	13.43	0.000002	0.000002			0.000004
15.5	13.66	0.000001	0.000001			0.000002
16	13.86	0.000001	0.000001			0.000002
<b>TOTAL</b>		0.236992	0.496412	0.199853	0.066743	1.000000

**Tension Fatigue Spreadsheet**

**Wave Frequency Standard Deviation**

	Vessel Heading [deg]	Hs (LT.EQ) 8m		Hs (GT) 8m	
		Alpha	Beta	Alpha	Beta
WF Contribution	0	1.6311818	0.7436134	1.0461084	1.0107268
	20	1.6311818	0.7436134	1.0461084	1.0107268
	45	1.6311818	0.7436134	1.0461084	1.0107268
	90	1.6311818	0.7436134	1.0461084	1.0107268

<b>Standard Deviation = (Hs ^ Alpha)*(Tz^Beta)* Factor</b>		
Factor	0.110252	Hs<8m
	0.201942	Hs>8m

ALL WAVES - WF Standard Deviations of Tension Variations					
Hs [m]	Tz [s]	Vessel Heading			
		0 deg	20 deg	45 deg	90 deg
0.5	4.13	0.10	0.10	0.10	0.10
1	5.21	0.38	0.38	0.38	0.38
1.5	5.8	0.79	0.79	0.79	0.79
2	6.25	1.33	1.33	1.33	1.33
2.5	6.61	2.00	2.00	2.00	2.00
3	6.97	2.80	2.80	2.80	2.80
3.5	7.33	3.74	3.74	3.74	3.74
4	7.75	4.85	4.85	4.85	4.85
4.5	8.19	6.12	6.12	6.12	6.12
5	8.33	7.36	7.36	7.36	7.36
5.5	8.76	8.93	8.93	8.93	8.93
6	8.99	10.49	10.49	10.49	10.49
6.5	9.2	12.16	12.16	12.16	12.16
7	9.65	14.22	14.22	14.22	14.22
7.5	9.74	16.03	16.03	16.03	16.03
8	9.93	18.06	18.06	18.06	18.06
8.5	10.13	19.67	19.67	19.67	19.67
9	10.37	21.39	21.39	21.39	21.39
9.5	10.65	23.25	23.25	23.25	23.25
10	10.92	25.16	25.16	25.16	25.16
10.5	11.2	27.16	27.16	27.16	27.16
11	11.48	29.24	29.24	29.24	29.24
11.5	11.73	31.30	31.30	31.30	31.30
12	12	33.49	33.49	33.49	33.49
12.5	12.25	35.69	35.69	35.69	35.69
13	12.49	37.92	37.92	37.92	37.92
13.5	12.73	40.21	40.21	40.21	40.21
14	12.96	42.53	42.53	42.53	42.53
14.5	13.19	44.92	44.92	44.92	44.92
15	13.43	47.39	47.39	47.39	47.39
15.5	13.66	49.90	49.90	49.90	49.90
16	13.86	52.35	52.35	52.35	52.35

**Tension Fatigue Spreadsheet**

**Low Frequency Standard Deviation**

	Vessel Heading [deg]	Hs (LT.EQ) 7.5m		Hs (GT) 7.5m	
		Alpha	Beta	Alpha	Beta
LF Contribution	0	2.820	-2.35	2.132	-2.7074289
	20	2.820	-2.35	2.132	-2.7074289
	45	2.820	-2.35	2.132	-2.7074289
	90	2.820	-2.35	2.132	-2.7074289

<b>Standard Deviation = (Hs ^ Alpha)*(Tz^Beta)* Factor</b>	
<b>Factor</b>	<u>14.6339</u> Hs<8m
	<u>137.248</u> Hs>8m

ALL WAVES - LF Standard Deviations of Tension Variations					
Hs [m]	Tz [s]	Vessel Heading			
		0 deg	20 deg	45 deg	90 deg
0.5	4.13	0.07	0.07	0.07	0.07
1	5.21	0.30	0.30	0.30	0.30
1.5	5.8	0.73	0.73	0.73	0.73
2	6.25	1.38	1.38	1.38	1.38
2.5	6.61	2.27	2.27	2.27	2.27
3	6.97	3.35	3.35	3.35	3.35
3.5	7.33	4.60	4.60	4.60	4.60
4	7.75	5.88	5.88	5.88	5.88
4.5	8.19	7.20	7.20	7.20	7.20
5	8.33	9.31	9.31	9.31	9.31
5.5	8.76	10.81	10.81	10.81	10.81
6	8.99	13.00	13.00	13.00	13.00
6.5	9.2	15.43	15.43	15.43	15.43
7	9.65	17.00	17.00	17.00	17.00
7.5	9.74	20.20	20.20	20.20	20.20
8	9.93	23.16	23.16	23.16	23.16
8.5	10.13	24.91	24.91	24.91	24.91
9	10.37	26.41	26.41	26.41	26.41
9.5	10.65	27.57	27.57	27.57	27.57
10	10.92	28.74	28.74	28.74	28.74
10.5	11.2	29.78	29.78	29.78	29.78
11	11.48	30.76	30.76	30.76	30.76
11.5	11.73	31.90	31.90	31.90	31.90
12	12	32.84	32.84	32.84	32.84
12.5	12.25	33.89	33.89	33.89	33.89
13	12.49	34.96	34.96	34.96	34.96
13.5	12.73	35.98	35.98	35.98	35.98
14	12.96	37.04	37.04	37.04	37.04
14.5	13.19	38.06	38.06	38.06	38.06
15	13.43	38.97	38.97	38.97	38.97
15.5	13.66	39.91	39.91	39.91	39.91
16	13.86	41.06	41.06	41.06	41.06

**Tension Fatigue Spreadsheet**

**Wave Frequency Accumulated Fatigue Damage**

<b>log N = log a - m log R</b>	
a	7.90E+01
m	5.05

<b>P(R) = EXP[-R<sup>2</sup>/8m<sub>0</sub>] = EXP[-(R/(SQRT(8)*S.D.))<sup>2</sup>]</b>	
<b>Q(R) = EXP[-(R/q)<sup>h</sup>]</b>	
<b>q = SQRT(8)*S.D.</b>	
h	2

<b>D = (No/a)*q<sup>m</sup>*GAMMA(1+(m/h))</b>	
Damage Period	
[sec], P	10800

Breaking strength	1500	T
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<b>ALL WAVES - WF Fatigue Damage Distribution</b>						
Hs [m]	Tz [s]	Vessel Heading				
		0 deg	20 deg	45 deg	90 deg	TOTAL
0.5	4.13	8.03E-22	6.99E-21	7.38E-21	3.00E-21	1.82E-20
1	5.21	1.93E-17	1.69E-16	1.79E-16	7.24E-17	4.39E-16
1.5	5.8	7.08E-15	2.30E-14	1.64E-14	7.28E-15	5.38E-14
2	6.25	1.78E-13	4.44E-13	2.46E-13	8.20E-14	9.51E-13
2.5	6.61	1.44E-12	3.19E-12	1.47E-12	5.95E-13	6.69E-12
3	6.97	6.13E-12	1.40E-11	5.18E-12	1.60E-12	2.69E-11
3.5	7.33	2.73E-11	5.11E-11	1.38E-11	3.16E-12	9.53E-11
4	7.75	6.30E-11	1.13E-10	3.71E-11	5.46E-12	2.19E-10
4.5	8.19	1.65E-10	2.78E-10	5.17E-11	6.31E-12	5.01E-10
5	8.33	3.42E-10	5.06E-10	7.27E-11	1.68E-12	9.21E-10
5.5	8.76	6.65E-10	9.62E-10	6.45E-11	0.00E+00	1.69E-09
6	8.99	1.14E-09	1.33E-09	2.25E-10	0.00E+00	2.69E-09
6.5	9.2	1.39E-09	2.46E-09	8.49E-11	2.83E-11	3.96E-09
7	9.65	2.47E-09	3.30E-09	1.50E-10	0.00E+00	5.92E-09
7.5	9.74	2.79E-09	4.44E-09	3.29E-10	0.00E+00	7.56E-09
8	9.93	4.19E-09	5.33E-09	0.00E+00	0.00E+00	9.52E-09
8.5	10.13	3.00E-09	6.51E-09	5.00E-10	0.00E+00	1.00E-08
9	10.37	3.67E-09	7.40E-09	0.00E+00	0.00E+00	1.11E-08
9.5	10.65	5.63E-09	6.03E-09	0.00E+00	0.00E+00	1.17E-08
10	10.92	4.09E-09	1.17E-08	0.00E+00	0.00E+00	1.58E-08
10.5	11.2	3.09E-09	6.74E-09	0.00E+00	0.00E+00	9.83E-09
11	11.48	1.04E-09	3.19E-09	0.00E+00	0.00E+00	4.23E-09
11.5	11.73	9.66E-10	3.94E-09	0.00E+00	0.00E+00	4.90E-09
12	12	9.19E-10	4.97E-09	0.00E+00	0.00E+00	5.89E-09
12.5	12.25	7.82E-10	6.30E-09	0.00E+00	0.00E+00	7.08E-09
13	12.49	7.35E-10	7.35E-10	0.00E+00	0.00E+00	1.47E-09
13.5	12.73	4.04E-10	4.85E-10	0.00E+00	0.00E+00	8.89E-10
14	12.96	5.27E-10	5.27E-10	0.00E+00	0.00E+00	1.05E-09
14.5	13.19	4.09E-10	4.09E-10	0.00E+00	0.00E+00	8.18E-10
15	13.43	3.51E-10	3.51E-10	0.00E+00	0.00E+00	7.03E-10
15.5	13.66	2.24E-10	2.24E-10	0.00E+00	0.00E+00	4.48E-10
16	13.86	2.81E-10	2.81E-10	0.00E+00	0.00E+00	5.62E-10
<b>TOTAL</b>		3.94E-08	7.86E-08	1.53E-09	4.72E-11	1.20E-07

**Tension Fatigue Spreadsheet**

**Low Frequency Accumulated Fatigue Damage**

<b>log N = log a - m log R</b>	
<b>a</b>	7.90E+01
<b>m</b>	5.05
$P(R) = EXP[-R^2/8m_0] = EXP[-(R/(SQRT(8)*S.D.))^2]$ $Q(R) = EXP[-(R/q)^h]$ $q = SQRT(8)*S.D.$	
<b>h</b>	2
<b>D = (No/a)*q<sup>m</sup>*GAMMA(1+(m/h))</b>	
<b>Damage Period [sec], P</b>	10800
<b>Natural Surge Period [sec]</b>	90
<b>Breaking strength</b>	1500 T

<b>ALL WAVES - LF Fatigue Damage Distribution</b>						
<b>Hs [m]</b>	<b>Tz [s]</b>	<b>Vessel Heading</b>				
		<b>0 deg</b>	<b>20 deg</b>	<b>45 deg</b>	<b>90 deg</b>	<b>TOTAL</b>
0.5	4.13	6.97E-24	6.07E-23	6.41E-23	2.60E-23	1.58E-22
1	5.21	3.58E-19	3.13E-18	3.31E-18	1.34E-18	8.15E-18
1.5	5.8	3.11E-16	1.01E-15	7.23E-16	3.20E-16	2.37E-15
2	6.25	1.48E-14	3.68E-14	2.04E-14	6.79E-15	7.87E-14
2.5	6.61	2.00E-13	4.44E-13	2.05E-13	8.28E-14	9.31E-13
3	6.97	1.17E-12	2.68E-12	9.91E-13	3.07E-13	5.15E-12
3.5	7.33	6.29E-12	1.18E-11	3.18E-12	7.30E-13	2.20E-11
4	7.75	1.43E-11	2.57E-11	8.43E-12	1.24E-12	4.97E-11
4.5	8.19	3.40E-11	5.71E-11	1.06E-11	1.30E-12	1.03E-10
5	8.33	1.03E-10	1.53E-10	2.19E-11	5.08E-13	2.78E-10
5.5	8.76	1.70E-10	2.46E-10	1.65E-11	0.00E+00	4.33E-10
6	8.99	3.35E-10	3.91E-10	6.63E-11	0.00E+00	7.92E-10
6.5	9.2	4.72E-10	8.37E-10	2.89E-11	9.62E-12	1.35E-09
7	9.65	6.52E-10	8.70E-10	3.95E-11	0.00E+00	1.56E-09
7.5	9.74	9.73E-10	1.55E-09	1.15E-10	0.00E+00	2.63E-09
8	9.93	1.62E-09	2.06E-09	0.00E+00	0.00E+00	3.68E-09
8.5	10.13	1.11E-09	2.41E-09	1.85E-10	0.00E+00	3.71E-09
9	10.37	1.23E-09	2.47E-09	0.00E+00	0.00E+00	3.70E-09
9.5	10.65	1.58E-09	1.69E-09	0.00E+00	0.00E+00	3.27E-09
10	10.92	9.74E-10	2.78E-09	0.00E+00	0.00E+00	3.76E-09
10.5	11.2	6.12E-10	1.34E-09	0.00E+00	0.00E+00	1.95E-09
11	11.48	1.71E-10	5.26E-10	0.00E+00	0.00E+00	6.97E-10
11.5	11.73	1.39E-10	5.65E-10	0.00E+00	0.00E+00	7.03E-10
12	12	1.11E-10	6.01E-10	0.00E+00	0.00E+00	7.12E-10
12.5	12.25	8.19E-11	6.60E-10	0.00E+00	0.00E+00	7.42E-10
13	12.49	6.76E-11	6.76E-11	0.00E+00	0.00E+00	1.35E-10
13.5	12.73	3.26E-11	3.91E-11	0.00E+00	0.00E+00	7.17E-11
14	12.96	3.78E-11	3.78E-11	0.00E+00	0.00E+00	7.55E-11
14.5	13.19	2.60E-11	2.60E-11	0.00E+00	0.00E+00	5.20E-11
15	13.43	1.95E-11	1.95E-11	0.00E+00	0.00E+00	3.90E-11
15.5	13.66	1.10E-11	1.10E-11	0.00E+00	0.00E+00	2.20E-11
16	13.86	1.27E-11	1.27E-11	0.00E+00	0.00E+00	2.54E-11
<b>TOTAL</b>		1.06E-08	1.95E-08	4.96E-10	1.38E-11	3.06E-08

**Tension Fatigue Spreadsheet**

**Fatigue Damage Distribution in Period P**

Damage Period, P = 10800 seconds  
 WF Component of Damage = 79.64 %  
 LF Component of Damage = 20.36 %  
 Total Fatigue Life = 2280.01 years

ALL WAVES - Total Fatigue Damage Distribution in Period P						
Hs [m]	Tz [s]	Vessel Heading				TOTAL
		0 deg	20 deg	45 deg	90 deg	
0.5	4.13	8.10E-22	7.05E-21	7.45E-21	3.02E-21	1.83E-20
1	5.21	1.97E-17	1.72E-16	1.82E-16	7.37E-17	4.47E-16
1.5	5.8	7.39E-15	2.40E-14	1.72E-14	7.60E-15	5.62E-14
2	6.25	1.93E-13	4.81E-13	2.66E-13	8.88E-14	1.03E-12
2.5	6.61	1.64E-12	3.63E-12	1.68E-12	6.77E-13	7.62E-12
3	6.97	7.31E-12	1.67E-11	6.17E-12	1.91E-12	3.21E-11
3.5	7.33	3.36E-11	6.29E-11	1.70E-11	3.89E-12	1.17E-10
4	7.75	7.73E-11	1.39E-10	4.55E-11	6.70E-12	2.68E-10
4.5	8.19	1.99E-10	3.35E-10	6.23E-11	7.61E-12	6.04E-10
5	8.33	4.45E-10	6.58E-10	9.46E-11	2.19E-12	1.20E-09
5.5	8.76	8.35E-10	1.21E-09	8.10E-11	0.00E+00	2.12E-09
6	8.99	1.47E-09	1.72E-09	2.91E-10	0.00E+00	3.48E-09
6.5	9.2	1.86E-09	3.30E-09	1.14E-10	3.79E-11	5.31E-09
7	9.65	3.13E-09	4.17E-09	1.89E-10	0.00E+00	7.48E-09
7.5	9.74	3.77E-09	5.99E-09	4.43E-10	0.00E+00	1.02E-08
8	9.93	5.81E-09	7.39E-09	0.00E+00	0.00E+00	1.32E-08
8.5	10.13	4.12E-09	8.92E-09	6.85E-10	0.00E+00	1.37E-08
9	10.37	4.90E-09	9.87E-09	0.00E+00	0.00E+00	1.48E-08
9.5	10.65	7.21E-09	7.72E-09	0.00E+00	0.00E+00	1.49E-08
10	10.92	5.07E-09	1.45E-08	0.00E+00	0.00E+00	1.96E-08
10.5	11.2	3.70E-09	8.08E-09	0.00E+00	0.00E+00	1.18E-08
11	11.48	1.21E-09	3.72E-09	0.00E+00	0.00E+00	4.93E-09
11.5	11.73	1.10E-09	4.50E-09	0.00E+00	0.00E+00	5.61E-09
12	12	1.03E-09	5.57E-09	0.00E+00	0.00E+00	6.60E-09
12.5	12.25	8.63E-10	6.96E-09	0.00E+00	0.00E+00	7.82E-09
13	12.49	8.03E-10	8.03E-10	0.00E+00	0.00E+00	1.61E-09
13.5	12.73	4.37E-10	5.24E-10	0.00E+00	0.00E+00	9.61E-10
14	12.96	5.65E-10	5.65E-10	0.00E+00	0.00E+00	1.13E-09
14.5	13.19	4.35E-10	4.35E-10	0.00E+00	0.00E+00	8.70E-10
15	13.43	3.71E-10	3.71E-10	0.00E+00	0.00E+00	7.42E-10
15.5	13.66	2.35E-10	2.35E-10	0.00E+00	0.00E+00	4.70E-10
16	13.86	2.94E-10	2.94E-10	0.00E+00	0.00E+00	5.88E-10
<b>TOTAL</b>		5.00E-08	9.80E-08	2.03E-09	6.10E-11	1.50E-07



**Worked example “b” –**

**Semi Sub - Atlantic Margin (risers not included)**

**(33 sheets)**

**Data necessary to complete the mooring analysis  
of an Atlantic Margin semisub,  
their reference in the DPD, and results of the analysis.**

Reference in EDG - DPD	Data / Calculations	Results
DPD 7.	<p><i>Site data, location</i></p> <p>Location wind wave current Water depth Seabed slope</p>	<p>Norwegian sea Davenport spectrum Vw = 40 m/s Jonswap spectrum <math>\gamma = 3.3</math> Hs = 16.1 m Tp = 16.75 s Uniform Vc = 1.5 m/s 1 500 m 0 %</p>
DPD 7.	<p><i>Platform data</i></p> <p>Frame orientation origin Type of vessel Dimensions length outside pontoons breadth outside pontoons draft static airgap Displacement, mass Position of the COG Mass moment of inertia Added mass coefficients surge sway yaw Linear damping (vessel) surge (% of critical damping) sway (% of critical damping) RAO's, QTF Wind and current coefficients</p> <p><i>No risers included (assuming that they are taken by thrusters)</i></p>	<p>see figure 1 centre of semisub still water level Semisub 84.48 m 84.48 m 21.0m 18.5 m 52,280 t (0,0,7.81) 65150,000 t.m<sup>2</sup> 0.5480 0.5480 0.5708 13 % 13 % RAOGV.xls and QTFGV.xls Appendix 1</p>

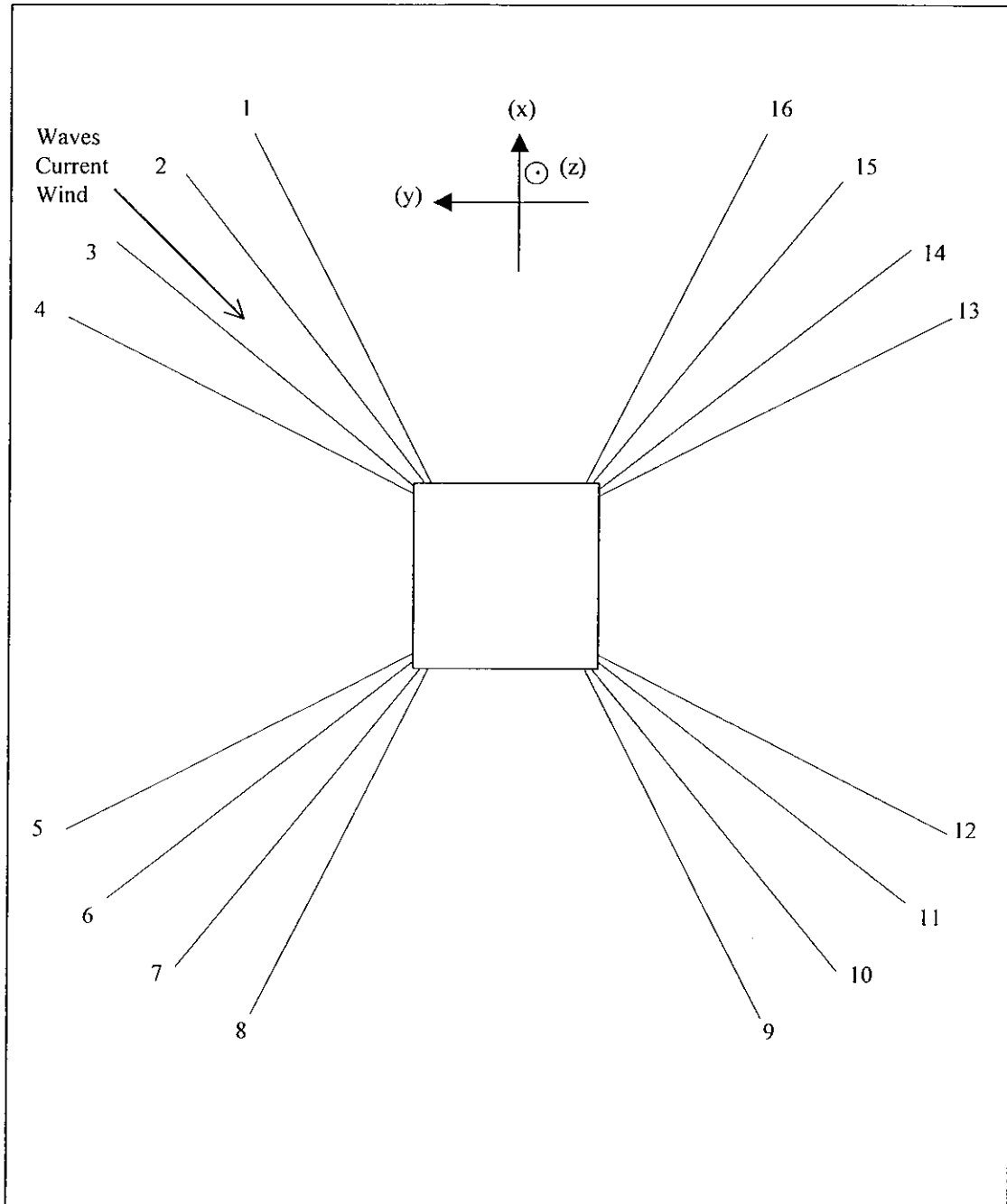
<i>Fairlead positions</i>	
fairlead 1	(28.75,38.50, -15.4)
fairlead 2	(31.98,39.50, -15.4)
fairlead 3	(35.15,39.58, -15.4)
fairlead 4	(38.29,38.50,-15.4)
fairlead 5	(38.29,-38.50, -15.4)
fairlead 6	(35.15,-39.58, -15.4)
fairlead 7	(31.98,-39.50, -15.4)
fairlead 8	(28.75,-38.50, -15.4)
fairlead 9	(-28.75,-38.50, -15.4)
fairlead 10	(-28.75,-38.50, -15.4)
fairlead 11	(-35.15,-39.58, -15.4)
fairlead 12	(-38.29,-38.50, -15.4)
fairlead 13	(-38.29,38.50, -15.4)
fairlead 14	(-35.15,39.58, -15.4)
fairlead 15	(-31.98,39.50, -15.4)
fairlead 16	(-28.75,38.50, -15.4)

<p>DPD 6.</p>	<p><b>First mooring system configuration</b></p> <p>Number of lines                  Number of groups of lines                  Spread angle between lines of the same group                  Length of lines                  Number of segments in a line</p> <p>First segment (near the anchor)</p> <p>material                  breaking load                  length                  bar diameter                  dry mass                  added mass                  submerged weight                  stiffness                  normal drag coefficient                  tangential drag coefficient                  friction coefficient</p> <p>Second segment</p> <p>material                  breaking load (BL)                  length                  diameter                  dry mass                  added mass                  submerged weight                  stiffness</p> <p>normal drag coefficient                  tangential drag coefficient                  friction coefficient</p> <p>Third segment                  same as first segment                  length                  Pretension</p> <p>(see figure 1)</p>	<p>16                  4                  10 deg                  2,625 m                  3</p> <p>chain (K4 studlink)                  14,715 kN                  25 m                  0.127 m                  0.3532 t/m                  0.0459 t/m                  3.0145 kN/m                  1.427x10<sup>6</sup> kN/m/m                  2.5                  0.5                  1</p> <p>fibre rope                  14,715 kN                  2,500 m                  0.208 m                  0.0349 t/m                  0.0341 t/m                  0.000854 kN/m                  variable from                  8xBL to 35xBL</p> <p>1.2                  0.05                  1</p> <p>100 m                  Variable from                  0.1xBL to 0.3xBL</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results for this first configuration</b></p> <p><b>Conclusion:</b>                  After little calculation with different dip angles, we saw that the line length is too small.</p>	<p>File EDG-GVA1.xls                  Min. tension too low</p>

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Figure 1:

### Schematic of mooring line layout for GVA 8000



**Semisub**

Fibre rope : **Polyester** 2500 m

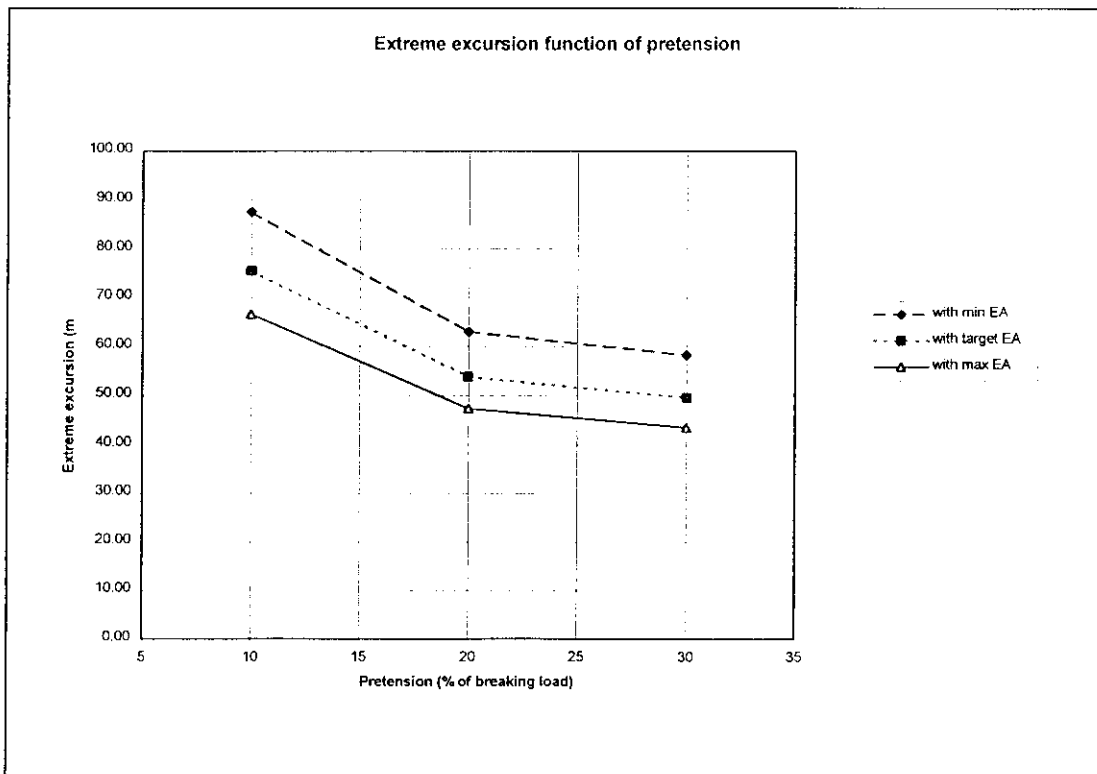
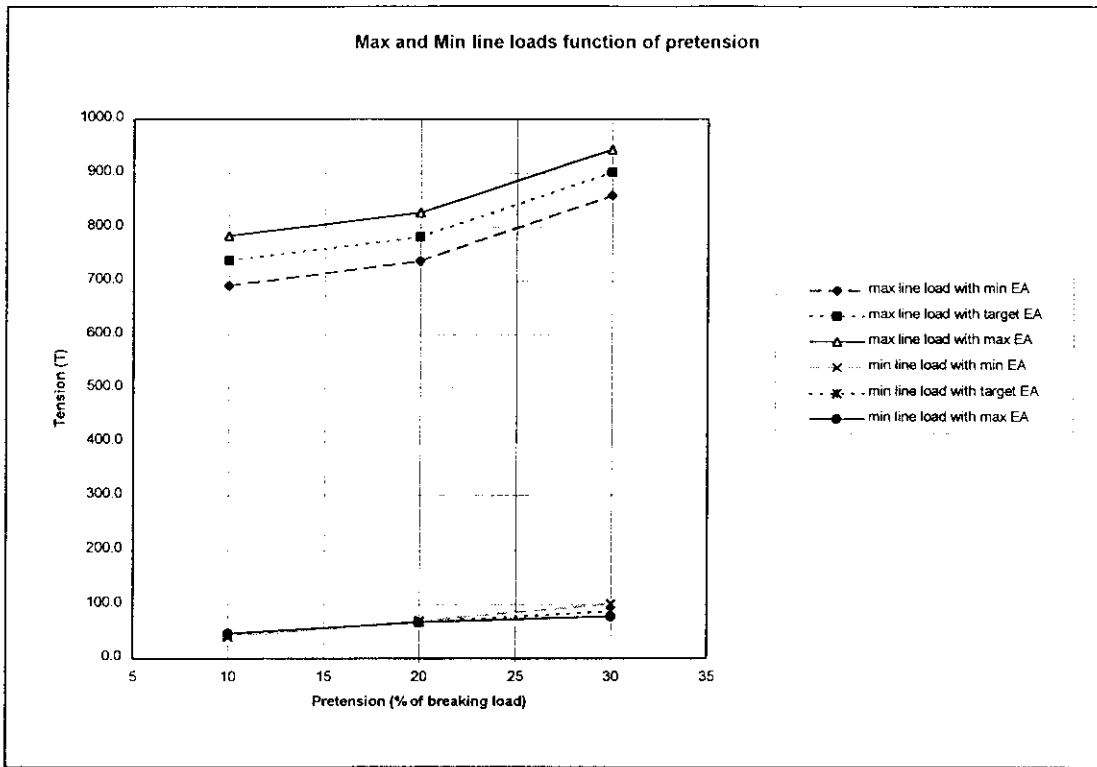
Breaking Load = 1 500 T  
Water depth = 1 500 m

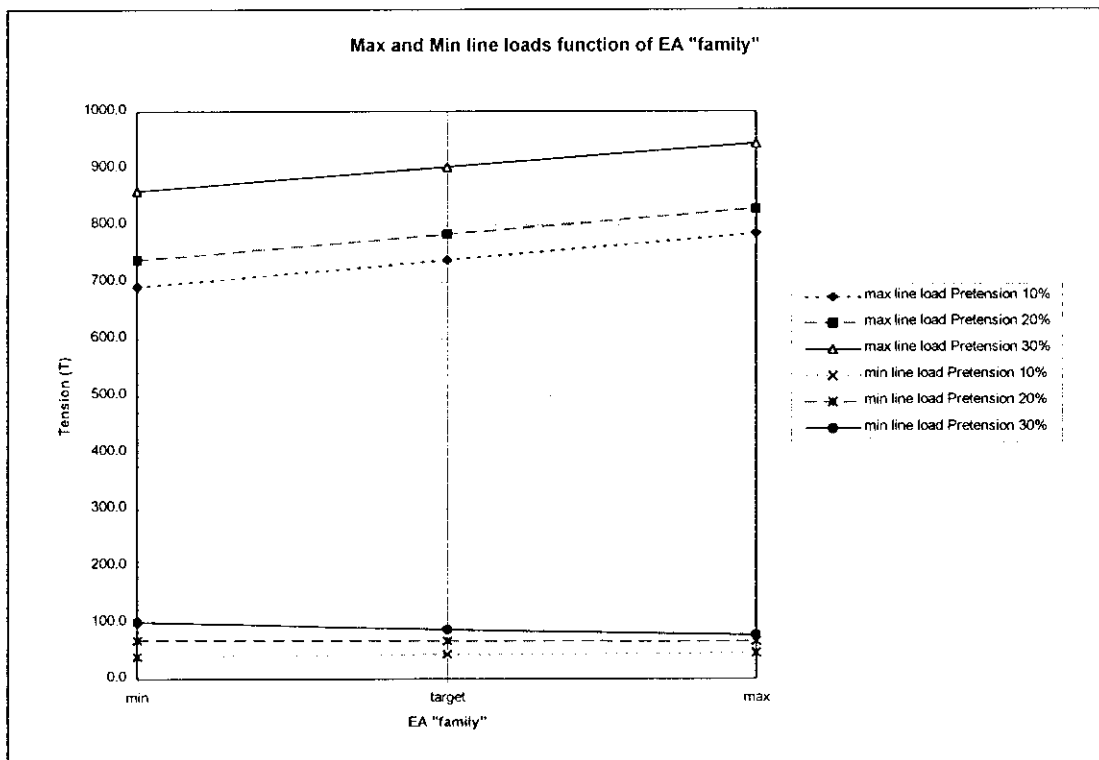
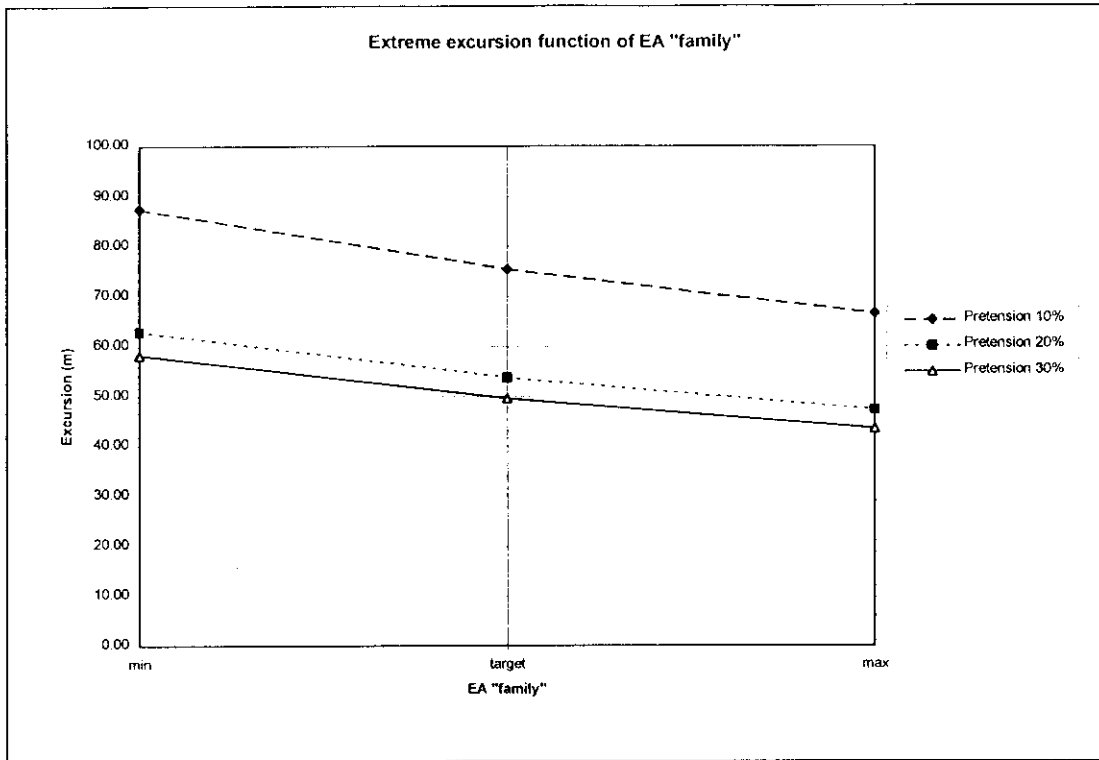
Pretension	EA			EA max	Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max						
10% BL	8 * BL	15 * BL	25 * BL	25 * BL	87.49	5.83	691.5	2.17	40.4
	10 * BL	20 * BL	30 * BL	30 * BL	75.42	5.03	739.0	2.03	44.0
	12 * BL	25 * BL	35 * BL	35 * BL	66.57	4.43	785.0	1.91	46.8
20% BL	8 * BL	15 * BL	25 * BL	25 * BL	62.99	4.20	738.4	2.03	69.7
	10 * BL	20 * BL	30 * BL	30 * BL	53.77	3.58	783.4	1.91	68.3
	12 * BL	25 * BL	35 * BL	35 * BL	47.34	3.16	828.4	1.81	67.1
30% BL	8 * BL	15 * BL	25 * BL	25 * BL	58.25	3.88	859.8	1.74	101.8
	10 * BL	20 * BL	30 * BL	30 * BL	49.59	3.31	902.6	1.66	87.6
	12 * BL	25 * BL	35 * BL	35 * BL	43.50	2.90	944.5	1.59	78.1

1 line damage

Line 2

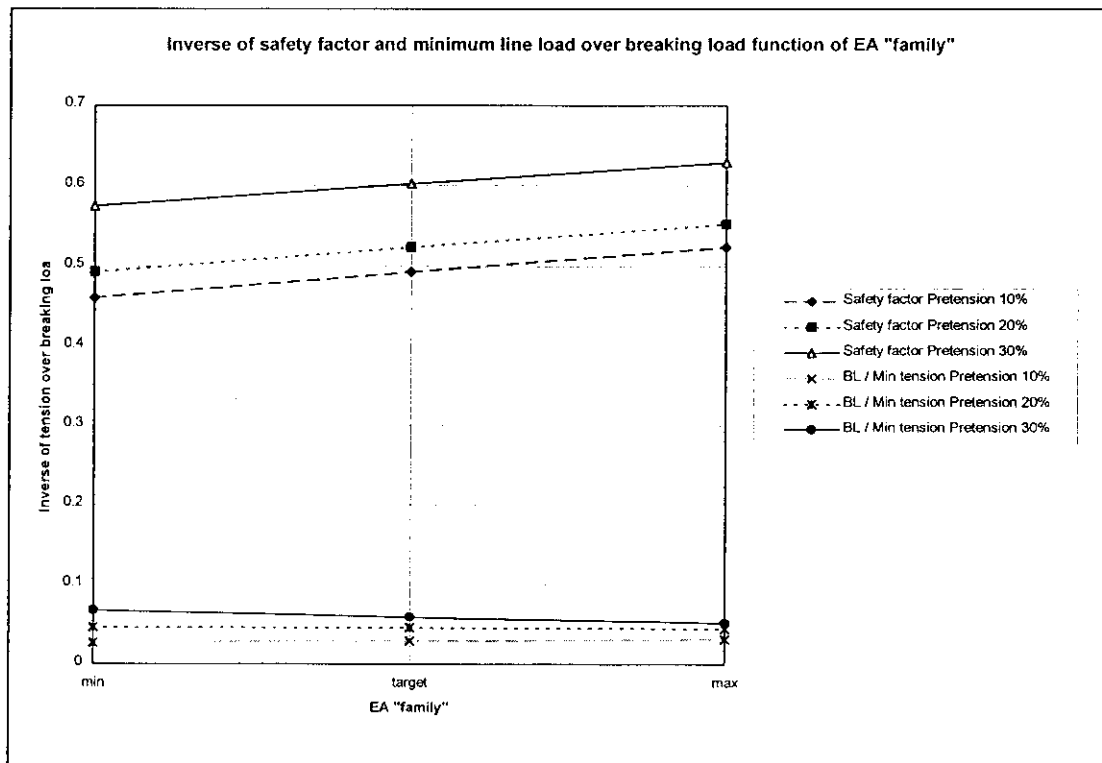
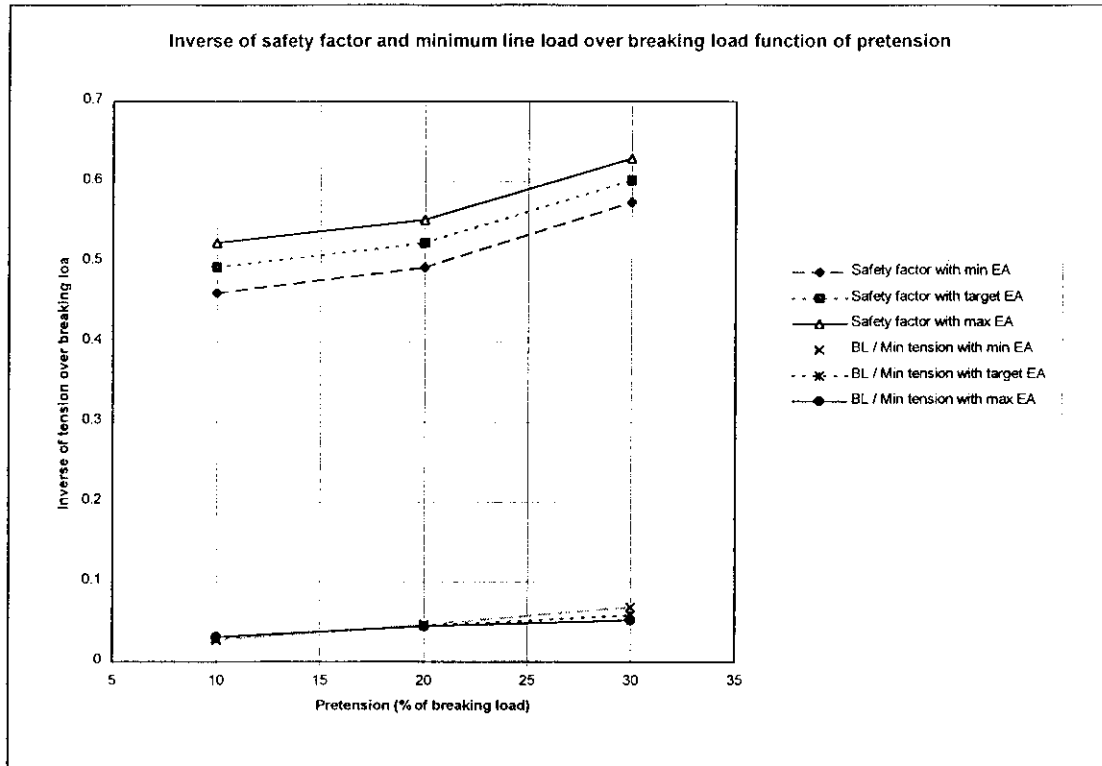
Pretension	EA			EA max	Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max						
10% BL	8 * BL	15 * BL	25 * BL	25 * BL	116.10	7.74	820.5	1.82	39.0







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<p>DPD 5.2.2.</p>	<p><b>Second mooring system configuration</b>                  The only thing that changes compared to the second configuration is the submerged weight of the second segment.                  Second segment submerged weight</p>	<p>0.868 kN/m</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results for this second configuration</b></p> <p><b>Conclusion:</b>                  The configuration with pretension equals 0.3xBL and with the smaller family of stiffness seems to be suitable. But we want to demonstrate the accuracy of our minimum tension calculation method on DMOOR 4.0 with the program ORCAFLEX.</p>	<p>File EDG-GVA2.xls</p>

**Semisub**

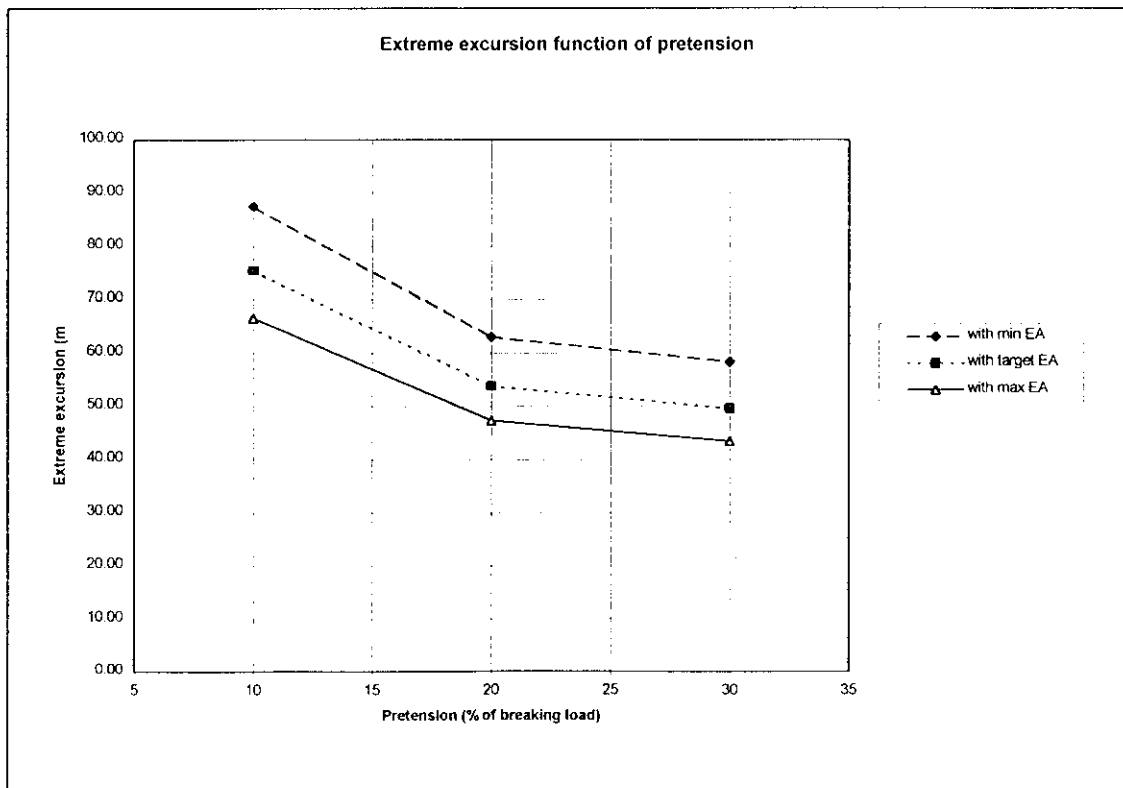
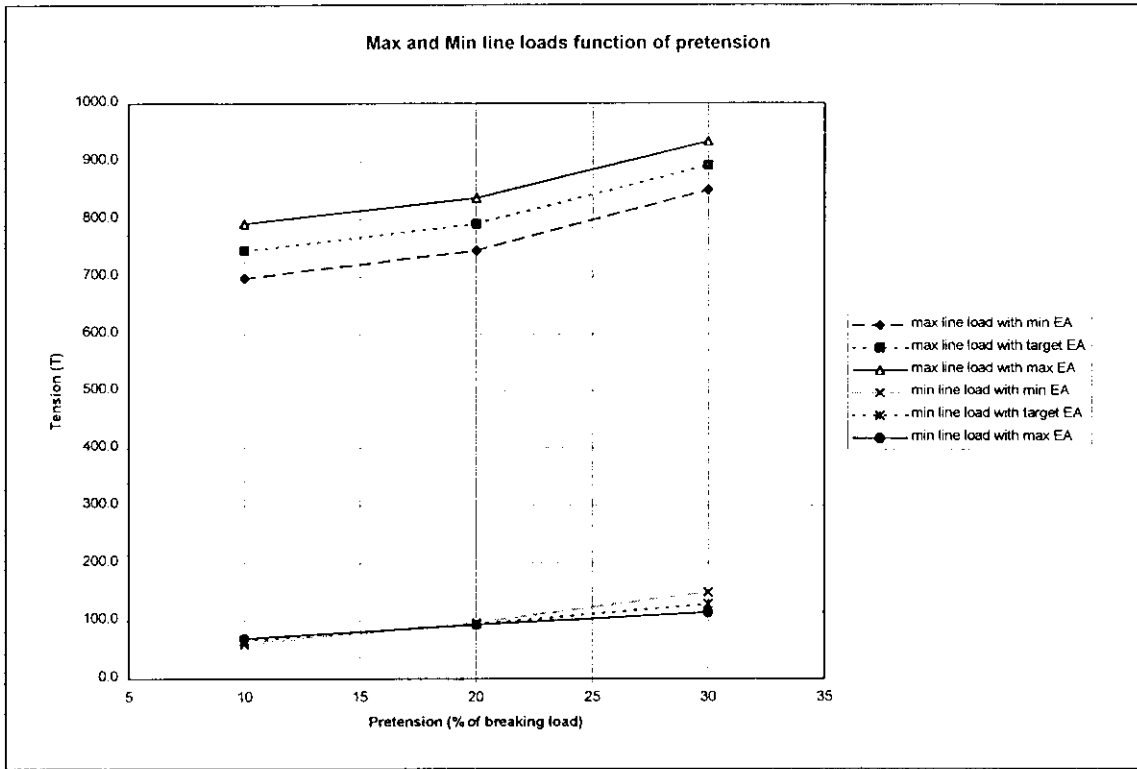
Fibre rope : **Polyester** 2 500 m

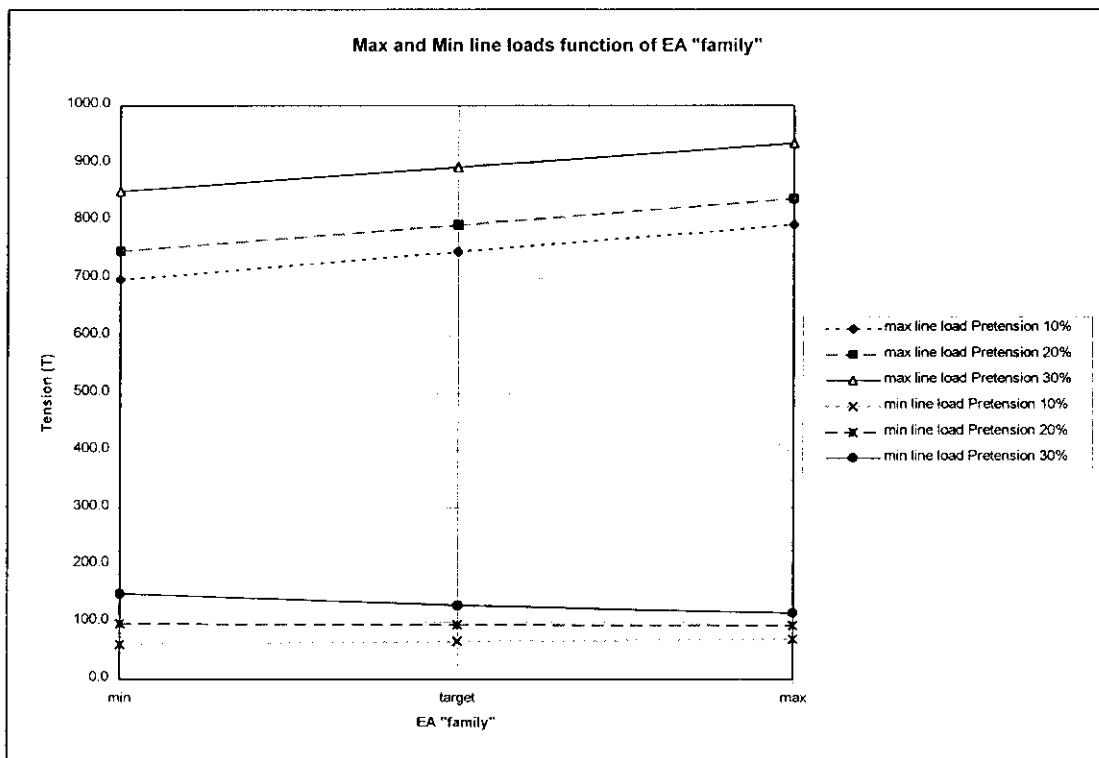
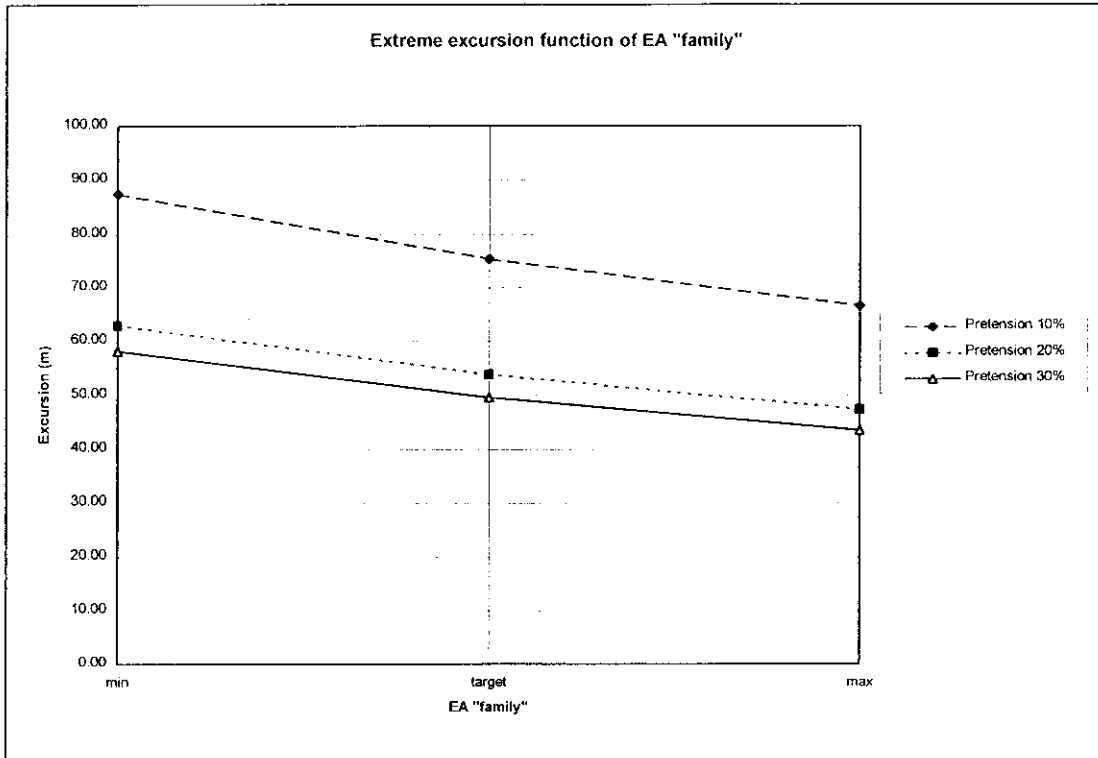
Breaking Load = 1 500 T  
Water depth = 1 500 m

Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	87.49	5.83	697.7	2.15	60.4
	10 * BL	20 * BL	30 * BL	75.42	5.03	745.6	2.01	65.8
	12 * BL	25 * BL	35 * BL	66.57	4.43	792.0	1.89	69.9
20% BL	8 * BL	15 * BL	25 * BL	62.99	4.20	746.2	2.01	96.8
	10 * BL	20 * BL	30 * BL	53.77	3.58	791.7	1.89	94.9
	12 * BL	25 * BL	35 * BL	47.34	3.16	837.2	1.79	93.2
30% BL	8 * BL	15 * BL	25 * BL	58.25	3.88	850.6	1.76	149.7
	10 * BL	20 * BL	30 * BL	49.59	3.31	892.9	1.68	128.9
	12 * BL	25 * BL	35 * BL	43.50	2.90	934.3	1.61	114.9

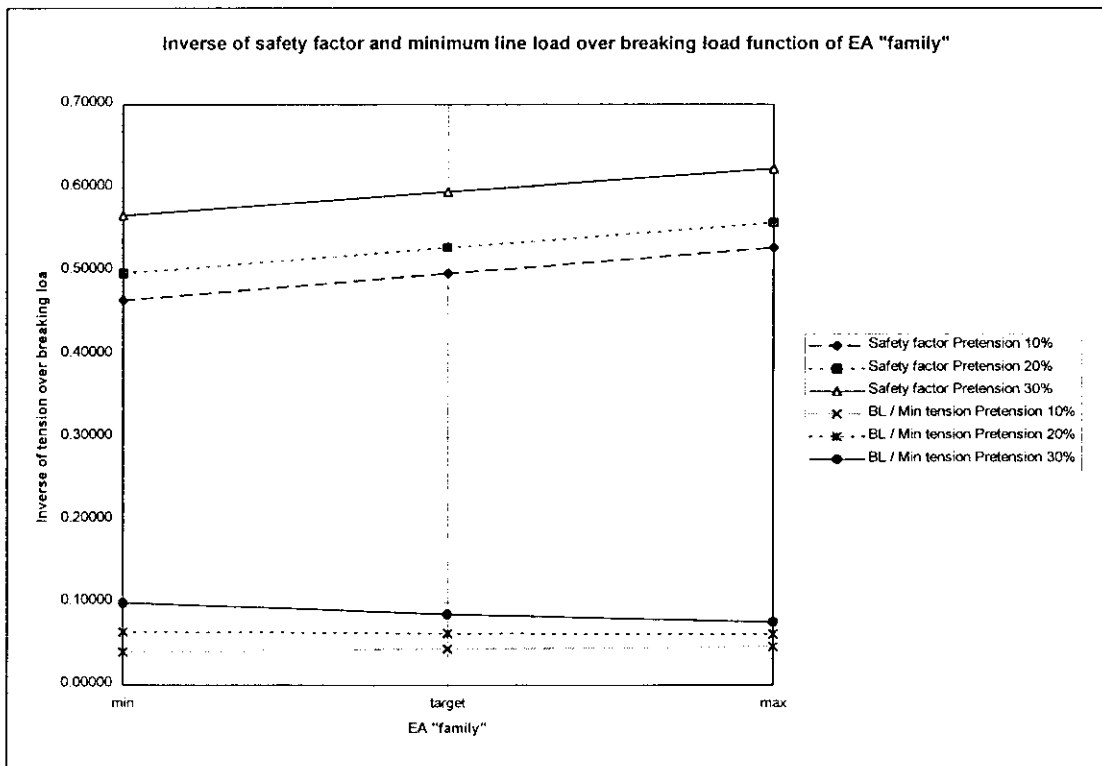
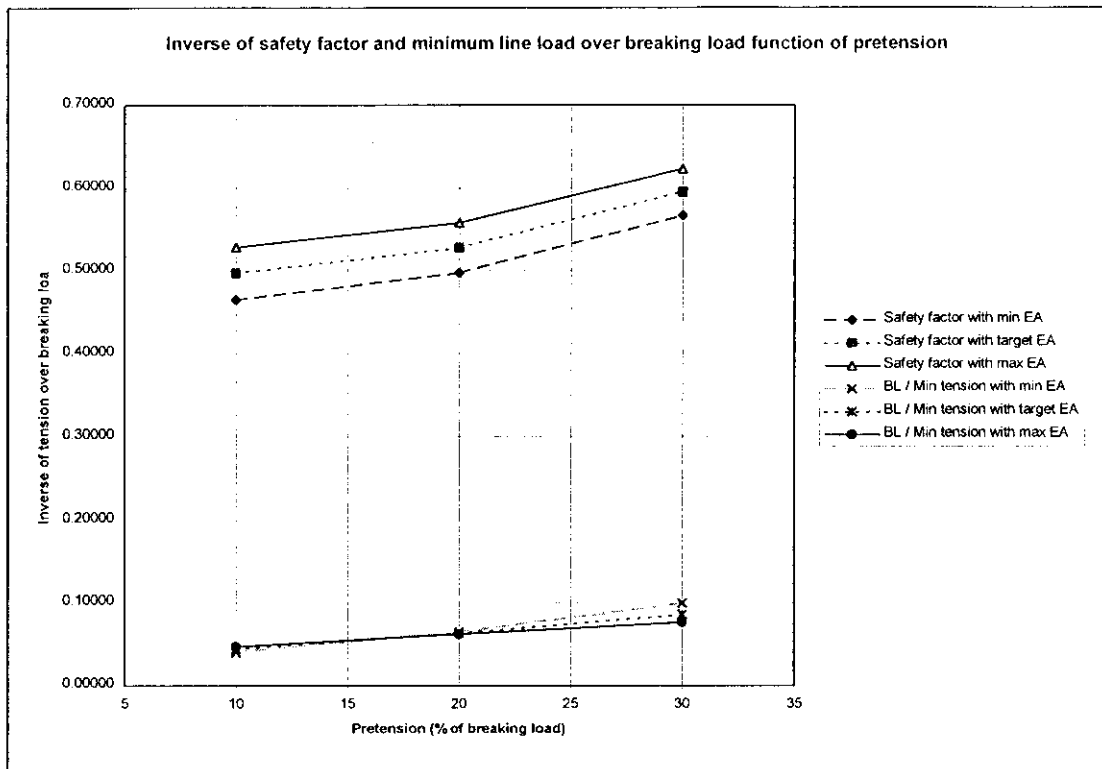
1 line damage Line 2

Pretension	EA			Extreme excursion (m)	% of water depth	Max tension (T)	Safety factor	Min tension (T)
	EA min	EA int	EA max					
10% BL	8 * BL	15 * BL	25 * BL	116.10	7.74	827.8	1.81	58.3

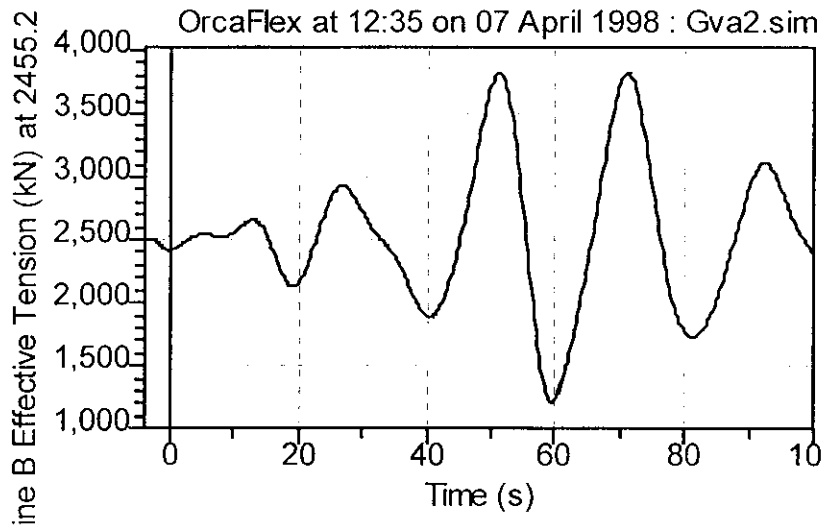




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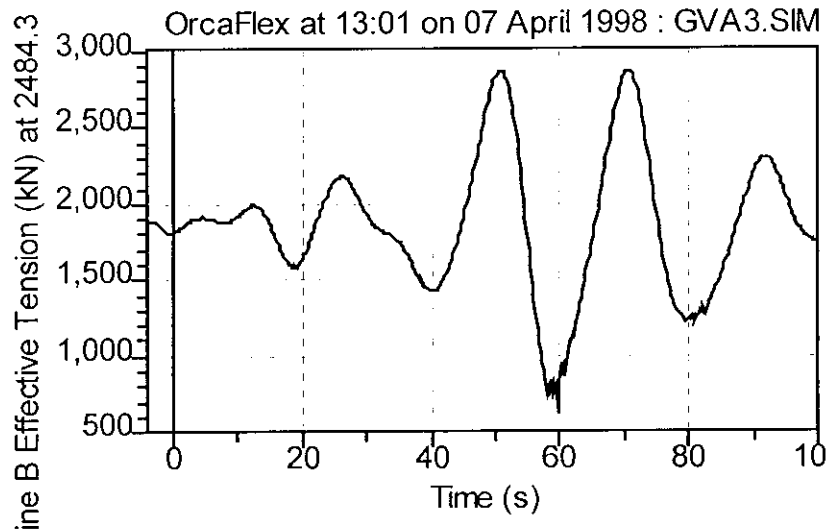


	<p><b>Third mooring system configuration</b>                  Model on ORCAFLEX                  The weight and bar diameter of the chain at the bottom and at the top are increased; the length of the bottom segment is increased to 150 m and the length of the second segment is decreased to 2,475 m.</p> <p>First segment</p> <ul style="list-style-type: none"> <li>breaking load 19,816 kN</li> <li>length 150 m</li> <li>bar diameter 0.304 m</li> <li>dry mass 1.0546 t/m</li> <li>added mass 0.1386 t/m</li> <li>submerged weight 10.207 kN/m</li> <li>stiffness 1.427x10<sup>6</sup> kN/m/m</li> <li>normal drag coefficient 2.5</li> <li>tangential drag coefficient 0.5</li> <li>friction coefficient 1</li> </ul> <p>Second segment</p> <ul style="list-style-type: none"> <li>length 2,375 m</li> <li>stiffness 20xBL</li> </ul> <p>Third segment</p> <ul style="list-style-type: none"> <li>breaking load 19,816 kN</li> <li>length 100 m</li> <li>bar diameter 0.152 m</li> <li>dry mass 0.5273 t/m</li> <li>added mass 0.0693 t/m</li> <li>submerged weight 5.1035 kN/m</li> <li>stiffness 1.427x10<sup>6</sup> kN/m/m</li> <li>normal drag coefficient 2.5</li> <li>tangential drag coefficient 0.5</li> <li>friction coefficient 1</li> </ul> <p>Pretension 0.3xBL</p>	
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results</b>                  DMOOR 4.0 prestudy                  Tension at fairlead (static + sig. second order motion)</p> <ul style="list-style-type: none"> <li>Line 3 7,044 kN</li> <li>Line 10 2,852 kN</li> </ul> <p>Max tension</p> <ul style="list-style-type: none"> <li>Line 3 9,185.5 kN</li> </ul> <p>ORCAFLEX                  FileGVA2.sim</p> <p>Min tension</p> <ul style="list-style-type: none"> <li>Line 10 1,172.4 kN</li> </ul> <p><b>Conclusion</b>                  The minimum tension is 7.9% of the breaking load, but the maximum tension in line 3 is too high. In the next configuration, the pretension will be decreased to obtain a good safety factor.</p>	





	<p><b>Fourth mooring system configuration</b> The only thing that changes compared to the fifth configuration is the pretension. Pretension</p>	<p>0.25xBL</p>
<p>DPD 8.2.4.1. DPD 8.2.4.2.</p>	<p><b>Results</b> DMOOR 4.0 prestudy (input file: Appendix 2) Tension at fairlead (static + sig. second order motion) Line 3 Line 10 Max tension Line 3 ORCAFLEX (input file: Appendix 3) Min tension Line 10</p> <p><b>Conclusion</b> The minimum tension is equal to 4.2% of the breaking load and the safety factor is 1.71.</p>	<p>6,480.2 kN 2,287.0 kN 8,598.7 kN FileGVA3.sim 624.7kN</p>



**Final conclusion:**

The conclusion is the same than for the F.P.S.O., i.e. it seems very difficult to reach the value of 10% of the breaking load for the minimum tension.

## **APPENDIX 1**

### **Response Amplitude Operators, Wave Drifts Coefficients Current and Wind Coefficients**

**RAO's for the semisub in the environmental direction**

Frequency rad/s	Period s	Surge		Sway		Heave		Roll		Pitch		Yaw	
		Amp m/m	Phase deg	Amp m/m	Phase deg	Amp m/m	Phase deg	Amp deg/m	Phase deg	Amp deg/m	Phase deg	Amp deg/m	Phase deg
0.157	40.0	0.978	90.76	0.980	89.33	1.020	0.47	0.439	-88.19	0.426	58.58	0.000	176.80
0.180	35.0	0.861	90.59	0.862	89.50	1.035	0.75	0.430	-90.69	0.407	66.90	0.000	-2.04
0.209	30.0	0.762	90.53	0.763	89.58	1.078	1.57	0.427	-91.39	0.401	72.83	0.000	-48.14
0.224	28.0	0.727	90.54	0.728	89.58	1.124	2.57	0.425	-91.41	0.400	74.70	0.000	175.30
0.233	27.0	0.711	90.55	0.712	89.56	1.166	3.60	0.423	-91.37	0.398	75.54	0.000	176.30
0.242	26.0	0.696	90.58	0.697	89.54	1.236	5.55	0.422	-91.32	0.397	76.34	0.000	-3.92
0.251	25.0	0.681	90.62	0.682	89.50	1.361	10.09	0.420	-91.24	0.395	77.07	0.000	173.70
0.262	24.0	0.666	90.67	0.667	89.45	1.575	23.96	0.417	-91.13	0.393	77.76	0.000	179.80
0.267	23.5	0.659	90.71	0.660	89.41	1.592	40.64	0.416	-91.07	0.392	78.09	0.000	177.70
0.273	23.0	0.651	90.75	0.652	89.37	1.233	61.52	0.414	-91.00	0.390	78.40	0.000	178.70
0.279	22.5	0.644	90.80	0.645	89.33	0.725	66.78	0.412	-90.92	0.389	78.69	0.000	177.30
0.286	22.0	0.637	90.85	0.638	89.27	0.479	48.91	0.410	-90.83	0.387	78.97	0.000	179.40
0.299	21.0	0.622	90.00	0.623	90.13	0.489	15.19	0.406	-91.61	0.382	80.48	0.000	-1.78
0.314	20.0	0.605	90.19	0.606	89.93	0.567	5.65	0.399	-91.35	0.376	80.93	0.000	179.50
0.331	19.0	0.587	90.45	0.588	89.67	0.615	3.13	0.392	-91.03	0.370	81.29	0.000	179.50
0.349	18.0	0.566	90.81	0.568	89.31	0.638	1.20	0.382	-90.60	0.361	81.55	0.000	-1.54
0.370	17.0	0.543	90.30	0.544	89.81	0.647	1.50	0.372	-91.04	0.351	82.67	0.000	178.30
0.393	16.0	0.515	90.97	0.516	89.13	0.643	0.60	0.359	-90.32	0.339	82.61	0.000	178.70
0.419	15.0	0.481	90.89	0.483	89.19	0.631	1.05	0.344	-90.33	0.325	83.32	0.000	174.70
0.449	14.0	0.441	91.15	0.443	88.90	0.607	2.55	0.326	-90.02	0.308	83.73	0.000	-3.23
0.483	13.0	0.392	90.90	0.395	89.11	0.569	4.20	0.306	-89.30	0.290	83.80	0.000	178.80
0.524	12.0	0.334	91.21	0.337	88.76	0.507	8.36	0.283	-89.83	0.267	85.21	0.000	-176.00
0.571	11.0	0.260	89.35	0.264	90.60	0.402	15.46	0.258	-91.56	0.242	87.95	0.000	-133.10
0.628	10.0	0.160	83.28	0.166	96.93	0.250	22.67	0.225	-98.34	0.209	95.87	0.000	-14.16
0.698	9.0	0.027	93.21	0.031	96.15	0.101	23.83	0.155	-115.90	0.139	114.10	0.000	-4.22
0.785	8.0	0.051	-179.10	0.049	-1.81	0.006	164.40	0.054	-128.90	0.047	125.40	0.000	-6.37
0.898	7.0	0.046	75.20	0.046	104.70	0.083	-163.00	0.014	-109.10	0.012	105.50	0.000	23.18
1.047	6.0	0.076	53.66	0.076	126.30	0.038	-112.70	0.002	129.60	0.002	-137.70	0.000	-175.50
1.257	5.0	0.034	84.68	0.034	95.30	0.002	-37.31	0.000	-69.45	0.000	70.33	0.000	-158.20
1.571	4.0	0.019	87.15	0.019	92.83	0.001	-161.30	0.000	-96.70	0.000	97.72	0.000	-2.17

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**QTF for the semisub  
in the environmental direction**

Frequency rad/s	Fx N/m <sup>2</sup>	Fy N/m <sup>2</sup>	Mz N/m
0.157	-775	-775	-62
0.180	-1033	-1033	68
0.209	-1547	-1547	357
0.224	-1946	-1946	581
0.233	-2249	-2249	738
0.242	-2693	-2693	936
0.251	-3420	-3420	1190
0.262	-4547	-4547	1517
0.267	-4422	-4422	1715
0.273	-2432	-2432	1942
0.279	-897	-896.8	2201
0.286	-699	-698.6	2498
0.299	-1234	-1234	3229
0.314	-1831	-1830	4199
0.331	-2399	-2399	5479
0.349	-2986	-2986	7180
0.370	-3638	-3639	9436
0.393	-4421	-4423	12420
0.419	-5452	-5458	16300
0.449	-6985	-7007	21240
0.483	-9564	-9632	27290
0.524	-14000	-14210	34080
0.571	-19550	-20180	40220
0.628	-22560	-24150	43600
0.698	-71530	-73500	51860
0.785	-140200	-140400	25210
0.898	-54570	-54510	1746
1.047	-159600	-159600	1587
1.257	-154200	-154200	30
1.571	-142800	-142700	156

**Wind coefficient  
in the environmental direction**

$F_x/V_w^2 = -2.577 \text{ kN} \cdot (\text{s/m})^2$ $F_y/V_w^2 = -2.345 \text{ kN} \cdot (\text{s/m})^2$ $M_z/V_w^2 = -10.698 \text{ kN} \cdot \text{m} \cdot (\text{s/m})^2$
--

**Current coefficient  
in the environmental direction**

$F_x/V_c^2 = -553.2 \text{ kN} \cdot (\text{s/m})^2$ $F_y/V_c^2 = -548.9 \text{ kN} \cdot (\text{s/m})^2$ $M_z/V_w^2 = -423 \text{ kN} \cdot \text{m} \cdot (\text{s/m})^2$
---

**APPENDIX 2**

**DMOOR 4.0**  
**Input Files**  
**For the last configuration**

```

#* 100-YEAR STORM ***** START OF DETER.INP AUG 1996 *****
#INPUT NO.1: TITLE DESCRIPTION
SEMISUBMERSIBLE GVA8000 IN 1000-M WD FOR FIBRE ROPE ANALYSIS
#INPUT NO.2: NL,NJ,NI,NT,IANAL; IANAL = 1 ,FOR FULL DYNAMIC ANALYSIS
1 1 1 1 1
#INPUT NO.3: IIT; INNIT = 1 ,ALL DATA IN METRIC ITS
1
#INPUT NO.4: FRQ1,FRQ2
0.209 1.57
#INPUT NO.5: (ANGI(I),I=1,NI) ... MOORING LINE SPREAD ANGLE
# FROM FAIRLEAD TO ANCHOR FROM BOW COTERCLOCK WISELY
40
#INPUT NO.6: (ANGJ(J),J=1,NJ) ... ENV HEADING (TO) FROM BOW C.C.W.
225.0
#INPUT NO.7: (LTYP(I),I=1,NI) ... LINE TYPES IF NI>1
#INPUT NO.8: (SEA(L),WINDY(L),CURRY(L),L=1,NL)
16.1 40.0 1.5
#INPUT NO.9: ISPEC,PARAM; ISPEC = 4, JONSWOP SPECTRUM
4 3.3
#INPUT NO.10: KSPEC
0
#INPUT NO.11: (XSPECT(JG),JG=1,NL) ... PEAK PERIOD OF WAVE SPECTRUM
16.75
#INPUT NO.13: IWSPEC,WPAR1,WPAR2
# IWSPEC = 3 , JONSWAP SPECTRUM
# WPAR1 = 0., NO WIND DYNAMICS, USE 1-MIN. MEAN WIND SPEED
# = 1200., WIND DYNAMICS IS CONSIDERED, USE 1-HOUR
3 1200. 0.
#INPUT NO.14: NCOEFF = THE NUMBER OF DISTINCT WIND FORCE COEFF.
1
#INPUT NO.15: (ICOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.16: (WIND(J),J=1,NCOEFF) .WIND FORCE COEFF. PER VELOCITY*2 ( N/(m/s)^2 )
3480.7
#INPUT NO.17: NCOEF1 = THE NUMBER OF DISTINCT CURRENT FORCE COEFF.
1
#INPUT NO.18: (JCOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.19: (CURR(J),J=1,NCOEF1) ... CURRENT FORCE COEFFICIENTS
779373.1
#INPUT NO.20: NCOEF2 = THE NUMBER OF DISTINCT WAVE DRIFT FORCE COEFF.
1
#INPUT NO.21: (KCOEFF(J),J=1,NJ) ... IN THE DEFINED ENVIR. DIRECTION
1
#INPUT NO.22: ((DRIFT(I,J),J=1,NF),I=1,NCOEF2)
# WAVE HDG = 45. N/m^2
2145.9 6437.8 2145.9 5364.8 8583.7
15021.5 24034.3 26824.0 60085.8 127682.4
196351.9 142703.9 77897.0 114163.1 189485.0
229184.5 233905.6 227038.6 219313.3 216309.0
212875.5 210085.8 207296.1 203862.7 201287.6
#INPUT NO.23: ITCODE,LPTS,MAXSEG ... IF ITCODE = 0, THEN TENSION OUTPUT
# AT FAIRLEAD & SKIP INPUT NO.24
0 0 0
#INPUT NO.24: (IOP (JG,JGG), JGG = 1, MAXSEG);OUTPUT FOR ALL SEGMENTS
#INPUT NO.25: IFINC = 1 , USE 25 FREQUENCIES IN FREQ. DOMAIN DYNAMICS
1
#***** END OF DETER.INP *****

```

```

***** START OF STEADY.INP *****
# GVA 8000 SEMISUBMERSIBLE
#INPUT NO.1: ITLP,ICURR
  0 2
# ICURR=2, CONSTANT CURRENT(ACTING ON MOORING LINES & BUOYS IF ANY)
#INPUT NO.2: N2, N3, NUMBER OF LINES & NUMBER OF LINE TYPES
  16,1
#INPUT NO.3: (ANGI(I),I= 1,N2) SPREAD ANGLES OF LINES (CCW FR BOW)
  30.,40.,50.,60.,120.,130.,140.,150.,210.,220.,230.,240.,300.,310.,320.,330
#INPUT NO.4: (LTYP(I),I= 1,N2) ... LINE TYPES OF ALL LINES
  1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1
#INPUTS NO.5-NO.8 SHOULD BE REPEATED FOR ALL THE LINE TYPES SPECIFIED.
#INPUT NO.5: NSEG, NBUOY, NTOT
  3 0 68
#INPUT NO.6: RLENG,RMASS,AMASS,WEIGHT,DIA,EA,TBREAK,ANMSE,CD,CDT,FRICTN
# 1500 T LINES
  150. 1054.6  138.6  10207  0.304  1.427E9  2.02E7  10  2 5  0.50  1.00
  2375.  34.91  34.05   86.8  0.208  4.410E8  1.50E7  50  1.2  0.05  0.00
  100.  527.3   69.29  5103.5  0.152  1.427E9  2.02E7   8  2.5  0.50  1.00
#INPUT NO.7: BUOY PROPERTIES
#INPUT NO.8:DEPTH,SLOPE,CURREF
  1500 0. 1.5
#INPUT NO.9: XO(L), YO(L), ZO(L), DPRE(L) ... FAIRLEAD COORDINATES
  38.29  38.50  0. 3678750.
  35.15  39.58  0. 3678750.
  31.98  39.50  0. 3678750.
  28.75  38.50  0. 3678750.
 -28.75  38.50  0. 3678750.
 -31.98  39.50  0. 3678750.
 -35.15  39.58  0. 3678750.
 -38.29  38.50  0. 3678750.
 -38.29 -38.50  0. 3678750.
 -35.15 -39.58  0. 3678750.
 -31.98 -39.50  0. 3678750.
 -28.75 -38.50  0. 3678750.
  28.75 -38.50  0. 3678750.
  31.98 -39.50  0. 3678750.
  35.15 -39.58  0. 3678750.
  38.29 -38.50  0. 3678750.
***** END OF STEADY.INP *****

```

# \*\*\*\*\*FILE3.DAT\*\*\*\*\*

GVA 8000 FPS FOR FIBRE ROPE STUDY

3 30

45 DEGREES

0.157	40.0	0.978	90.76	0.980	89.33	1.020	0.47	0.439	-88.19	0.426	58.58	0.000	176.80
0.180	35.0	0.861	90.59	0.862	89.50	1.035	0.75	0.430	-90.69	0.407	66.90	0.000	-2.04
0.209	30.0	0.762	90.53	0.763	89.58	1.078	1.57	0.427	-91.39	0.401	72.83	0.000	-48.14
0.224	28.0	0.727	90.54	0.728	89.58	1.124	2.57	0.425	-91.41	0.400	74.70	0.000	175.30
0.233	27.0	0.711	90.55	0.712	89.56	1.166	3.60	0.423	-91.37	0.398	75.54	0.000	176.30
0.242	26.0	0.696	90.58	0.697	89.54	1.236	5.55	0.422	-91.32	0.397	76.34	0.000	-3.92
0.251	25.0	0.681	90.62	0.682	89.50	1.361	10.09	0.420	-91.24	0.395	77.07	0.000	173.70
0.262	24.0	0.666	90.67	0.667	89.45	1.575	23.96	0.417	-91.13	0.393	77.76	0.000	179.80
0.267	23.5	0.659	90.71	0.660	89.41	1.592	40.64	0.416	-91.07	0.392	78.09	0.000	177.70
0.273	23.0	0.651	90.75	0.652	89.37	1.233	61.52	0.414	-91.00	0.390	78.40	0.000	178.70
0.279	22.5	0.644	90.80	0.645	89.33	0.725	66.78	0.412	-90.92	0.389	78.69	0.000	177.30
0.286	22.0	0.637	90.85	0.638	89.27	0.479	48.91	0.410	-90.83	0.387	78.97	0.000	179.40
0.299	21.0	0.622	90.00	0.623	90.13	0.489	15.19	0.406	-91.61	0.382	80.48	0.000	-1.78
0.314	20.0	0.605	90.19	0.606	89.93	0.567	5.65	0.399	-91.35	0.376	80.93	0.000	179.50
0.331	19.0	0.587	90.45	0.588	89.67	0.615	3.13	0.392	-91.03	0.370	81.29	0.000	179.50
0.349	18.0	0.566	90.81	0.568	89.31	0.638	1.20	0.382	-90.60	0.361	81.55	0.000	-1.54
0.370	17.0	0.543	90.30	0.544	89.81	0.647	1.50	0.372	-91.04	0.351	82.67	0.000	178.30
0.393	16.0	0.515	90.97	0.516	89.13	0.643	0.60	0.359	-90.32	0.339	82.61	0.000	178.70
0.419	15.0	0.481	90.89	0.483	89.19	0.631	1.05	0.344	-90.33	0.325	83.32	0.000	174.70
0.449	14.0	0.441	91.15	0.443	88.90	0.607	2.55	0.326	-90.02	0.308	83.73	0.000	-3.23
0.483	13.0	0.392	90.90	0.395	89.11	0.569	4.20	0.306	-89.30	0.290	83.80	0.000	178.80
0.524	12.0	0.334	91.21	0.337	88.76	0.507	8.36	0.283	-89.83	0.267	85.21	0.000	-176.00
0.571	11.0	0.260	89.35	0.264	90.60	0.402	15.46	0.258	-91.56	0.242	87.95	0.000	-133.10
0.628	10.0	0.160	83.28	0.166	96.93	0.250	22.67	0.225	-98.34	0.209	95.87	0.000	-14.16
0.698	9.0	0.027	93.21	0.031	96.15	0.101	23.83	0.155	-115.90	0.139	114.10	0.000	-4.22
0.785	8.0	0.051	-179.10	0.049	-1.81	0.006	164.40	0.054	-128.90	0.047	125.40	0.000	-6.37
0.898	7.0	0.046	75.20	0.046	104.70	0.083	-163.00	0.014	-109.10	0.012	105.50	0.000	23.18
1.047	6.0	0.076	53.66	0.076	126.30	0.038	-112.70	0.002	129.60	0.002	-137.70	0.000	-175.50
1.257	5.0	0.034	84.68	0.034	95.30	0.002	-37.31	0.000	-69.45	0.000	70.33	0.000	-158.20
1.571	4.0	0.019	87.15	0.019	92.83	0.001	-161.30	0.000	-96.70	0.000	97.72	0.000	-2.17



```

***** LOWFRQ.INP *****
#INPUT 1: ICODE=0 , AN ORIGINAL RUN ABOUT THE STATIC OFFSET
0
#INPUT 2: NMASS, NDAMP
#      NUMBER OF DISTINCT ADDED MASS AND DAMPING RATIO
1,1
#INPUT 3 : ADDED MASS ID NUMBER
1
#INPUT 4 : ADDED MASS (KG)
28650000
#INPUT 5 : DAMPIG RATIO ID NUMBER
1
#INPUT 6 : DAMPING RATIO
0.131
#INPUT 7 : TOTAL VESSEL MASS (KG)
52280000
*****END OF LOWFRQ.INP *****

```

```

***** WAVFRQ.INP *****
#INPUT NO.1: KDATA = 0, READ INPUTS 4 & 5 FOR THE MOTION RAO TABLE.
#      .NE. 0, READ THE DATA FROM FILE1.DAT.
0
#INPUT NO.2: NHD, NFRE ... NUMBERS OF WAVE HEADINGS & FREQUENCIES OF THE
#      MOTION RAO DATA, WHICH MUST BE STORED IN FILE3.DAT.
1 30
#INPUT NO.3: (LYNCO(J), J = 1,NJ) ... CODE MATRIX FOR THE DEFINED
#      ENVIR. DIRECTIONS CORRESPONDING
#      TO THE HEADINGS OF MOTION RAO DATA.
#      NO.2 HEADING (OBLIQUE) IS SELECTED HERE .....
1
#INPUT NO.4: NM = THE NUMBER OF DISTINCT FAIRLEAD MOTION RAO TABLES.
1
#INPUT NO.5: ((IA(J,I), I = 1,NI), J = 1,NJ)
1
#      IA(J,I) = THE ID NO. OF DISTINCT FAIRLEAD MOTION RAO TABLES.
1

```

**APPENDIX 3**

**ORCAFLEX**  
**Input Files**  
**For the last configuration**

Title:

OrcaFlex Example Data

Units:

System	Length	Mass	Force	Time	g (m/s <sup>2</sup> )
SI	m	te	kN	s	9.807

Statics

Buoys included in Static Analysis:

All

Convergence:

Max Iterations	Tolerance	Min Damping	Mag. Of Std. Error	Mag. Of Std. Change
30	0.0001	1.000	2.500	0.070

Dynamics

Stages:

1

Stage Number	Duration (s)
0	4.000
1	100.000

Time Steps (s)		No. of Log Samples
Inner	Outer	
0.00010	0.0500	400

Target Damping (% Critical)
10.0000

Sea:

Surface Z (m)	Depth (m)	Density (t/m <sup>3</sup> )
0.000	1000.000	1.024

Sea Bed:

Slope (deg)	Direction (deg)	Stiffness (kN/m/m <sup>2</sup> )	Damping (% Critical)
0.000	0.000	100.000	100.000

Waves:

Direction (deg)	Height (m)	Period (s)	Simulation Time Origin (s)	Wave Type
180.000	6.30	14.600	4490.000	JONSWAP

Current

Current:

Speed (m/s)	Direction (deg)	Ramp during build-up
1.500	180.000	<input type="checkbox"/>

Current Profile:

Level Number	Depth (m)	Factor	Rotation (deg)
1	0.000	1.000	0.000
2	1000.000	1.000	0.000

Random Waves

Data

Number of Components:

Parameters:

Gamma		Alpha	Sigma1	Sigma2	fm
Auto	Value				
No	3.300	0.0011	0.070	0.090	0.053

Name:  Included in Static Analysis:  Dynamics:

Initial Position:

X	Position (m)			Orientation (deg)		
	Y	Z		Heel	Trim	Heading
0.00	0.00	0.00		0.0	0.0	0.0

RAOs

Periods:

Period (s)	Surge		Sway		Heave		Roll		Pitch		Yaw	
	Ampl. (m/m)	Phase (deg)	Ampl. (m/m)	Phase (deg)	Ampl. (m/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)	Ampl. (deg/m)	Phase (deg)
4.0	0.019	87	0.019	93	0.001	-161	0.000	-97	0.000	98	0.000	-2.2
6.0	0.076	54	0.076	126	0.038	-113	0.002	130	0.002	-138	0.000	-176
8.0	0.051	-179	0.049	-1.8	0.006	164	0.054	-129	0.047	125	0.000	-6.4
10.0	0.160	83	0.166	97	0.250	23	0.225	-98	0.209	96	0.000	-14.2
11.0	0.260	89	0.264	91	0.402	15	0.258	-92	0.242	88	0.000	-133
12.0	0.334	91	0.337	89	0.507	8.4	0.283	-90	0.267	85	0.000	-176
13.0	0.392	91	0.395	89	0.569	4.2	0.306	-89	0.290	84	0.000	178.8
14.0	0.441	91	0.443	89	0.607	2.6	0.326	-90	0.308	84	0.000	-3.2
15.0	0.481	91	0.483	89	0.631	1.0	0.344	-90	0.325	83	0.000	174.7
16.0	0.515	91	0.516	89	0.643	0.60	0.359	-90	0.339	83	0.000	178.7
17.0	0.543	90	0.544	90	0.647	1.5	0.372	-91	0.351	83	0.000	178.3
18.0	0.566	91	0.568	89	0.638	1.2	0.382	-91	0.361	82	0.000	-1.5
19.0	0.587	90	0.588	90	0.615	3.1	0.392	-91	0.370	81	0.000	179.5
20.0	0.605	90	0.606	90	0.567	5.6	0.399	-91	0.376	81	0.000	179.5
21.0	0.622	90	0.623	90	0.489	15	0.406	-92	0.382	80	0.000	-1.8
23.0	0.651	91	0.652	89	1.233	62	0.414	-91	0.390	78	0.000	178.7
25.0	0.681	91	0.682	90	1.361	10	0.420	-91	0.395	77	0.000	173.7
27.0	0.711	91	0.712	90	1.166	3.6	0.423	-91	0.398	76	0.000	176.3
30.0	0.762	91	0.763	90	1.078	1.6	0.427	-91	0.401	73	0.000	-48.1
Infinity	0.762	91	0.763	90	1.078	1.6	0.427	-91	0.401	73	0.000	-48.1

Slow Drift

Period (s)	Surge		Sway		Heave		Roll		Pitch		Yaw	
	Ampl. (m)	Phase (deg)	Ampl. (m)	Phase (deg)	Ampl. (m)	Phase (deg)	Ampl. (deg)	Phase (deg)	Ampl. (deg)	Phase (deg)	Ampl. (deg)	Phase (deg)
100.0	0.000	90	0.000	90	0.000	90	0.000	90	0.000	90	0.000	90.0

Steady Motion

Stage Number	Duration (s)	Velocity		Rate of Turn
		Mode	Value	
0	4.000	Constant Velocity	0.000	0.000
1	100.000	Constant Velocity	0.000	0.000

Applied Load

X	Force (kN)			Moment (kN.m)		
	Y	Z		Roll	Pitch	Yaw
0.0	0.0	-		-	-	0.0

Multiple Statics

Azimuths:

From (deg)	To (deg)	Number of steps
0.00	-	0

Offsets:

From (m)	To (m)	Number of steps
0.00	~	0

Drawing

Vertices: 16

No.	x	y	z
1	0.000	59.800	10.000
2	0.000	59.800	-21.000
3	0.000	-59.800	10.000
4	0.000	-59.800	-21.000
5	59.800	0.000	10.000
6	59.800	0.000	-21.000
7	-59.800	0.000	10.000
8	-59.800	0.000	-21.000
9	0.000	49.800	10.000
10	0.000	49.800	-21.000
11	0.000	-49.800	10.000
12	0.000	-49.800	-21.000
13	49.800	0.000	10.000
14	49.800	0.000	-21.000
15	-49.800	0.000	10.000
16	-49.800	0.000	-21.000

Edges: 32

No.	From	To
1	1	5
2	5	3
3	3	7
4	7	1
5	13	5
6	1	9
7	15	7
8	3	11
9	9	13
10	13	11
11	11	15
12	15	9
13	2	6
14	6	4
15	4	8
16	8	2
17	10	14
18	14	12
19	12	16
20	16	10
21	10	2
22	14	6
23	12	4
24	16	8
25	1	2
26	5	6
27	3	4
28	7	8
29	13	14
30	9	10
31	11	12
32	15	16

Geometry, Mass, Drawing

	Name	Diameters		Unit Mass (t/m)	Width	Pen Style	Colour
		Outer (m)	Inner (m)				
1	chain	0.560	0.000	1.054	2	---	□
2	fibre	0.208	0.000	0.034	2	---	□
3	LType A	0.280	0.000	0.527	2	---	□
4	chain1	0.240	0.000	0.353	1	---	□

Tension, Bending, Contact

	Name	Axial (kN)	Stiffnesses		Contact (kN/m)	Limit Compression	Maximum Tension (kN)	Minimum Radius (m)
			Bending (kN.m^2)					
1	chain	1.427E6	0.000	0.000	No	~	~	
2	fibre	441.45E3	0.000	0.000	No	~	~	
3	LType A	1.427E6	0.000	0.000	No	~	~	
4	chain1	1.427E6	0.000	0.000	No	~	~	

Hydrodynamics

	Name	Drag Coefficients		Added Mass Coefficients	
		Normal	Axial	Normal	Axial
1	chain	1.180	0.500	1.000	0.000
2	fibre	1.200	0.050	1.000	0.000
3	LType A	1.180	0.500	1.000	0.000
4	chain1	1.180	0.500	1.000	0.000

Friction

	Name	Friction Coefficients		Bias Power
		Normal	Axial	
1	chain	1.000	~	1.000
2	fibre	1.000	~	1.000
3	LType A	1.000	~	1.000
4	chain1	1.000	~	1.000

Stress

	Name	Stress Diameters (m)	
		Outer	Inner
1	chain	~	~
2	fibre	~	~
3	LType A	~	~
4	chain1	~	~

Geometry, Mass

	Name	Mass (te)	Volume (m <sup>3</sup> )	Height (m)	Offset (m)
1	CType A	0.1000	0.2000	0.2000	0.0000

Drag

	Name	Drag Areas (m <sup>2</sup> )			Drag Coefficients		
		x	y	z	x	y	z
1	CType A	0.600	0.600	0.600	1.100	1.100	1.100

Added Mass

	Name	Added Mass Coefficients		
		x	y	z
1	CType A	1.000	1.000	1.000



Name:

Line A

Total Line Length = 1550.00 m

Connections:

Object	Object Relative Position (m)			No Moment Direction (deg)		Gamma (deg)	Stiffness (kN.m/deg)	Release at Start of Stage
	x	y	z	Azimuth	Declination			
Vessel A	59.800	0.000	-21.00	0.000	0.000	0.000	0.000	-
Anchored	1285.2	0.000	0.000	0.000	0.000	0.000	0.000	-

Statics:

Statics Method	Full Statics	Pre-Tension (kN)	Lay Azimuth (deg)	
Catenary	No	-	180.00	Set

Contents:

Density (te/m^3)	Pressure (kN/m^2)	Flow Rate (te/s)
1.000	-	0.00

Structure

Sections:

3

Clumps:

0

No.	Line Type	Length (m)	No. of Segments	Clash Check
1	chain1	100.000	5	No
2	fibre	1300.00	30	No
3	chain1	150.000	8	No

Catenary Convergence

Max Iterations	Delta	Tolerance	Min Damping	Shooting Factor	BackTrack Factor	Mag. Of Std. Error	Mag. Of Std. Change
100	-5E-9	50E-9	1.000	1.500	2.000	0.200	0.600

Name:

Line B

Total Line Length = 1550.00 m

Connections:

Object	Object Relative Position (m)			No Moment Direction (deg)		Gamma (deg)	Stiffness (kN.m/deg)	Release at Start of Stage
	x	y	z	Azimuth	Declination			
Vessel A	-59.80	0.000	-21.00	0.000	0.000	0.000	0.000	~
Anchored	-1243	0.000	0.000	0.000	0.000	0.000	0.000	~

Statics:

Statics Method	Full Statics	Pre-Tension (kN)	Lay Azimuth (deg)	
Catenary	No	~	180.00	Set

Contents:

Density (te/m^3)	Pressure (kN/m^2)	Flow Rate (te/s)
1.000	~	0.00

Structure

Sections:

3

Clumps:

0

No.	Line Type	Length (m)	No. of Segments	Clash Check
1	LType A	100.000	5	No
2	fibre	1300.00	30	No
3	chain	150.000	8	No

Catenary Convergence

Max Iterations	Delta	Tolerance	Min Damping	Shooting Factor	BackTrack Factor	Mag. Of Std. Error	Mag. Of Std. Change
100	-5E-9	50E-9	1.000	1.500	2.000	0.200	0.600

**Worked example “c” –**

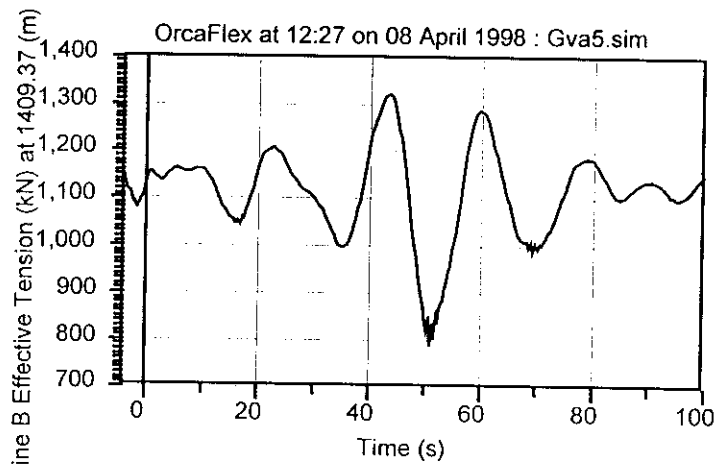
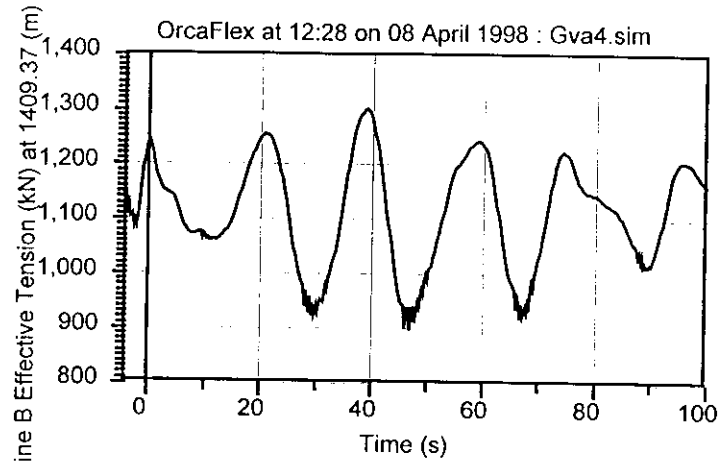
**Semi sub - Brazilian Margin (including risers)**

**(3 sheets)**

**Data necessary to complete the mooring analysis  
of an Brazilian Margin semisub,  
their reference in the DPD, and results of the analysis.**

Reference in EDG - DPD	Data / Calculations	Results
DPD 7.	<i>Site data, location</i> Location Environmental conditions wind  wave  current Water depth Seabed slope	Brazil  Davenport spectrum Vw = 40 m/s Jonswap spectrum $\gamma = 3.3$ Hs = 6.3 m Tp = 14.6 s Uniform Vc = 1.5 m/s 1 000 m 0 %
DPD 7.	<i>Platform data</i>  Linear damping: vessel, mooring lines, risers (assumption) Surge (% of critical damping) Sway (% of critical damping)	See file data-gva.doc  30 30
	<i>Other</i> Risers data (assumption) total load on risers in environmental direction	2,943 kN
	<i>Fairlead positions</i>	See file Data-gva.doc

<p>DPD 6.</p>	<p><b>Mooring system configuration</b></p> <p>Number of lines                  Number of groups of lines                  Spread angle between lines of the same group                  Length of lines                  Number of segments in a line                  First segment (near the anchor)                      material                      breaking load                      length                      bar diameter                      dry mass                      added mass                      submerged weight                      stiffness                      normal drag coefficient                      tangential drag coefficient                      friction coefficient                  Second segment                      material                      breaking load (BL)                      length                      diameter                      dry mass                      added mass                      submerged weight                      stiffness                      normal drag coefficient                      tangential drag coefficient                      friction coefficient                  Third segment                      same as first segment                      length                  Pretension</p> <p><i>(see figure 1)</i></p>	<p>16                  4                  10 deg                  1,550 m                  3                  chain (K4 studlink)                  14,715 kN                  150 m                  0.127 m                  0.3532 t/m                  0.0459 t/m                  3.0145 kN/m                  1.427x10<sup>6</sup> kN/m/m                  2.5                  0.5                  1                  fibre rope                  14,715 kN                  1,300 m                  0.208 m                  0.0349 t/m                  0.0341 t/m                  0.868 kN/m                  4.410x10<sup>5</sup> kN/m/m                  1.2                  0.05                  1                  100 m                  2943 kN</p>
<p>DPD 8.2.4.1.                  DPD 8.2.4.2.</p>	<p><b>Results</b></p> <p>DMOOR 4.0 prestudy                  Max excursion                  Tension at fairlead (static + sig. second order motion)                      Line 3                      Line 10                  Max tension                      Line 3                  ORCAFLEX                  Min tension                      Line 10</p> <p><b>Conclusion</b></p> <p>The minimum tension is 5.3% of the breaking load. The safety factor is acceptable.</p>	<p>35.9 m                  6,160.9 kN                  1,549.2 kN                  7,447.1 kN                  GVA4.sim GVA5.sim                  786.35 kN</p>





**Engineers Design Guide - Deepwater Fibre Moorings****Meeting Agenda****Steering Committee Meeting Number 6**

Location : Noble Denton Europe, Noble House, 131 Aldersgate Street,  
London EC1A 4EB

Date : and Wednesday 1<sup>st</sup> July 1998 at 10.00

Team Representatives: NDE (John Trickey, R.V. Ahilan, T. Versavels, Richard  
Stonor)

TTI (Mike Parsey, Steve Banfield,)

**Tuesday 30<sup>th</sup> June**

09.30 - 10.00 Reception / Coffee  
10.00

- Review Membership
- Apologies for Absence
- Review Minutes of Previous Meeting
- Review Latest Document Issue:  
Design Practice Document (Rev 4) Draft for Approval

13.00 Lunch (at Noble Denton offices)

14.00 Presentation on draft Worked Example  
Review of Worked Example  
Continue Review of Design Practice Document

17.30 Close meeting for the day.

18.00 Drinks Reception at Noble House

**Wednesday 1<sup>st</sup> July 1998**

08.45 Complete Review of Design Practice Document

11.00 Review of Fibre Mooring Guideline, Appendices and Engineering  
Commentary

13.00 Lunch (at Noble Denton offices)

14.00 Continue Document Reviews

15.30 Agree dates for completion of member review of documents and issue of  
finalised report.  
Review proposal for User Group

16.00 Close Meeting



**Engineers Design Guide - Deepwater Fibre Moorings****Project Membership at 31<sup>st</sup> June 1998**

<b>Membership</b>	<b>Attendance</b>
1. ABS	
2. Aker Marine a.s	Apologies for Absence
3. Akzo Nobel	
4. Allied Signal	
5. Amerada Hess Limited	
6. Bluewater Engineering b.v.	Apologies for Absence
7. BP Exploration Operating Company Ltd	
8. Bridon International	(see Marlow)
9. Bureau Veritas	
10. Chevron	
11. Det Norske Veritas	
12. DSM High Performance Fibres	
13. Elf Enterprise Caledonia Ltd	
14. Exxon	Apologies for Absence
15. Hoechst	
16. Le Lis N.V.	Apologies for Absence
17. Lloyd's Register of Shipping	
18. Maersk Supply Service	Apologies for Absence
19. Marlow Ropes Limited	
20. Norsk Hydro	
21. Petrobras	Apologies for Absence
22. Quintas and Quintas	
23. Rockwater Limited	
24. SAGA	Apologies for Absence
25. ScanRope a.s.	
26. Shell Norske A/S	Apologies for Absence
27. Single Buoy Moorings	Apologies for Absence
28. Smit Engineering	Apologies for Absence
29. STATOIL	
30. The American Manufacturing Co., Inc.	

**Engineers Design Guide - Deepwater Fibre Moorings****Suggested Project Completion Schedule****Key Dates Proposed for Final Project Stages :**

<b>Date</b>	<b>Activity</b>
30 <sup>th</sup> June / 1 <sup>st</sup> July 1998	<ul style="list-style-type: none"><li>• Review DPD "Draft for Approval"; Fibre Mooring Guideline, Appendices, Worked Example and Engineering Commentary</li></ul>
31 <sup>st</sup> August 1998	<ul style="list-style-type: none"><li>• Final Date for receipt of written comments to DPD</li></ul>
30 <sup>th</sup> September 1998	<ul style="list-style-type: none"><li>• Issue of Finalised Document to Participants</li></ul>

**Engineers Design Guide - Deepwater Fibre Moorings**

## **Suggested Engineers Design Guide User Group**

**On completion of the project and issue of the final Working Draft of the documents we suggest the formation of a User Group to follow-up the document for the initial three years.**

**User Group members would pay a single fee of \$2,000 to provide a three-year membership. This would provide them with:**

- **issue of revision sheets updating the document as appropriate**
- **a seminar in the third year to review the Document and Industry's perception of:**
  - **Capability of Fibre Rope Moorings**
  - **Current R and D**
  - **Project News**

**Membership of the User Group would be open to all. A minimum of 10 members is required for the group to be viable.**

**The User Group will be open to all organisations that wish to participate.**

**A chairman and secretary will be elected by the membership. The group will be administered by NDE/TTI.**

Document History:

r2va	new	RWPS	Oct 97
	Plus additional changes	JWSH	25 Nov '97
r3va	Changes advised by	JWSH	10 Mar 98

**EC - 1. INTRODUCTION ..... 1**

**EC - 1. INTRODUCTION**

The Engineering Commentary (EC) provides additional background information and advice to complement the requirements specified by the Design Practice Document (DPD).

This information is arranged to cross-reference to the DPD by means of the section numbering system.

Comments on items covered in the Introduction (Section 1 of the DPD) are given elsewhere in the EC under the appropriate sections.

Particularly relevant definitions are included in the Glossary in the opening pages of the DPD and a full set of definitions in Appendix 1.1.

Appendix 1.2 deals with units and conversions, especially covering the relations between "textile" and "engineering" units.

Appendix 1.3 covers various definitions of modulus.

## FIGURES

### ENGINEERING COMMENTARY - REV 3

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- Figure EC 2.2.4 Schematic representation of changes in polyester stress-strain curve as a result of cyclic loading.
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- Figure EC 12.7.4 c Installation of a Fibre Rope Insert Catenary Mooring

**Document History:**

r1 vA :	Draft :	jwsh :	2 April 1996
r2 vA :	revision :	jwsh	14/15th Oct.97
	plus typed in changes provided by e-mail	jwsh	5.Nov.97
	plus changes agreed	mrp/jwsh	6.Nov.'97
	Plus additional changes	JWSH	25 Nov '97
r3va	edits	spo/rwps	26 Feb 98
r3va	changes advised by	jwsh	10 Mar 98
r3va	text corrections	rwps	5.May.98
r3va	mods to appendix ref nos. and add notes for action	rwps	22 May 98
r3va	TTI changes	rwps	24 June 1998
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	editorial	rwps	28 June 98

**EC - 2. ROPE MATERIALS 2**

**EC - 2.1 INTRODUCTION 2**

**EC - 2.2 LOAD BEARING CORE YARNS 2**

**EC - 2.2.1 YARN TYPES 2**

**EC - 2.2.1.1 Yarns used in ropes 2**

**EC - 2.2.1.2 Yarn property values 2**

**EC - 2.2.1.3 Yarn properties for rope performance 3**

**EC - 2.1.1.4 Yarn properties for quality assurance 5**

**EC - 2.1.1.5 Yarn test methods 6**

**EC - 2.1.1.6 Yarn costs 6**

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**EC - 2.1.1.9 (Para)-aramid [See also Yang (1993)] 11**

**EC - 2.1.1.10 Gel-spun HMPE (high modulus polyethylene) [See also Jacobs and Mencke (1995)] 12**

**EC - 2.1.1.11 Melt-spun high-modulus polyethylene 12**

**EC - 2.1.1.12 LCAP [See also Beers (1995)] 12**

**EC - 2.1.1.13 Nylons 12**

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**EC - 2.1.3 EXISTING STANDARDS, GUIDELINES AND SPECIFICATIONS 13**

**EC - 2.1.4 YARN QUALITY 13**

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**EC - 2.3.1 GENERAL REQUIREMENTS 13**

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**EC - 2.4 FINISH AND FILLERS 14**



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**EC - 2. ROPE MATERIALS**

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## EC - 2.1 INTRODUCTION

The choice of fibre type for yarns in the load bearing core is the most important material factor in determining rope assembly performance. Other materials used include yarns for braided jackets, plastic covers, lubricants and fillers, and materials used in terminations.

## EC - 2.2 LOAD BEARING CORE YARNS

## EC - 2.2.1 YARN TYPES

## EC - 2.2.1.1 Yarns used in ropes

The fibre yarns principally considered for use in deepwater moorings are as follows:

- **polyester** (high-tenacity industrial forms) - many suppliers and trade names: e.g. Allied-Signal Seaguard IW81, Akzo Nobel Diolen 855TN, and Hoechst-Celanese Trevira 785 are designed for marine use
- **(para-)aramid**: e.g. Akzo Nobel Twaron, Kevlar and Technora
- **HMPE** : e.g. DSM Dyneema, Allied-Signal Spectra

A number of other fibres are used in ropes, and some new high-performance fibres may be important in future.

Nylon 6 or 66, available in high tenacity industrial forms from many suppliers, is used in ropes for many purposes. It could be considered in substantially parallel constructions for shallower depths for which lower axial stiffness may be required.

A new polyester fibre, PEN, polyethylene naphthalate, is being developed as a high-tenacity tyre cord yarn by Allied Signal and may also be evaluated for ropes.

The LCAP fibre, Vectran from Hoechst Celanese, could be considered for some specialised applications.

A lower strength HMPE, formerly available as Certran from Hoechst Celanese, made by a melt-spinning route has also been used in ropes.

PBO fibres are being commercialised by Toyobo under the name *Zylon* and may be considered when they become available. Akzo Nobel have reported on a new polymer fibre M5, which is under development.

When very high stiffness ropes are needed, carbon fibres may be used as composite pultrusions. Glass, and other high-modulus fibres, may also be used as pultrusions for some applications.

Regular polyethylene and polypropylene, as well as some continuing use of natural fibres, are found in many commodity ropes, but are not suitable for the more demanding engineering uses, such as deepwater moorings.

## EC - 2.2.1.2 Yarn property values

There are not single sets of properties for each given yarn material. In addition to the obvious dimensional features of fibre size, as indicated by linear density (tex, denier) or diameter, properties differ according to: [a] secondary variants in chemical composition (likely in yarns for some general

textiles, but not in engineering yarns); [b] molecular weight (polymer chain length) distribution; [c] detailed extrusion conditions and, of major importance, subsequent thermo-mechanical processing; [d] finish applied.

An analogy with metals may be helpful. The variety of fibres could be compared with a variety of different metals. Even with a given basic type, there are differences. Merely to specify steel, for example, is not enough. There are many different types. When a particular application is well developed, the type of steel to use will be well defined, but, during development of the technology for a new use, trials and process modifications are needed in order to select the steel for optimum performance. Similarly, the polyester, aramid, HMPE or other fibre types are tailored to meet the needs of different markets.

Consequently, within certain ranges for each material, yarn properties differ between different suppliers and between different types from a given supplier. Values of properties in this and accompanying documents are intended for general guidance. If standard commercially available yarns are to be used, the properties of the yarns should be obtained from the manufacturer or measured. The properties of new yarn types or variants will need to be measured. Joint development may be necessary to obtain yarns which give the best performance in mooring lines. It is also essential that top quality yarns, intended for marine ropes, should be used. For less demanding rope uses, economy has led to the use of second grade tyre-cord yarns, but this would not be acceptable for moorings in deep water.

The specification of yarn properties falls into two categories, which overlap but have different functions:

1. properties needed in design studies to predict rope performance
2. properties to be tested in quality assurance during manufacture to ensure that the yarn used is the yarn specified, or the yarn used in a tested prototype rope (as required for marine hawsers under OCIMF guidelines)

Yarn properties, as quoted in this document, are for continuous multifilament yarns. These will approximate to the material properties as measured on single fibres. Yarn test methods are listed or described in Appendix 2.1.

#### EC - 2.2.1.3 Yarn properties for rope performance

The yarn properties that are important in determining rope performance in deepwater moorings are listed below. Information on these properties should be included in any specification of rope yarns, taking account of the environment (time, temperature, moisture etc.) in which the yarns will be used in ropes. Variability in properties is also important, in order to determine acceptable tolerances, so that coefficients of variation or other variability measures for each property should also be quoted.

Standard SI units, which include the use of tex (g/km), are used in this section. Further information on quantities, units, conversion factors and conversion equations is given in Appendix 1.2. More comment on some yarn properties as they affect ropes is included in the EC-5. on rope properties. The status of properties takes different forms: some properties, such as dimensional features, will be specified by the manufacturer; some will be acceptable from standard tables or, at least for certain fibres, from common knowledge; others will need to be measured specifically. The need is not the same for all fibre types. For example, for some materials creep rupture is not a practical problem, but for others it must, at least, be considered.

#### DIMENSIONAL FEATURES

- fibre density ( $\text{g/cm}^3$ ), which, in combination with packing factor, determines relation of rope weight to rope size (diameter, circumference, area)
- fibre linear density (mass per unit length in tex), which with density determines fibre diameter

- yarn linear density (tex), equal to (fibre linear density × number of filaments in yarn)

#### TENSILE RUPTURE FEATURES (STRENGTH)

- strength, given by yarn break load, namely maximum load in a tensile test, normally specified on weight basis as yarn tenacity (N/tex)
- strength/length effect: due to weak-link effect, the strength of the effective free yarn length in a rope differs from strength at test length, and may be estimated from coefficient of variation (CV) of strength:

$$[\text{mean } S(\text{NL}) \div \text{mean } S(\text{L})] = N^{(-\text{CV}/120)}$$

where  $S(\text{NL})$  is strength at effective length NL

and  $S(\text{L})$  is strength at test length L

- creep rupture, reduction in strength with time under load, given by the strength/time coefficient  $k$  in the following formula for rupture after a time  $t$  under load  $S$ :

$$S = S_g [1 - k \log(t/t_g)]$$

where  $S_g$  and  $t_g$  are the strength and time under given test conditions.

For cyclic loading between constant limits, tests have shown that peak load should be used in the above equation. There has been no testing of the effect of variable cyclic loading. A suitable procedure would be to take a conservative estimate of the “average” peak operational load acting over the life of the rope. Short periods under high peak load in storm conditions could be ignored, provided that these do not in themselves occur over times approaching those leading to creep rupture according to the above equation.

Note that use of this formula will generally give a conservative estimate of long-term rope creep leading to rupture, though additional permanent elongation will occur during initial loading.

#### ENVIRONMENTAL EFFECTS ON STRENGTH:

1. reduction of strength at elevated temperature, given by strength/temperature coefficient, namely percentage reduction in strength per °C
2. effect of moisture (difference between wet and dry)

#### EXTENSION FEATURES (STIFFNESS)

A note on the definitions of stiffnesses, dynamic moduli, hysteresis, energy loss,  $\tan \delta$  and other inter-related quantities is given in Appendix 1.3. The choice of particular stiffness values for use in mooring analyses is discussed in EC 5.3.2.

#### *general information*

- full non-linear load/elongation curve from zero load to break, measured under standard conditions; may be expressed as relation between specific stress (N/tex) and axial strain or percentage extension
- change in load-elongation curve after single or repeated loading
- creep, continuing elongation under load, given by rate of extension with  $\log(\text{time})$  as a function of load; this may be primary creep, which is recovered in time when the load is reduced, or secondary creep, which is non-recoverable response in cyclic loading;

- values of dynamic modulus and loss modulus or  $\tan \delta$  under appropriate test conditions, which determine energy loss due to hysteresis, contributing to damping and rope heating

*information specific to application*

The load/elongation (stress/strain) behaviour of yarns depends on many conditions: rate of loading; temperature; moisture condition; difference between increasing and decreasing load (extension and recovery); loading sequence and rate; prior loading and thermal history. The information is best expressed by selected plots of stress versus strain. Energy dissipation, which causes heating, will be given by the area within hysteresis loops. This is most conveniently expressed by the fractional energy loss  $\psi = \delta U/U$ , where  $\delta U$  is the energy loss per cycle and  $U$  is the strain energy of oscillation.

Alternatively to stress/strain plots, values of yarn modulus  $E$  (N/tex), appropriate to the loading sequence and history, may be used, but care must be taken to distinguish between secant moduli, namely stress÷strain, and tangent moduli, namely local slope of stress/strain curve. The energy loss will be related to the loss modulus  $E''$  or to  $\tan \delta$ . For a strain amplitude  $\pm e(\max)$ :

$$\begin{aligned} \text{energy loss/cycle per unit mass} &= \pi E'' [e(\max)^2] \\ &= \pi E [e(\max)^2] \tan \delta \end{aligned}$$

Data relevant to the rope use conditions are required. The following have been identified as particularly relevant to deepwater mooring design studies.

1. The initial load-elongation curve of the yarn as received, or more strictly after the stresses imposed during rope manufacture and proving, which is related to rope response during installation.
2. The load-elongation response under typical load cycling, expected to be experienced during use of the rope, over a sufficient number of cycles for the response to stabilise, and including peak loads in storm conditions.
3. The creep, namely continuing elongation, over long times under loads typical of those to be experienced in use.
4. The effects of temperature on properties, up to the maximum temperature expected to be reached.
5. The effects, if any, of moisture on properties.

The particular tests needed will vary with the yarn type, depending on the sensitivity of the material to particular effects.

#### DURABILITY FEATURES

- yarn-on-yarn abrasion resistance, as given by numbers of cycles to failure in yarn-on-yarn abrasion testing under appropriate conditions
- axial compression fatigue resistance, as given by rate of loss of strength in yarn buckling test under appropriate conditions
- effects of hydrolysis due to action of water

For most yarns, the information in the literature or obtained in joint industry studies, will provide an adequate guide to the properties listed above. Information on sources and summaries of available data are included in Appendix 2.2.

#### EC - 2.1.1.4 Yarn properties for quality assurance

These details are set out in the specification instructions in DPD 11.2.2.2. Following OCIMF

guidelines (1987), the criteria for selection of properties to be measured are ease of testing and effectiveness in identifying changes in polymer, yarn manufacturing conditions, finish applied and any other factors that will influence the yarn performance in use. It is not necessary to know what these changes are, so, for example, detailed chemical analysis is not needed, but it is necessary to determine that the yarn is as specified within agreed tolerances.

#### EC - 2.1.1.5 Yarn test methods

A list of relevant standard yarn test methods is given in Appendix 2.1, which also includes information on test methods for properties where standards have not been issued.

#### EC - 2.1.1.6 Yarn costs

Yarn prices depend on the particular type selected, for example a special marine grade polyester is likely to be more expensive than a commodity yarn, and high modulus aramid or low creep HMPE will be more expensive than forms which require less post-treatment by the fibre manufacturer. Finer yarns will be more expensive on a weight basis than heavier yarns. Special prices may be offered for development projects or for large quantities.

As a rough guide, some typical yarn prices at publication data are listed in Table EC-2.2.1.

**TABLE EC-2.2.1**  
**ROUGH GUIDE TO CURRENT YARN PRICES**

	£/kg	\$/lb
polyester	2.4	1.6
aramid	10 - 25	7 - 17
HMPE	25	17

#### EC - 2.1.1.7 Broad classification and comparative properties of yarns

Except for carbon and glass, the yarn types mentioned in *EC-2.2.1.1* are all linear organic polymers, namely materials composed of long-chain molecules, which typically would have more than 10,000 atoms in the main chain. These synthetic polymer yarns used in ropes fall into two main groups:

##### ENGINEERING VARIANTS OF COMMODITY TEXTILE YARNS

Polyester and nylon are comparatively low-modulus high-extension yarns, consequent upon substantial folding and disorder of the polymer chains (typically 50% crystalline). High-tenacity forms were developed for the large tyre-cord market, and variants of these are used for other engineering applications, such as deepwater mooring lines. Regular polyethylene and polypropylene have the same general character as polyester and nylon, but their properties are not generally suitable for demanding engineering uses.

##### NEWER HM-HT (HIGH-MODULUS, HIGH-TENACITY) YARNS

(Para)-aramid, HMPE, LCAP, PBO and M5 fibres have a structure consisting of highly elongated (i.e. chain-extended), highly oriented, highly ordered (crystalline) polymer chains.

All these organic polymer fibres have a low density (0.9 to 1.5 g/cm<sup>3</sup>) so that, in comparison with steel, their properties are more favourable when treated on a weight basis rather than an area or volume basis. In water, the effective density is even less; HMPE fibres have positive buoyancy.

A collection of comparative yarn properties is given in Table EC-2.2.2 and typical stress-strain curves in Figure EC-2.2.1. These data are only intended to be indicative of the different yarn properties.

They may be used as a guide in preliminary design studies, but values for the selected yarns of a particular type used by a particular rope manufacturer should be employed in final design calculations. A more extensive set of values for commercially available yarns, either from manufacturer's data sheets or other test programmes, is given in Appendix 2.2. More information on physical properties of textile fibres, including high-performance fibres, is given by Morton and Hearle (1993).

TABLE EC-2.2.2.2

## YARN PROPERTIES

Typical values for commercial rope yarns, based on manufacturers' data, FIBRE TETHERS  
2000 (1995), Morton and Hearle (1993)

	Polyester	aramid	HMPE	nylon
Trade names (examples)	Seaguard Diolen Trevira	Twaron Kevlar	Dyneema Spectra	
fibre density (g/cm <sup>3</sup> )	1.39	1.44	0.97	1.14
melting point (°C)	258	430 <sup>(9)</sup>	144-152	260
water absorption (wet) (%)	1		0	8
tenacity (N/tex)	0.82 <sup>(10)</sup>	2.1	2.8-3.5	0.84 <sup>(10)</sup>
strength (GPa)	1.1	3.0	2.7-3.4	0.96
wet strength/dry strength (65% relative humidity)	<u>1</u>	<u>1</u>	<u>1</u>	<u>0.8</u>
break extension (%)	13 <sup>(10)</sup>	2.9-4.4	3.5-3.8	20 <sup>(10)</sup>
modulus values (N/tex) <sup>(11)</sup>		58-80	90-110	
modulus values (GPa)		83-115	90-105	
chemical resistance	good	good <sup>(8)</sup>	excellent	
UV resistance		poor	good	
abrasion fatigue resistance <sup>(1)</sup>	95,000	1,000	8,000	
axial compression fatigue resistance <sup>(2)</sup>	50,000	1,000	20,000	
	1,000,000	20,000	200,000	
creep at 30% break load (% extension, 10→100 days <sup>(3)</sup> )	0.01-0.03	0.01-0.03	8 <sup>(4)</sup>	
creep rupture times at 30% break load <sup>(5)</sup>	>10 <sup>6</sup> years	>10 <sup>6</sup> years	123 days <sup>(6)</sup>	1,000 days
coefficient of friction <sup>(7)</sup>	0.06-0.1	0.12-0.18	0.058-0.066	

## Notes to Table EC-2.2.2.2

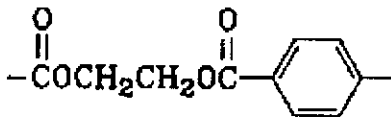
- 1) Representative values from FT 2000 Figures 4.7.3, 4.7.4, wet yarn-on-yarn abrasion at 2% break load
- 2) Estimates from restrained buckling test, FT2000 Table 4.6.2, top figures for detectable strength loss, bottom figures for severe strength loss
- 3) From FT2000 Table 4.5.1
- 4) Best value; other yarns broke
- 5) From estimate of strength/time coefficient.
- 6) Best yarn in FT2000 Table 4.5.1
- 7) From FT2000 Table 4.8.1, wet yarn-on-yarn friction. Values strongly dependent on finish applied by yarn manufacturer
- 8) Attacked by strong acids and alkalis

- 9) Decomposition starts; does not melt  
 10) For high-tenacity industrial yarns. Yarns with lower strength and modulus and higher break extensions are made for general textile purposes.  
 11) Typical initial modulus values. Values depend on test conditions and prior history.

[FIBRE PRODUCERS: please check and fill gaps]

**EC - 2.1.1.8 Polyester [See also Brunschweiler and Hearle (1993)]**

Copolymers and other polyesters are used for some textile purposes, and the new polyesters fibre PEN is described in EC 2.2.1.14. The polyester fibres currently used for ropes are composed of long-chain molecules of polyethylene terephthalate (PET).



**Poly (ethylene terephthalate) (PETP) [25038-59-9]**

PET is usually continuously polymerised from intermediates and fed directly to melt extrusion. For high-tenacity types, the yarns are highly drawn and the thermal processing sequence is adapted to provide desirable values of modulus, thermal shrinkage and other properties. Proprietary finishes will be applied by fibre manufacturers to improve performance in subsequent processing and use.

Rope-making polyester yarns are characterised, among the materials listed in EC-2.2.1.1, by moderately high strength, moderately high break extension, intermediate values of modulus, low creep, and very little effect of moisture. Polyester fibres have good resistance to internal abrasion and axial compression fatigue in ropes, but under some loading conditions these forms of fatigue will develop after very large numbers of cycles. The properties change appreciably with temperature, with a "glass transition" temperature around 100°C. For about 25°C on either side of the transition, there will be substantial energy dissipation in cyclic loading. The polymer melts at about 265°C, but fibres stick together at about 240°C.

Figure EC-2.2.2 (a) and (b) are illustrative of the variations of mechanical properties, which result from different processing conditions. Figure EC-2.2.2(a) shows how increasing the orientation of the molecules in the fibres increases strength and stiffness and reduces break elongation. However, although the theoretical strength of a highly oriented and chain-extended polyester fibre would be much greater, this structure has not been achieved in practice and the maximum attainable commercial tenacity is about 0.8 N/tex (9 g/den). Figure EC-2.2.2 (b) shows how the stress-strain curve of a particular polyester yarn as received has a continuously decreasing stiffness, as given by the tangent modulus, namely the slope of the curve. The decrease in slope is slow over most of the range, but with a sharp change at about 80% of break load. However, after the yarn had been allowed to shrink due to heating, a shoulder appears in the curve at about 20% of break load.

Depending on the yarn manufacturing process, some yarns as supplied will have a shoulder in the load-elongation curve. For example, Figure EC-2.2.3 (b) shows the variation of tangent modulus in an industrial polyester yarn, as reported by van Miltenburg (1991). The modulus first increases, then decreases at the first shoulder region, rises again and falls at the second shoulder.

Changes in the shape of the load-elongation curve can also be induced by application of tension,



particularly if this is repeatedly cycled. Figure EC-2.2.4 shows schematically what might be expected after a single loading to about 30% of break load, with a dwell time at peak load and after recovery to zero load. Also shown is the likely response after many cycles without dwell time.

Although most reports in the literature involve cycling back to zero load, it is more relevant for mooring lines to consider cycling between higher load values. Figure EC-2.2.5 shows data reported by Bosman (1996) for AKZO Diolen 855T, which is a typical rope-making polyester yarn. Note that this yarn shows the shoulder in the load-elongation curve at about 25% of break load. Repeated cycling with a 100 second period between 10% and 30% of break load gives a cyclic response which stabilises after about 10,000 cycles. The dynamic modulus in this range is much higher than the tangent modulus from the load-elongation curve. The modulus is even greater after cycling between 45% and 55% of break load.

Time dependence of the elongation of polyester yarns can be separated into several categories. (1) There is an effectively instantaneous extension on application of tension. This is elastic and instantaneously recoverable on removal of tension. (2) There is time-dependent recoverable extension or primary creep. This shows up as a hysteresis loop in cyclic loading and is partially responsible for the elongation during the dwell time after the first loading in Figure EC-2.2.4 and for all the recovery in the dwell time at zero load. (3a) There are two forms of non-recoverable time-dependent extension or secondary creep. The first is the removal of the lower shoulder in the load-elongation curve. This will be due to some detailed rearrangement of molecular segments and is not a mechanism that would lead to creep rupture. (3b) The other form of secondary creep becomes more important at high loads and is due to whole molecules sliding past one another. This leads eventually to creep rupture, but there will only be a noticeable effect for loads over about 70% of break load.

The converse of creep is stress relaxation, a decrease in tension with time for yarn held at fixed length. Miltenburg's data in Figure EC-2.2.3(a) show that the stress relaxation occurs quite rapidly. Changes are small after 6000 seconds (about 2 hours). There is a correlation between stress relaxation and modulus, which is to be expected since one of the reasons for a decrease in modulus is stress relaxation (or creep) occurring during the time of the tensile test.

The recoverable time-dependence can cause inverse stress relaxation. This is an increase in stress with time for a yarn held at fixed length after a sequence of elongation followed by retraction to a shorter length.

Figure EC-2.2.6 shows the effect of temperature on the load-elongation curves of a polyester yarn. Between 20°C and 50°C, the strength falls by 12% and the break extension increases by 22%, giving a reduction in average stiffness to break of 28%. It is reasonable to assume a linear change in values over this temperature range and the shift of the break point can be used to scale the curve. Similar percentage changes can be expected in the higher tenacity rope yarns. It is likely that the dynamic modulus in cyclic tests would scale in the same way.

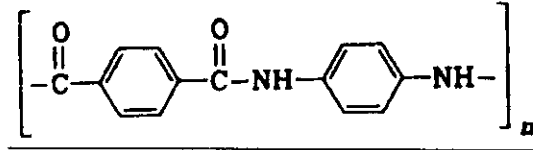
Figure EC-2.2.7 shows the change in dynamic modulus  $E'$  and  $\tan \delta$  in a polyester yarn cycled at about 10 Hz. Note that wetting has only a small effect. The glass transition is shown by the peak in  $\tan \delta$  at about 125°C, which is accompanied by a sharp drop in the dynamic modulus. At lower frequencies, characteristic of wave loading, the temperature of the transition would be lower. The energy loss associated with  $\tan \delta$  begins to increase above about 50°C and can then lead to a cumulative substantial rise in temperature. It would therefore be undesirable to allow polyester yarns in ropes to go to temperatures appreciably greater than 50°C.

At room temperature, the value of  $\tan \delta$  in Figure EC-2.2.7 is about 0.02. The conventional view has been that this is a substantially constant parameter for any polymer and is independent of strain amplitude, though nylon, but not polyester, shows a change with mean strain. However the recent study reported by Bosman (1996) has shown a strong dependence on strain amplitude, but no effect of mean load, as illustrated in Figure EC-2.2.8(a). These values are approached asymptotically with time over many cycles as shown in Figure EC-2.2.8(b). The higher initial values of  $\tan \delta$  will lead to

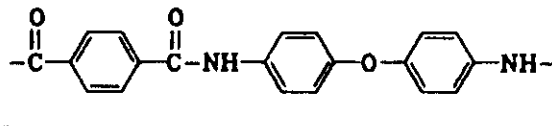
greater heating. Less surprising is the change of dynamic modulus with mean load and strain amplitude shown in Figure EC-2.2.9. The frequency used in these tests was 0.07 Hz (14 second period).

#### EC - 2.1.1.9 (Para)-aramid [See also Yang (1993)]

Twaron and Kevlar are composed of polyphenylene terephthalamide:



Technora is a copolymer variant. Included with the phenylene terephthalamide is 50% of:



Aramid fibres are spun from solution in concentrated sulphuric acid into a bath of caustic soda. In solution, the polymer chains form liquid crystals, which become highly oriented on extrusion. Aramid fibres are characterised by high strength, high modulus and low break extension. The process conditions cause some pleating of the chains and this leads to a stress/strain curve which becomes steeper with continuing extension (see Figure EC-2.2.1). Changes in manufacturing processes can reduce this disorientation and lead to higher modulus, lower extension variants.

Aramid fibres have a high resistance to creep rupture. However, there is a significant amount of creep under comparatively low loads as the disorientation is pulled out; this is different from creep due to molecules slipping past one another, and is not a mechanism leading to fracture. Repeated cycling will tend to remove the initial easier elongation, and lead to a more linear stress/strain curve. Generally, the stress-strain responses of aramid fibres are much less sensitive to temperature, time and cyclic loading than fibres like polyester and nylon.

Like all highly oriented linear systems, the polymer chains in aramid fibres buckle under axial compressive loads. This buckling within the fibres is visible as kink-bands. When tension is applied, the kinks pull out and the tensile stress-strain behaviour is almost unchanged. Any loss of strength, compared to virgin fibre, would be less than 10%. Such losses in strength might occur in the ordinary handling of yarns. However, in repeated cycling, damage accumulates and eventually leads to failure; the resistance to axial compression fatigue is poor. Although straight axial compression is possible, it is more common on the inside of bends when fibres buckle into sharp kinks due to an axial compressive load on a rope component (see EC-5.2.2). Hearle and Wong (1987) report fatigue life times in various flex tests between about 1000 and 100,000 cycles, depending on the severity of the conditions. It is therefore essential to design moorings and select rope structures so as to avoid repeated compressive loads on aramid yarns within ropes. Aramid fibres are also sensitive to abrasion, which causes peeling and splitting.

Aramids absorb a small amount of water, which causes some change of properties. Temperature has little effect, until chemical degradation sets in rapidly around 500°C and more slowly at lower temperatures. Aramid fibres are sensitive to ultra-violet light degradation, but this is not a problem in jacketed ropes.

NOTE: (Meta)-aramid fibres, such as Nomex from DU PONT, are lower strength, higher extension fibres, combining good "textile" properties with heat resistance.

**EC - 2.1.1.10 Gel-spun HMPE (high modulus polyethylene) [See also Jacobs and Mencke (1995)]**

Polyethylene is the simplest polymer:



Dyneema and Spectra are made by "dissolving" very high molecular weight polyethylene in an organic solvent so as to form a gel. After extrusion, the gel fibres are highly drawn to produce the required highly crystalline, highly oriented, chain-extended form. These HMPE fibres are characterised by very high strength, very high modulus, and low break extension.

All polyethylene fibres are sensitive to temperature. They melt at around 145°C, but lose properties at much lower temperatures. HMPE fibres exhibit fairly high creep, though this can be reduced by varying the manufacturing process, and are sensitive to creep rupture. Their resistance to axial compression fatigue is better than for aramid fibres, but not as good as polyester.

Figure 2.2.10 is a plot of dynamic mechanical properties for HMPE. The modulus, which is plotted on a logarithmic scale, decreases with temperature with the fall becoming steeper above 30°C. The loss factor  $\tan \delta$  is low (about 0.01) up to 0°C, but then starts to rise reaching about 0.02 at 20°C.

HMPE yarns have excellent chemical and UV resistance and low friction.

**NOTE ON POLYETHYLENE TERMINOLOGY:** The first technique to be used for manufacturing polyethylene gave branched polymer molecules: this is usually known as *low-density polyethylene* and has poor mechanical properties. Later other catalysts gave unbranched molecules: this material in its common forms is known as *high-density polyethylene* and has moderate strength and high extensibility. The *HMPE* forms depend on the use of high-molecular weight polymer (very long molecules) and special processing conditions.

**EC - 2.1.1.11 Melt-spun high-modulus polyethylene**

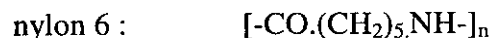
Another form of high modulus polyethylene fibres is made by extruding from the melt and then super-drawing the fibre. Certran from Hoechst Celanese was a fibre made by this method but is not now available. The strength and modulus are about half those of gel-spun HMPE.

**EC - 2.1.1.12 LCAP [See also Beers (1995)]**

Vectran is a wholly aromatic polyester copolymer, containing benzene rings joined by ester links. Fibre properties are similar to those of aramid fibres, but with some differences that lead to advantages in specialised end-uses. In particular, there is an absence of creep and no moisture absorption.

**EC - 2.1.1.13 Nylons**

The polyamides commonly used in nylon fibres are:



Nylon fibres are made by similar methods to polyester fibres and most properties are qualitatively similar to those of polyester. The strength and break extension have about the same limiting values. However, the initial modulus is lower and this might be useful in reducing peak load in deepwater moorings.

Nylon shows substantial primary creep under moderate loads, which will cause additional extension over time when loads are increased, followed by delayed elastic recovery when the load is reduced. Secondary creep in nylon is also greater than in polyester, and, as discussed further in EC-5.2.5, this

causes greater sensitivity to creep rupture.

Nylon fibres absorb substantial amounts of water. This causes a reduction in strength and modulus. The abrasion resistance of nylon is poor when wet. However internal abrasion in wet nylon ropes can be minimised by the use of low twist rope constructions and by avoiding high cycle loads.

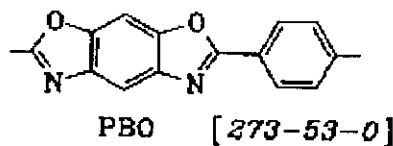
The use of nylon for deepwater moorings is discussed, in comparison with polyester and aramid, by Cloos and Bosman (1997).

#### EC - 2.1.1.14 PEN, PBO and M5

Several new fibres are currently being developed and may be used in ropes in the future.

PEN is a new polyester fibre. The chemical formula is similar to that shown for polyethylene terephthalate in EC 2.2.1.8 except that double naphthalene rings replace the single benzene rings. Current development is aimed particularly at tyre cord yarns, because of the higher modulus and melting point of PEN.

Polybenzoxazole (PBO) is one of a group of polymers with very stiff chains developed in US Air Force research. It is being produced as a fibre by Toyobo, with the name Zylon, and is expected to be available in commercial quantities in 1998. The chemical formula of PBO is:



PBO fibres are made by a process similar to the aramid fibres, with liquid crystal formation leading to a highly oriented, highly crystalline, chain-extended structure. The properties of PBO fibres are similar to those of aramid fibres, but with higher strength and modulus.

At a conference in April 1997, Akzo Nobel described fibres made from a new polymer called M5. The molecule has a similar shape to that shown above for PBO, but has -OH groups as side chains. Hydrogen bonding between chains then causes stronger transverse cohesion than with the other very highly oriented fibres. This results in a higher shear modulus and a higher compressive yield stress.

#### EC - 2.1.2 YARN SELECTION

No additional comment.

#### EC - 2.1.3 EXISTING STANDARDS, GUIDELINES AND SPECIFICATIONS

No additional comment.

#### EC - 2.1.4 YARN QUALITY

No comment beyond EC 2.2.1.4 above.

#### EC - 2.3 ROPE JACKETS AND COVERS ON SPLICES

##### EC - 2.3.1 GENERAL REQUIREMENTS

No additional comment.

##### EC - 2.3.2 BRAIDED JACKETS

No additional comment.

### EC - 2.3.3 PLASTIC JACKETS

Plastic jackets are typically made from polyethylene (PE), ethylene vinyl acetate (EVA) polyester (PET), nylon (PA), and polyurethane (PU).

One of the most common grades used for ropes is based on a PE material used for coating subsea power cables. Sometimes a mixture of PE and EVA is used which produces a softer coating with higher stress cracking resistance.

The other materials listed above used for coating ropes are based on grades commonly used for coating hydraulic hoses.

### EC - 2.4 FINISH AND FILLERS

Finished may typically be based on mineral or natural oils or waxes. The lubricant or filler could be applied in 100% form or in a water or solvent based solution.

Finish or fillers may reduce or eliminate hot-spots where any localised temperature rise could exceed a safe limit. Around 2-3°C temperature, variability along the rope length was found in the Norsk Hydro JIP (1997) for small strain amplitudes and 4-7° C for large strain amplitudes.

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**Figures**

- Figure EC-2.2.1 Typical yarn stress/strain curves for rope yarns: HMPE, aramid, polyester, nylon; and steel for comparison.
- Figure EC-2.2.2 (a) Effect of orientation on polyester stress/strain curves.  
(b) Effect of heat treatment: a - as received; b - after immersion in boiling water at 95°C. From Morton and Hearle (1993).
- Figure EC-2.2.3 (a) Stress relaxation in an industrial polyester from increasing elongations.  
(b) Variation of tensile modulus with strain. From van Miltenburg (1991).
- Figure EC-2.2.4 Schematic representation of changes in polyester stress-strain curve as a result of cyclic loading.
- Figure EC-2.2.5 Stress-strain response of AKZO Diolen 855T polyester yarn in initial extension and in repeated cycling. From Bosman (1996).
- Figure EC-2.2.6 Effect of temperature on the load-elongation of a polyester yarn. From Mwaisengela (1987).

Figure EC-2.2.7	Dynamic modulus and $\tan \delta$ for a polyester yarn, dry and wet. From Morton and Hearle (1993) after van der Meer (1970).
Figure EC-2.2.8	(a) Variation of $\tan \delta$ of AKZO Diolen 855T polyester yarn with strain amplitude, stabilised after 10,000 cycles. The different points are for single filaments and 1100 dtex yarns at mean loads of 20%, 30% and 40% of break load.
Figure EC-2.2.8	(b) Change of dynamic modulus and $\tan \delta$ with time from start of test at 0.07 Hz ( $\log t = 5$ is 100,000seconds, just over 1 day, or 7,000 cycles). From Bosman (1996).
Figure EC-2.2.9	Change of dynamic modulus of AKZO Diolen 855T polyester yarn with mean load and strain amplitude. From Bosman (1996).
Figure EC-2.2.10	Dynamic Modulus and $\tan \delta$ for Dyneema HMPE.

**Tables Mentioned**

Table EC-2.2.1	<u>Rough Guide To Current Yarn Prices</u>
Table EC-2.2.2.2	<u>Yarn Properties : Typical Values For Commercial Rope Yarns, Based On Manufacturers' Data, Fibre Tethers 2000 (1995), Morton And Hearle (1993)</u>

**Appendices Mentioned**

Appendix 1.2	<u>Fibre Rope Units and Conversions</u>
Appendix 1.3	<u>Fibre Rope Modulus Definitions</u>
Appendix 2.1	<u>List of Yarn Tests</u>
Appendix 2.2	<u>Information from Fibre Producers</u>

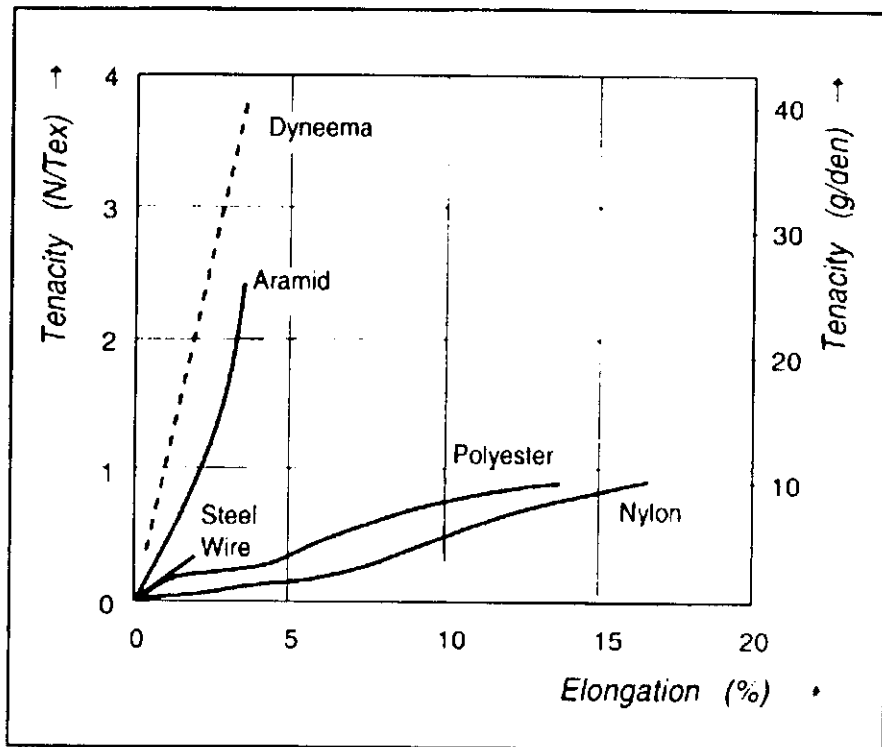


Figure EC-2.2.1 Typical stress/strain curves for rope yarns: HMPE; aramid; polyester; nylon; and steel for comparison.



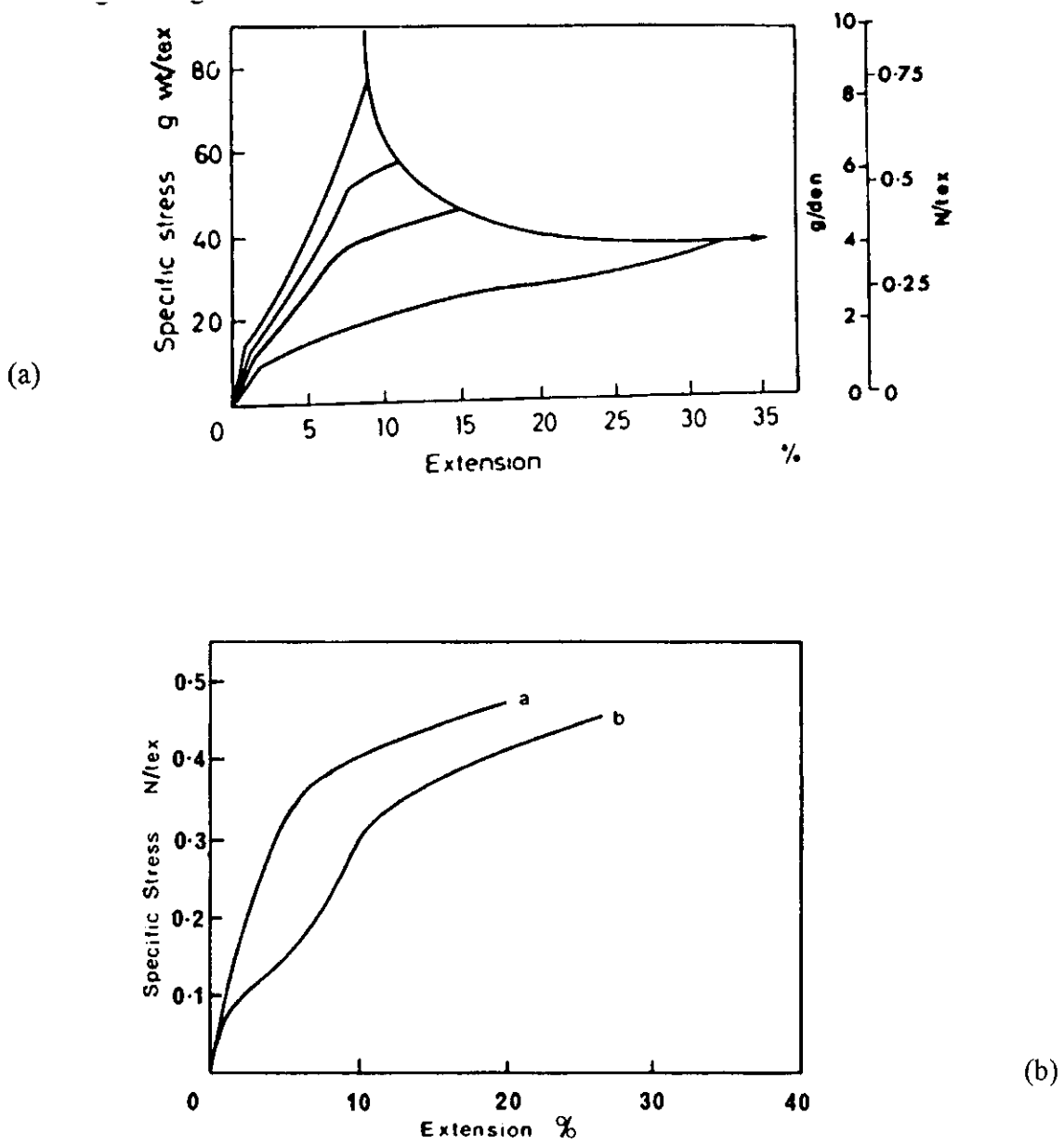


Figure EC-2.2.2 (a) Effect of orientation on polyester stress/strain curves: high to left, low to right.  
 (b) Effect of heat treatment: a - as received; b - after immersion in boiling water at 95°C. From Morton and Hearle (1993).

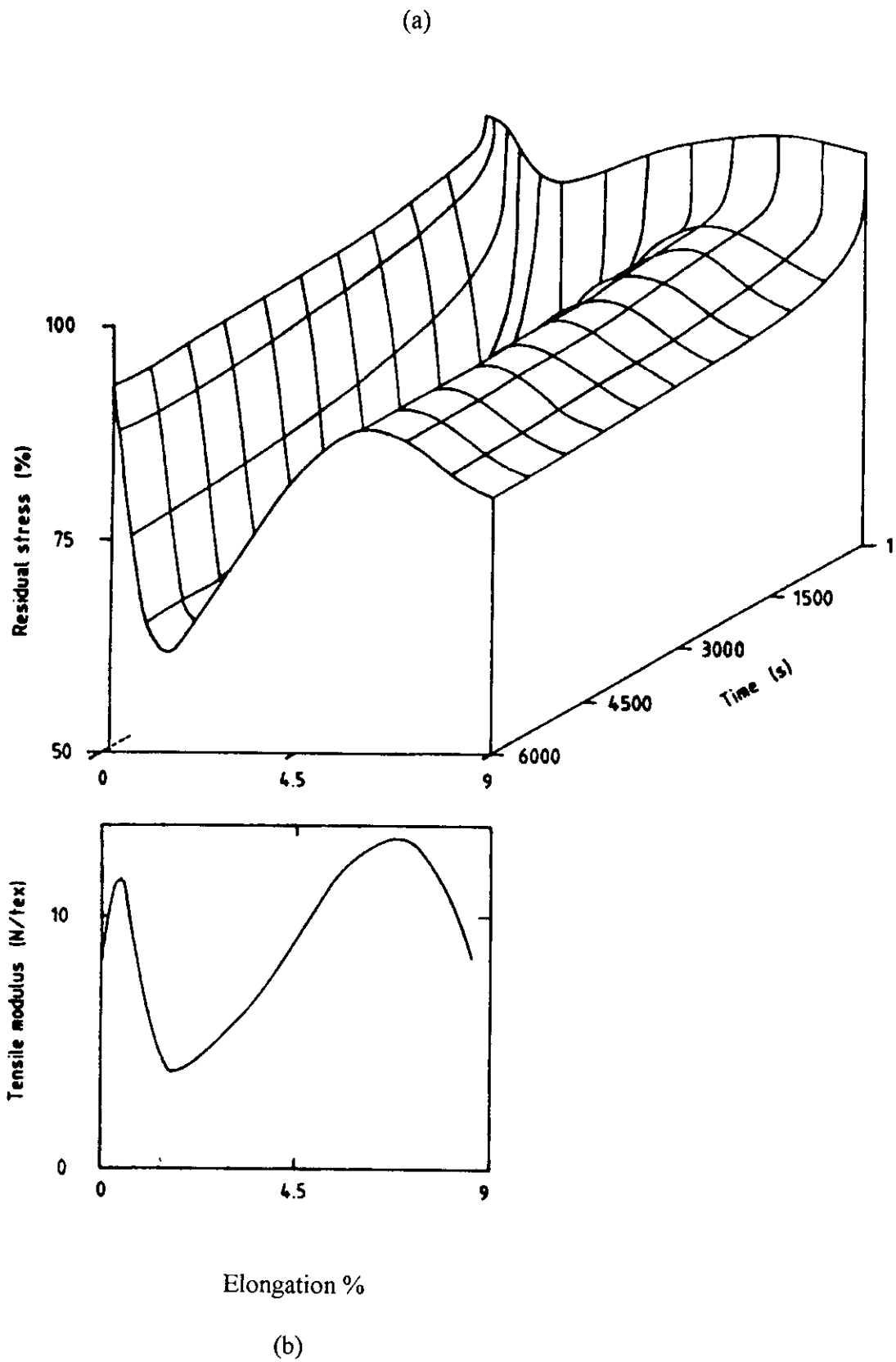


Figure Ec-2.2.3

(a) Stress relaxation in an industrial polyester from increasing elongations.  
(b) Variation of tensile modulus with strain. From van Miltenburg (1991).

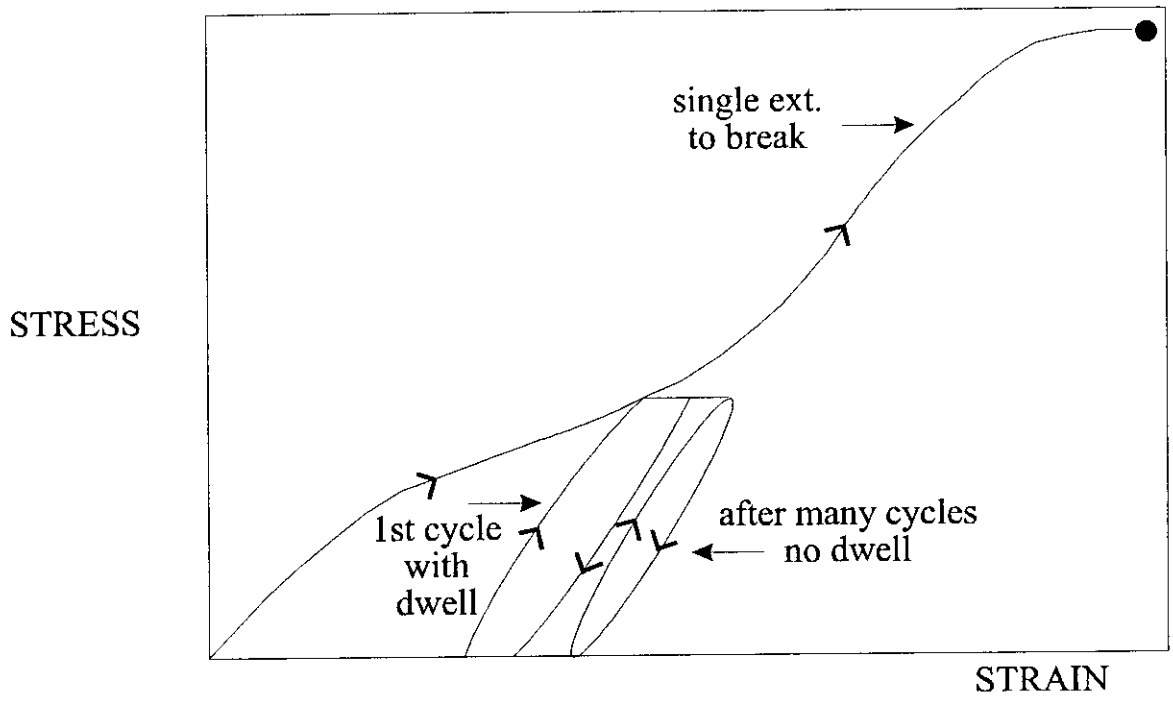


Figure EC-2.2.4 Schematic representation of changes in polyester stress-strain curve as a result of cyclic loading.

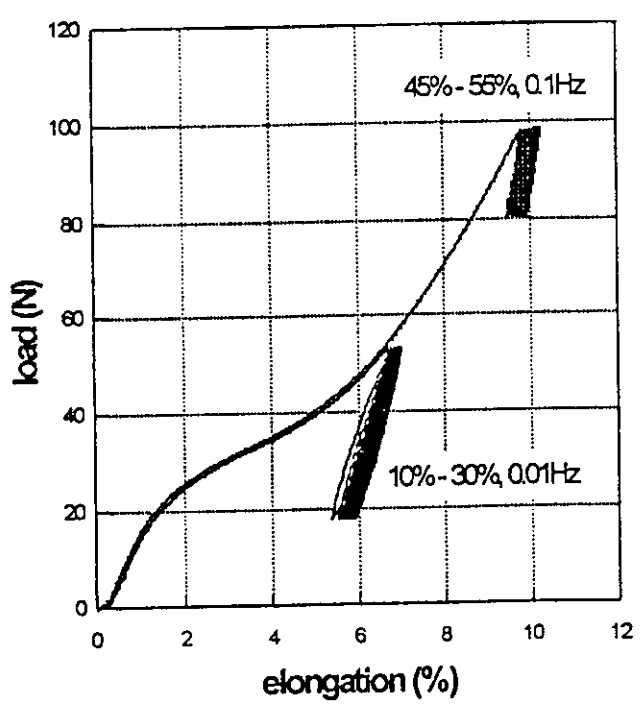


Figure EC-2.2.5 Stress-strain response of AKZO Diolen 855T polyester yarn in initial extension and in repeated cycling. From Bosman (1996).

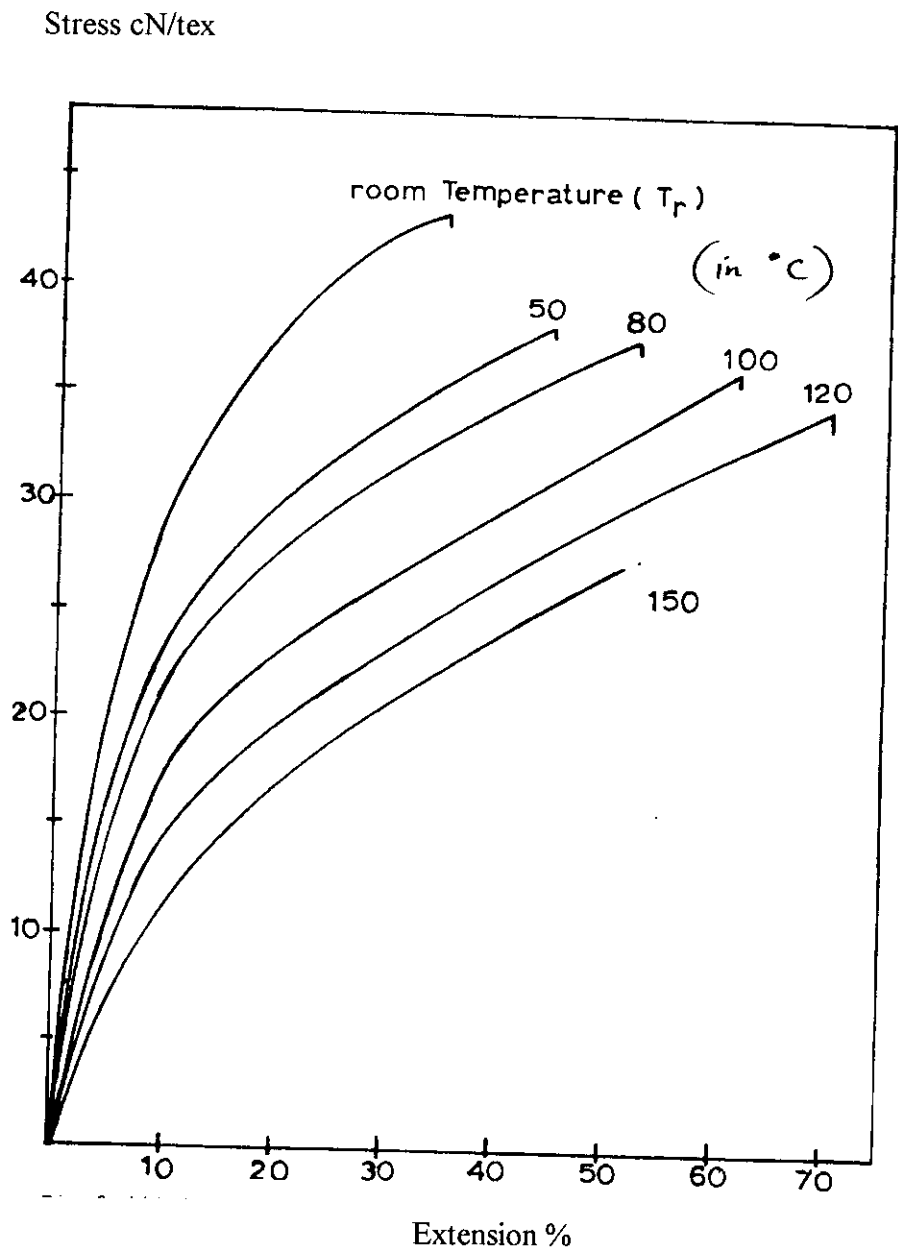


Figure EC-2.2.6 Effect of temperature on the load-elongation of a polyester yarn. From Mwaisengela (1987).

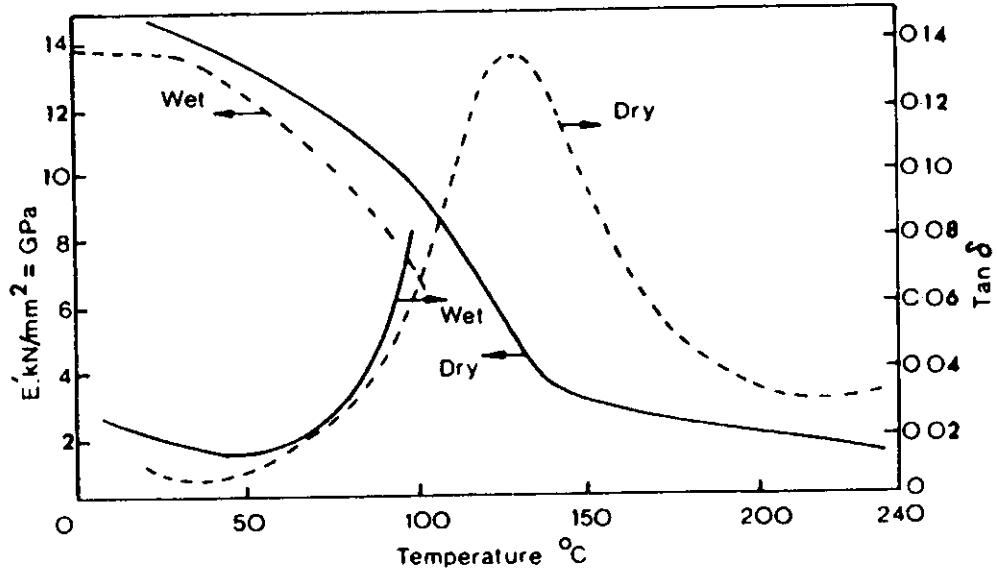
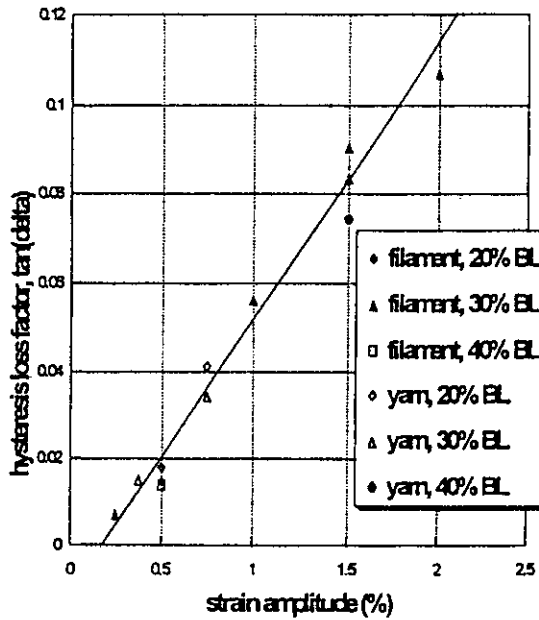
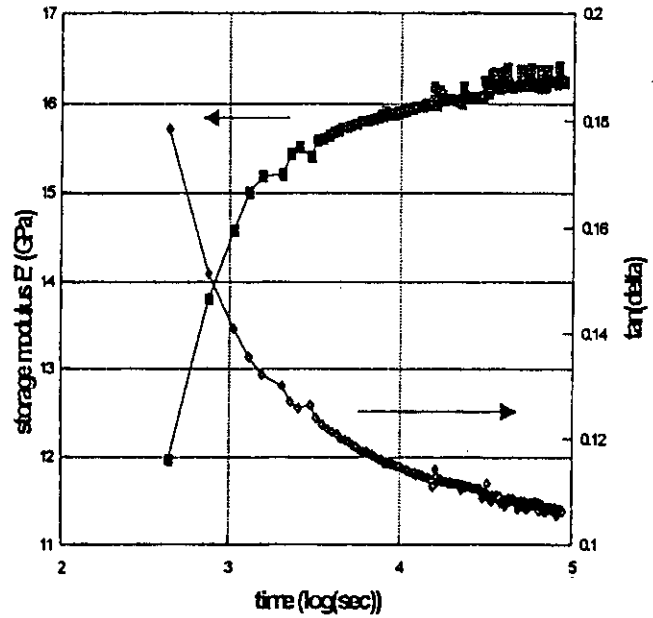


Figure EC-2.2.7 Dynamic modulus and  $\tan \delta$  for a polyester yarn, dry and wet. From Morton and Hearle (1993) after van der Meer (1970).



(a)



(b)

Figure EC-2.2.8

(a) Variation of  $\tan\delta$  of AKZO Diolen 855T polyester yarn with strain amplitude, stabilised after 10,000 cycles. The different points are for single filaments and 1100 dtex yarns at mean loads of 20%, 30% and 40% of break load.

(b) Change of dynamic modulus and  $\tan\delta$  with time from start of test at 0.07 Hz ( $\log t = 5$  is 100,000seconds, just over 1 day, or 7,000 cycles). From Bosman (1996).

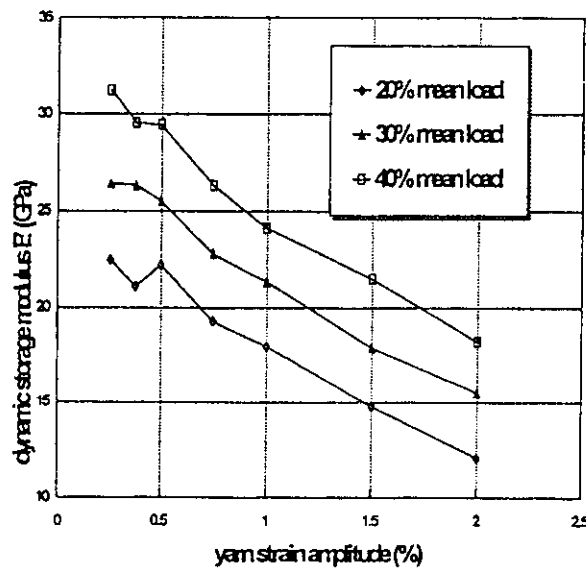


Figure EC-2.2.9

Change of dynamic modulus of AKZO Diolen 855T polyester yarn with mean load and strain amplitude. From Bosman (1996).

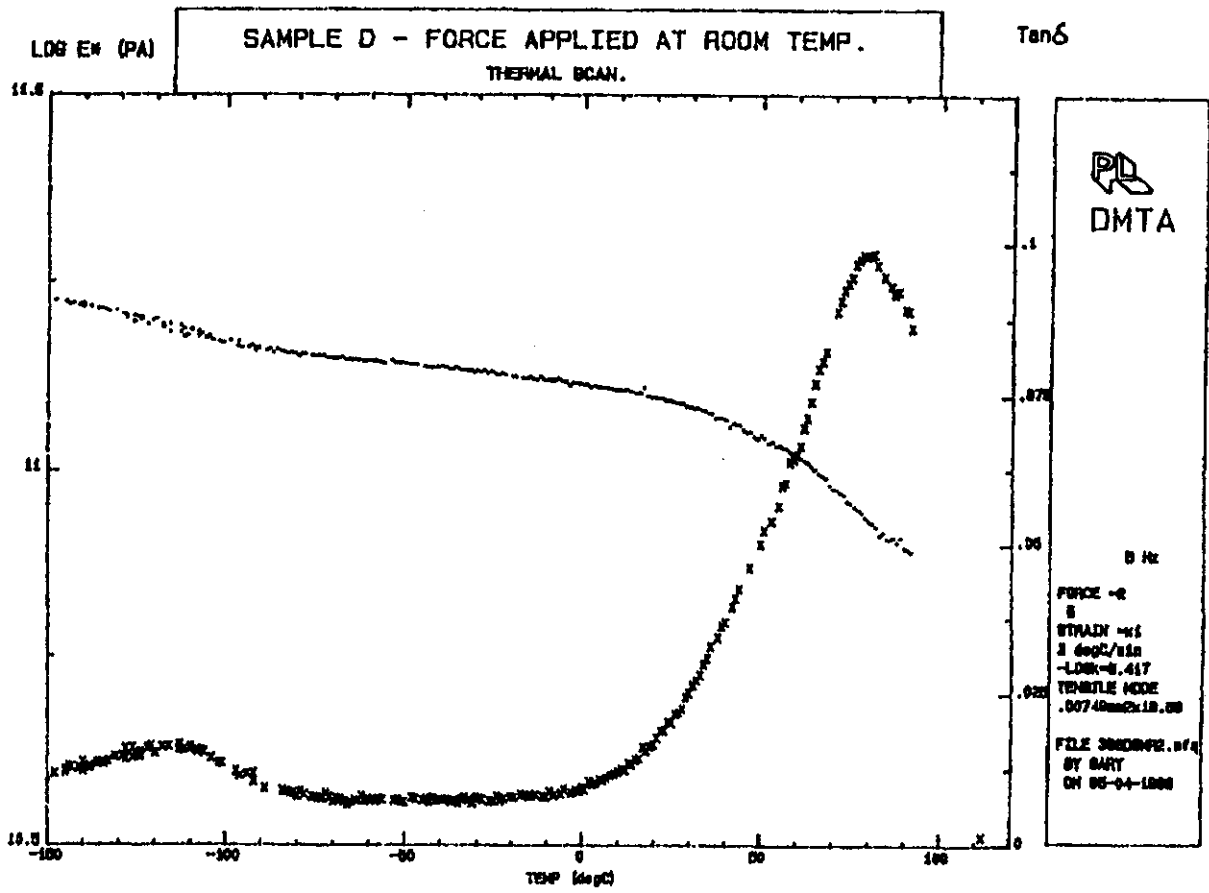


Figure EC-2.2.10: Dynamic Modulus and  $\tan \delta$  for DYNEEMA HMPE

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**EC - 3. ROPE CONSTRUCTIONS** **2**

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**EC - 3. ROPE CONSTRUCTIONS**

EC - 3.1 FIBRE ROPE COMPONENTS

No additional comment.

EC - 3.2 ROPE CONSTRUCTION AND PROPERTIES

EC - 3.2.1 ROPE TYPES

EC - 3.2.1.1 VARIOUS CONSTRUCTIONS

Table EC-3.2.1 lists the principal rope constructions in current use. Traditionally, ropes were made from natural fibres of limited length, which were held together by twist. This led to the common three-strand ropes and similar forms: twisted yarns were twisted into strands, which were then twisted together to form the rope.

Table EC-3.2.1

General Listing of Main Rope Types	
General Types	Sub-Types
• traditional twisted ropes	three-strand variants, such as four and nine-strand
• braided ropes	eight-strand twelve-strand braid-on-braid
• low-twist ropes	wire-rope constructions parallel-strand ropes parallel yarn ropes

The introduction of manufactured continuous filament yarns meant that it was no longer necessary to provide a means of holding short fibres together. A loose tow, (a collection of parallel filaments), has tensile strength, but this is not a practical form of rope construction due to the lack of control and ease of damage to filaments. These developments in fibre supply triggered innovations by ropemakers, which has led to many new types in the last fifty years.

Braiding had long been used for small cords, but the development of large braiding machines led to new large braided ropes; the common forms are eight-strand, twelve-strand and braid-on-braid. Conventional twisting and braiding provide very compact ropes, and the yarn paths from one side of the rope to the other are advantageous in bending, but there is a loss in tensile efficiency due to the angle of the fibre orientation. This led to the development of ropes with low fibre obliquity, which are currently the preferred forms for deepwater mooring.

Parallel yarn ropes are the extreme form. As made for the last 25 years these are a parallel assembly of zero or low-twist rope yarns encased in a plastic jacket. The main limitation of this rope construction is in the bending and twisting response. Because of the parallel arrangement of yarns, there is no relief of yarn tension on the outside of a bend and yarn compression on the inside, nor of the path length changes in twisting.

Two other well established low twist constructions are parallel strand and wire-rope construction. Twist in the various components can be selected as S (left-handed) or Z (right-handed) of appropriate magnitude so as to make torque-balanced ropes, without a tendency to twist when tension is applied.

Parallel strand ropes consist of a number of low-twist three-strand sub-ropes arranged in parallel and covered with a braided jacket. Other forms of parallel strand constructions are under development and include parallel assemblies of braided ropes of various constructions.

Steel wire ropes, which were introduced in the last century, are made by twisting wires into strands and then assembling the ropes by twisting strands in layers round a core strand. Examples are 7-strand, with 6 round 1, and 36-strand, with layers of 6, 12, and 18 round the core. The wire-rope construction fibre ropes have a similar structure with rope yarns taking the place of the metal wires.

In order to show more clearly the typical construction of ropes suitable for deepwater mooring lines, the following examples are described in detail. However the specific construction to be used in any installation will be designed by the rope maker to fit the performance specification set as given in DPD 9.

#### EC - 3.2.1.2 PARALLEL YARN ROPES

Basic textile yarns as received from the fibre producer are assembled into circular cross section bundles of zero or low twist yarns. A number of bundles are assembled in a circular cross section with all the elements parallel to the axis of the tension member.

The parallel elements must then be held together by an external cover. The cover may be an extruded polymer, a braided jacket, a single helical or counter-helical double winding or some other design. Usually the cover does not carry significant tensile load; however, it may be quite substantial in volume if severe external abrasion is anticipated.

Parallel yarn rope is illustrated in Figure EC-3.2.1.

#### EC - 3.2.1.3 PARALLEL STRAND ROPES

Basic textile yarns as received from the fibre producer are assembled into low twist 3 strand sub-ropes. A number of 3 strand ropes, half 'S' and half 'Z' twist are assembled in a circular cross section with all the sub-ropes parallel to the axis of the tension member.

The external cover is the same as the parallel yarn rope.

Parallel strand rope is illustrated in Figure EC-3.2.2.

#### EC - 3.2.1.4 WIRE ROPE CONSTRUCTIONS (WRC)

In this construction, twisted strands are arranged in one or more concentric rings around a central core strand as in making wire rope. The core strand may or may not be designed to carry load. The most common constructions are 6x1 (six strands around the core); 12x6x1 (twelve strands around six strands); and 18x12x6x1. If, in the 12x6x1 construction, the rings of 6 and 12 strands are stranded in the same direction of rotation, the 12 strands are of alternating size so that they nest in the valleys or on top of the strands of the 6 strand ring; this provides a uniform outer circumference and gives the maximum fibre density in the cross sectional area.

Normally, in the 18x12x6x1 construction, the ring of 18 strands are all of the same size. In 12x6x1 and 18x12x6x1 constructions, various combinations of rotation of the stranding of each ring of strands can be used. This will impart a variety of torque properties to the tension member. Maximum torque under load occurs if all rings of strands are stranded in the same direction. With a skilled design, very near zero torque can be achieved over a certain load range if rings are stranded in different directions. Maximum control of torque is obtained with a 36 strand construction (18x12x6x1) in which the direction of lay of the outer 18 strands opposes that of the inner 18 strands.

The individual strands are often jacketed with a thin cover. This holds the fibre yarns together during production but can also be a factor in providing optimum performance when flexing over pulleys particularly for aramids.

Two forms of wire rope construction are illustrated in Figures EC-3.2.3 (a) and (b).

**EC - 3.2.1.5 RELATION OF YARN PROPERTIES TO ROPE PROPERTIES: FORMAL DEFINITIONS**

**INTRODUCTION**

The formulae in the following sections are intended to enable provisional estimates to be made of the properties of rope in particular constructions from selected yarns for use in initial design studies. More complete and correct values should be obtained from measurements on ropes or from computer modelling using software such as OPTTI-ROPE, CABLESOLVE, KNAPSAC or other programs used by ropemakers. SI units are used in this section. Further information on units can be found in Appendix 1.2. Table EC-3.2.2 gives indicative values of the various conversion and other factors for different rope types. More exact values should be found from measurements on prototype or closely similar ropes.

**Table EC-3.2.2**

**Indicative Factors For Low-Twist Fibre Ropes**

Rope Type	Contraction Factor	Packing Factor	Strength Conversion Factor (Weight)	Strength Conversion Factor (Number)	Stiffness Conversion Factor (Weight)	Stiffness Conversion Factor (Number)
<b>Low Twist Fibre Ropes</b>						
• parallel yarn	1.0	0.75	0.75	0.75	0.8	0.8
• parallel strand	1.1	0.7	0.75	0.8	0.8	0.9
• wire rope construction	1.1	0.65	0.75	0.8	0.8	0.9
<b>Other Ropes for Comparison</b>						
• three-strand rope	1.3	0.6	0.4	0.5	0.5	0.65

The expressions below apply to the main core of the rope. The contribution of the jacket to the rope dimensions and mechanical properties is ignored. When data is required for the whole rope, including the jacket, corrections should be made to take account of the weight and thickness of the jacket. To a first approximation, the contribution of the jacket to strength and stiffness can be neglected, but, if necessary, values can be estimated and included.

Engineers may find it more familiar to think in spatial terms, areas, diameters etc., with conventional stresses, moduli etc. as force per unit area. However there is uncertainty in defining the area of cross-section of a rope, both because of the irregularly shaped external boundary and because of the void spaces within the rope. Rope weight (per unit length) is a clearly defined quantity, and there are advantages in the use of specific mechanical quantities related to rope weight.

#### DIMENSIONS

- rope linear density, usually called *rope weight* (kg/m or Mtex)

$$= \text{yarn linear density (tex)} \times \text{number of yarns} \times \text{contraction factor} \times 10^{-6}$$

Contraction occurs in rope-making due to twist or other effects, which make yarn follow a longer path in the rope:

- contraction factor (or twist uptake factor)

$$= \text{length of yarn supply} / \text{length of rope produced}$$

$$= \text{rope linear density} / (\text{yarn linear density} \times \text{number of yarns})$$

- rope density ( $\text{g/cm}^3$ )

$$= \text{fibre density (g/cm}^3\text{)} \times \text{packing factor}$$

- packing factor

$$= \text{ratio of volume occupied by fibre to total rope volume}$$

- rope area of cross-section ( $\text{cm}^2$ )

$$= 10 \times \text{rope weight (kg/m)} \div \text{rope density (g/cm}^3\text{)}$$

- rope diameter (cm)

$$= 2 (\text{rope area}/\pi)^{1/2}$$

$$= 3.57 \times [\text{rope weight (kg/m)} \div \text{rope density (g/cm}^3\text{)}]^{1/2}$$

- rope circumference (cm)

$$= \pi \times \text{rope diameter}$$

Note that rope area can be defined in various ways and it is necessary to ensure consistency in calculations. For rope tensile properties, it is most convenient to use the rope fibre area, namely the area occupied by fibres in the rope cross-section, this is preferably restricted to the load-bearing fibres excluding the jacket. The fibre area concept is similar to the "approximate" metallic area, which is commonly used for wire ropes. It should also be noted that, because of the angles of fibres in the rope, the rope fibre area perpendicular to the rope axis is larger than the total fibre area perpendicular to the fibre axis. Rope diameter and circumference, which are relevant to such factors as drag and marine growth, are measured on the whole rope, and are related to total rope area.

## STRENGTH

- rope break load (MN)  
= yarn tenacity (N/tex) × rope weight (kg/m) × *weight* strength conversion factor
- or
- rope break load (MN)  
= yarn break load (N) × number of yarns × *number* strength conversion factor
- *number* conversion factor (realisation factor)  
= *weight* conversion factor × contraction factor

Note that there are two alternative conversion factors, since contraction in rope-making means that the weight of the rope (per unit length) is greater than the number of yarns times the weight of a yarn per unit length.

The same relations can be applied to calculation of strengths reduced by creep and environmental factors.

## EXTENSION AND STIFFNESS

Stiffness can be defined in various ways. The choice of particular stiffness values approximated from the non-linear inelastic load-elongation properties of fibre ropes, for use in mooring analyses, is discussed later in EC-5.3.2. The expressions below are the formal relations between yarn and rope properties.

Axial stiffness is the relation between tension and elongation, but precise definitions depend on the normalisation. The basic definitions are as follows:

- spring constant of a system (N/m)  
= rope tension (N)/ total elongation of system (m)
- rope axial stiffness (N)  
= rope tension (N)/ rope strain  
where rope strain = elongation (m) / rope length (m)
- rope stress (Pa)  
= rope tension (N) / rope area of cross-section (m<sup>2</sup>)
- rope modulus (N/m<sup>2</sup> or Pa - usually as MPa)  
= rope stress (Pa)/ rope strain
- rope [specific] stress (N/tex)  
= rope tension (N) / rope linear density (tex)
- rope [specific] modulus (N/tex)  
= rope specific stress (N/tex)/ rope strain

The relations to yarn properties are:

- rope modulus (MPa)

$$= \text{yarn modulus (MPa)} \times \text{area stiffness conversion factor}$$

- area stiffness conversion factor

$$= [(\text{yarn packing factor}/\text{rope packing factor}) \div \text{contraction factor}] \times \text{weight stiffness conversion factor}$$

- rope modulus (N/tex)

$$= \text{yarn modulus (N/tex)} \times \text{weight stiffness conversion factor}$$

- rope axial stiffness (MN)

$$= \text{rope modulus (N/tex)} \times \text{rope weight (kg/m)}$$

or

- rope axial stiffness (MN)

$$= [\text{yarn axial stiffness (N)} \times \text{number of yarns} \times \text{number stiffness conversion factor}] \times 10^{-6}$$

The same formulae can be used for the various modulus values and to change yarn stresses into rope stresses in stress-strain relations and cyclic loading.

#### INTERNAL ABRASION AND AXIAL COMPRESSION FATIGUE

There are no direct relations for conversion of yarn-on-yarn abrasion resistance or yarn buckling resistance into rope fatigue due to internal abrasion or axial compression. If rope fatigue data is not available, the yarn data should be scaled by factors which have been found to apply to ropes of similar construction and material class. For new yarn materials, it will be necessary to measure the yarn abrasion and buckling properties.

#### EC - 3.2.1.6 EFFECT OF CONSTRUCTION ON PROPERTIES

In the simplest terms, the strength, axial stiffness and load/elongation properties of a rope might be expected to be equal to the sum of the values of the component yarns. Several factors lead to differences from such an ideal result.

Obliquity of fibre orientation leads to loss of efficiency in carrying tension. Table EC-3.2.3 shows a comparison between steel wire and fibre ropes for the commonly used lay angles. Rope lay angle can either be expressed in degrees by fibre angle relative to rope axis or as an L/d ratio where L = rope lay length and d = rope diameter.

Table EC-3.2.3

**Comparison Of Commonly Used Lay Angles For Fibre And Steel Rope Constructions.**

L/d Ratio	Lay Angle, Degrees	$\cos^4 \theta$	Typical Products
4-5	38-32	0.38-0.52	3, 4 & 9 Strand Hawser Laid (Fibre)
5-7	32-24	0.52-0.69	Plaited/Braided (Fibre) Conventional Wire Rope (Steel)
9-10	19-17	0.8-0.83	Bridge Strand (Steel) Pultrusion (Fibre)
10-15	17-12	0.83-0.92	Wire Rope Construction (Fibre) Parallel Lay (Fibre)
20	9	0.95	Strand Components (Fibre)
40	4.5	0.99	Yarns (Fibre)
PARALLEL	0	1	Parallel Yarn

L = lay length; d = rope diameter

An approximate analysis, with some simplifying assumptions, shows that the specific quantities - tenacity, modulus and stress at a given strain - are reduced by a factor equal to the mean value of  $\cos^4 \theta$ , where  $\theta$  is the angle between fibre direction and the rope axis. The influence on rope properties, assuming no variability, shown in Figure EC-3.2.4 by the change in  $\cos^4 \theta$ , as  $\theta$  is reduced and  $\cos \theta$  tends to 1, is most dramatic up to around an L/d ratio of 10. Thereafter, there is less benefit in strength increase in going to higher L/d values versus the potential risk of increasing other problems associated with very low twist structures. More detailed analyses, which are the basis of computer programs (referenced in EC-3.2.1.5) will give more accurate predictions.

Two factors lead to an uneven sharing of load: variability in fibre properties; and, probably of greater importance, differences in lengths of neighbouring yarns, strands or sub-ropes, which are introduced in rope manufacture. Through averaging, this has some effect on axial stiffness. However the major effect is on strength. Yarns which are under excess tension will break first, and, when a critical number have broken, will lead to a cumulative breakage across the rope. Since the other fibres, for example from yarns introduced with a greater length, will not be carrying full loads, the strength is reduced. In parallel yarn ropes, where obliquity is not a significant factor, variability is a cause of conversion factors below 100%.

The third factor is change of packing of components within a rope. Hexagonal packing of circular cylinders, as shown in Figure EC-3.2.5(a), gives a packing factor of 0.91, but if this was applied at the levels of filaments, textile yarns, rope yarns and strands, with spaces between each of these components, it would give a packing fraction of  $(0.91)^4$  or 0.69. Irregularity in packing leads to lower values. However, there is a countervailing factor in distortion of components. In principle, this can lead to a completely solid structure with no spaces between the components, which are squashed into polygonal shapes with a packing factor of 1, as shown in Figure EC-3.2.5(b). The effect of this on mechanical properties is that, as made, the rope will be more loosely packed than after application of tension. When the rope is loaded, the components pack more closely together and this allows additional extension. The magnitude of the change of structure will depend on the magnitude of the tension applied and the number of repeated loadings. Unless the rope has been repeatedly pre-cycled, some continuous increase in packing factor and hence in length can be expected during the initial

period of use. If the rope is allowed to go slack and is twisted or buckled, the structure may be disturbed, so that the packing becomes more open again.

In addition to the changes in transverse packing, there will also be some readjustment along the length of components, as sections under high tension are relieved by slip from neighbouring sections under low tension. Creep of localised portions of yarns under higher tension can also serve to reduce variability.

EC - 3.2.2 *EXISTING STANDARDS, GUIDELINES AND SPECIFICATIONS*

No additional comment.

EC - 3.2.3 *STRENGTH*

(See also comments in EC-3.2.1.5 and EC-3.2.1.6 above.)

Rope strength and weight are shown in Tables EC-3.2.4., EC-3.2.5 and EC-3.2.6 for the above constructions. This data has been taken from the manufacturer's literature values and is based on jacketed ropes. The terminology to describe breaking load (B.L.) is quoted as stated in the manufacturer's literature. This is generally the Manufacturer's Certified Breaking Strength (CBS) which is the designation used in the Design Practice Document. The specific strength has been calculated on the total rope weight given in the tables, which includes the respective jacketing type.

Though not all the values have been verified by testing at the sizes appropriate for deepwater moorings, extrapolation and interpolation from existing data can be considered to be accurate to better than 10%.

Table EC-3.2.4

**Typical Polyester Wire Rope Construction Literature Values**

Diameter(m m)	Certified Break Strength (Tonnes)	Tensile Strength (GPa)	Weight (kgs/100m)	Specific Strength (N/tex)	Max Storm Stiffness Tonnes	Post Installation Stiffness Tonnes
44.5	79.4	0.5	150	0.52	3969	1323
50.8	99.8	0.5	194	0.50	4990	1663
57.2	129.3	0.5	259	0.49	6464	2155
63.5	156.5	0.5	314	0.49	7825	2608
69.9	181.4	0.5	368	0.48	9072	3024
76.2	215.5	0.5	441	0.48	10773	3591
82.6	249.5	0.5	531	0.46	12474	4158
88.9	281.2	0.4	609	0.45	14062	4687
95.3	317.5	0.4	704	0.44	15875	5292



Table EC-3.2.5

**Typical Polyester Parallel Strand Literature Values  
(Marlow Ropes : Superline)**

Diameter (mm)	Certified Break Strength (Tonnes)	Tensile Strength (GPa)	Weight (kgs/100m)	Specific Strength (N/tex)	Max Storm Stiffness Tonnes	Post Installation Stiffness Tonnes
44	55	0.4	144	0.37	2750	917
48	67	0.4	171	0.38	3350	1117
56	90	0.4	240	0.37	4500	1500
64	117	0.4	297	0.39	5850	1950
80	183	0.4	456	0.39	9150	3050
88	222	0.4	560	0.39	11100	3700
104	309	0.4	743	0.41	15450	5150
136	507	0.3	1226	0.41	25350	8450
144	558	0.3	1367	0.40	27900	9300
184	796	0.3	2139	0.37	39800	13267
192	857	0.3	2326	0.36	42850	14283
250	1500	0.3	3850	0.38	75000	25000

Table EC-3.2.6

**Typical Polyester Parallel Yarn Literature Values**

Diameter (mm)	Certified Break Strength (Tonnes)	Tensile Strength (GPa)	Weight (kgs/100m)	Specific Strength (N/tex)	Max Storm Stiffness (Tonnes)	Post Installation Stiffness (Tonnes)
47	50	0.3	165	0.30	2500	833
53	60	0.3	215	0.27	3000	1000
64	100	0.3	310	0.32	5000	1667
90	200	0.3	622	0.32	10000	3333
99	250	0.3	763	0.32	12500	4167
140	500	0.3	1440	0.34	25000	8333

The specific strengths for WRC in Table EC-3.2.4 are greater than those for parallel strand and parallel yarn in Tables EC-3.2.5 and 3.2.6. This suggests that WRC gives the highest strength, but in fact this comparison illustrates the different jacketing thickness and conservatism employed by various manufacturers in quoting values for rope strength. The conversion factors in Table EC-3.2.2 shows that all these ropes have essentially the same strength at the same size.

EC - 3.2.4      *AXIAL STIFFNESS*

(See also comments in EC-3.2.1.5 and 3.2.1.6 above.)

Rope stiffness values are given in Tables EC-3.2.4, EC-3.2.5 and EC-3.2.6 for the three constructions. In broad terms, for the above constructions rope modulus lies between 6 and 16 GPa. The actual modulus for any given rope will have to be specified in the performance specification and verified by prototype testing.

A detailed discussion of rope elongation properties and of the definitions and typical stiffness values used in mooring analyses is given in DPD-5.3 and EC-5.3.

EC - 3.2.5      *TENSION - TENSION FATIGUE LIFE*

Rope fatigue is discussed in the context of the rope assemblies in EC-5.5.

FIBRE TETHERS 2000 (1995) has been the only comprehensive study of fatigue in fibre rope constructions used in deepwater moorings. Within the size limits and cycles tested in this study, it was concluded that there is no fatigue difference between parallel yarn and strand constructions. The wire rope construction showed marginally lower performance, though this may not be representative of wire rope constructions in larger sizes or from other manufactures. The study concluded that most of the fibre tethers tested had superior tension-tension fatigue endurance compared with steel wire rope and strand of comparable breaking load.

## EC - 3.3          PROTECTIVE JACKET CONSTRUCTIONS

EC - 3.3.1      *JACKET DESIGN*

Jacket design is to be conducted by the ropemaker and the following factors should be addressed or specified by the system designer.

Some data by TTI (1996) suggests that hot spots can occur due to hysteresis heating caused by storm conditions, particularly when high radial compression occurs due to jacketing or rope construction. This aspect is material sensitive, polyester and HMPE mechanical properties are highly sensitive in comparison with aramid. The jacket should have adequate shear strength to resist failure during installation. The jacket should also be designed not to be too slack or too tight.

Some fibre ropes can exhibit high Poisson's ratio, typically greater than 1 (rubber = 0.5) during bedding-in cycles. With this feature it is possible to design a braided jacket to either remain in contact with the load bearing core or to go slack.

Hose braiding technology, described by Evans (1979), has determined the neutral angle of 54.44° and the response of the hose can be predicted when the braid angle is changed. This assumes no elongation of the material and constant internal pressure.

a) When the braid angle is higher than neutral:

the braid will increase in length and its diameter will decrease

b) When the braid angle is lower than neutral:

the braid will shorten in length and its diameter increase

EC - 3.3.2      *EXTERNAL ABRASION*

No additional comment.

EC - 3.3.3      PARTICLE INGRESS AND AIR POCKET SUPPRESSION

In studies of yarn-on-yarn abrasion of polyester and nylon rope yarns by Goksoy and Hearle (1988), there was very little difference between the effect of different aqueous environments (distilled water and various salt solutions) when the abrasion took place with the yarns immersed. However, there was a major reduction in life for yarns that had been immersed in a sodium chloride solution, dried and then abraded. The reduction was even greater after drying from a synthetic sea-water sea solution. Some results are given in Table EC-3.3.1.

The increased abrasion was attributed to dried salt crystals, which were clearly visible in SEM pictures of the yarns. This could be a problem if the top portion of a mooring rope was allowed to be wetted and dried. However, it is also an indication that particles of sand, grit or other water-born particles would be likely to cause abrasion damage.

**Table EC-3.3.1****Yarn-on-yarn abrasion of wetted and dried yarns**

<u>Mean abrasion life (cycles)</u>		
	<u>polyester</u>	<u>nylon</u>
<u>wetted and dried from:</u>		
<u>distilled water</u>	<u>3220</u>	<u>31936</u>
<u>tap water</u>	<u>4590</u>	<u>27666</u>
<u>NaCl solution</u>	<u>51</u>	<u>119</u>
<u>synthetic sea-water</u>	<u>16</u>	<u>76</u>

Little work has been conducted on the aspect of whether a rope should be free flooding or all water excluded from the rope. It is not clear to what extent water will be able to displace air completely from the spaces between strands, yarns and fibres [ see Bowie and Williams (1997)].

Air pockets could lead to localised dry spots where hysteresis heating has been shown to fail ropes very quickly as shown by TTI (1997), though at much higher cyclic strains than will be experienced on deepwater moorings.

Another possible hazard with an impermeable jacket is that the hydrostatic pressure at the bottom of the mooring might act on the air within the rope and lead to blow-out during installation. This possibility needs to be examined, but due to the resistance to water flow through small spaces may not occur in any realistic situation.

Further work is required in this area to quantify the sensitivity of air pocket suppression.

EC - 3.3.4      FISHBITE RESISTANCE

Some work has been conducted in this area on ropes typically used for oceanographic buoy moorings and a maximum bite depth of 50mm was recorded by Berteaux et al (1990). This work has shown that fishbite is localised by geographical area and depth. Indeed, recent work by Berteaux et al (1991) and Winkler and McKenna (1995) on larger ropes has shown no fishbite damage.

If necessary, pre-trials should be carried out or inspection routines established to check for jacket damage during the life of the mooring.

In areas where fishbite is perceived to be a major problem, rope sheath design should be chosen in accordance with Woods Hole field trial or other results (i.e. Berteaux et al (1990)).

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**EC - 3.3.5      *UV RESISTANCE***

Melt-spun HMPE has excellent resistance to UV light.

Nylon and LCAP are similar to aramid in that they may suffer degradation from exposure to UV light.

No additional comment.

**EC - 3.3.6      *MARINE GROWTH***

No additional comment.

**EC - 3.3.7      *JACKET BENDING RIGIDITY***

No additional comment.

**EC - 3.3.8      *VORTEX INDUCED VIBRATION SUPPRESSION***

No additional comment.

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**Figures**

Figure EC-3.2.1	Parallel yarn rope.
Figure EC-3.2.2	Parallel strand rope.
Figure EC-3.2.3 (a)	Wire-rope constructions.
Figure EC-3.2.3 (b)	Wire-rope constructions.
Figure EC-3.2.4	Lay angle vs L/d ratio
Figure EC-3.2.5 (a)	Hexagonal packing of circular cylinders
Figure EC-3.2.5 (b)	Compression into solid wedge packing

**Tables**

<u>Table EC-3.2.1</u>	<u>General Listing of Main Rope Types</u>
<u>Table EC-3.2.2</u>	<u>Indicative Factors for Low-Twist Fibre Ropes</u>
<u>Table EC-3.2.3</u>	<u>Comparison of Commonly Used Lay Angles for Fibre and Steel Rope Constructions</u>
<u>Table EC-3.2.4</u>	<u>Typical Polyester Wire Rope Construction Literature Values</u>
<u>Table EC-3.2.5</u>	<u>Typical Polyester Parallel Strand Literature Values (Marlow Ropes : Superline)</u>
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<u>Table EC-3.3.1</u>	<u>Yarn-on-Yarn Abrasion of Wetted and Dried Yarns</u>

**Appendices**

<u>Appendix 2.1</u>	<u>Fibre Rope Units and Conversions</u>
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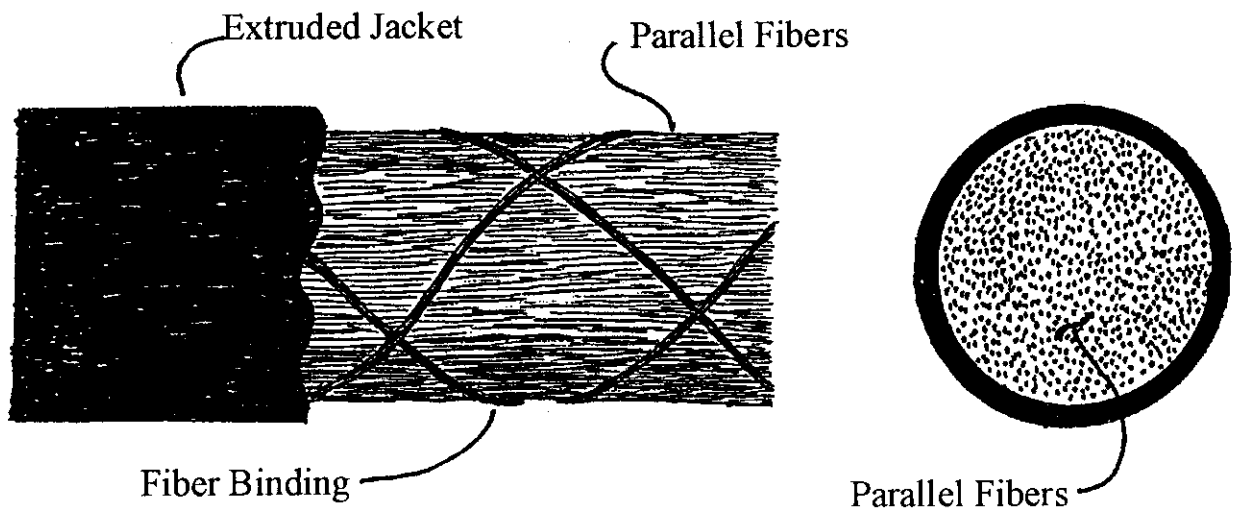
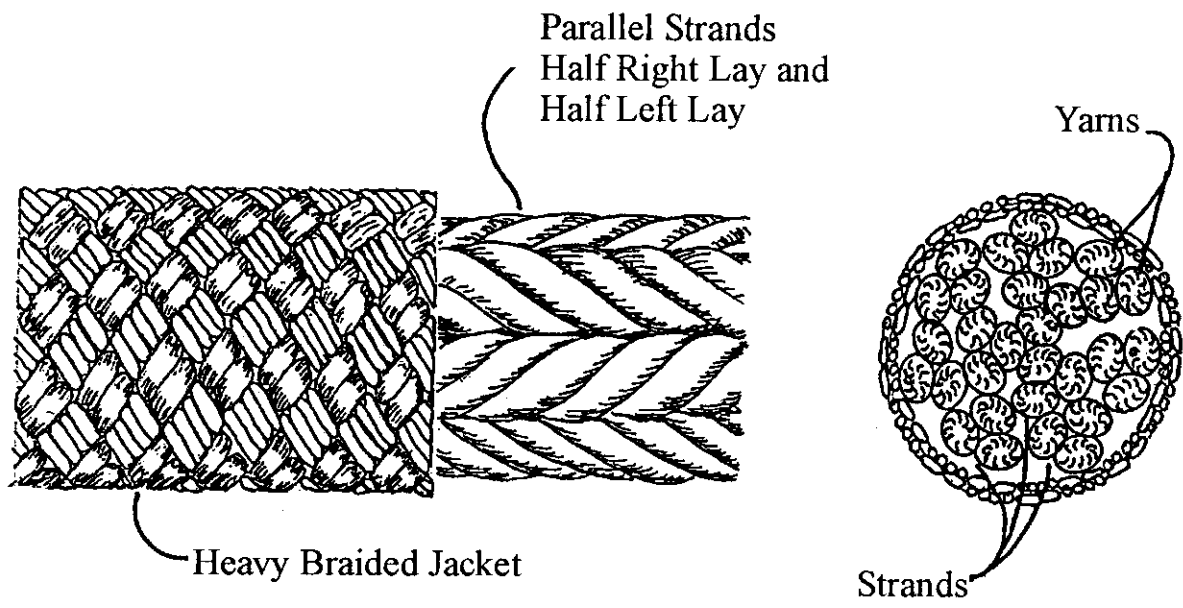
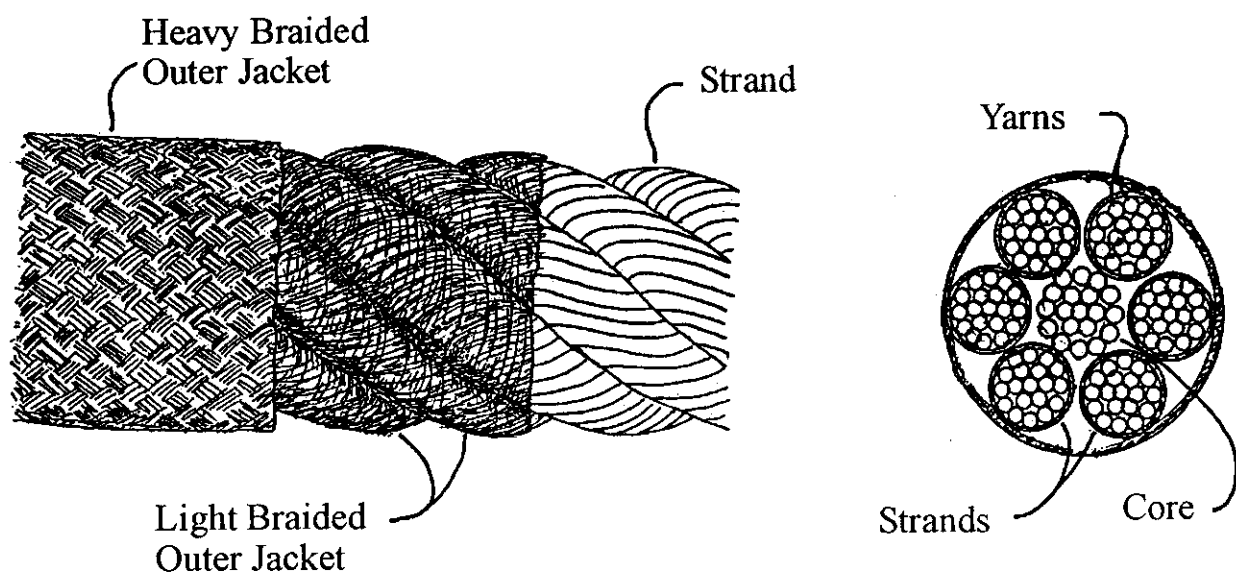


Figure EC- 3.2.1: Parallel Yarn Rope

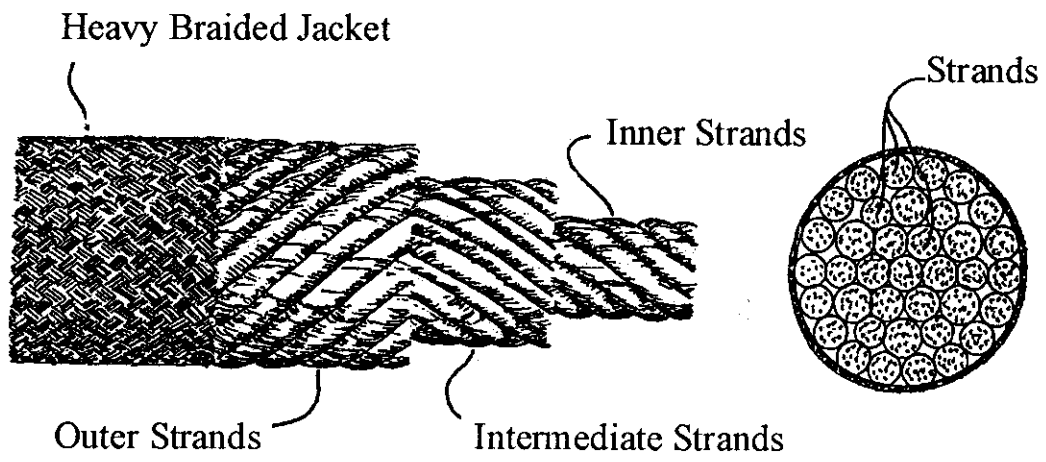


### EC 3.2.2: Parallel Strand Rope

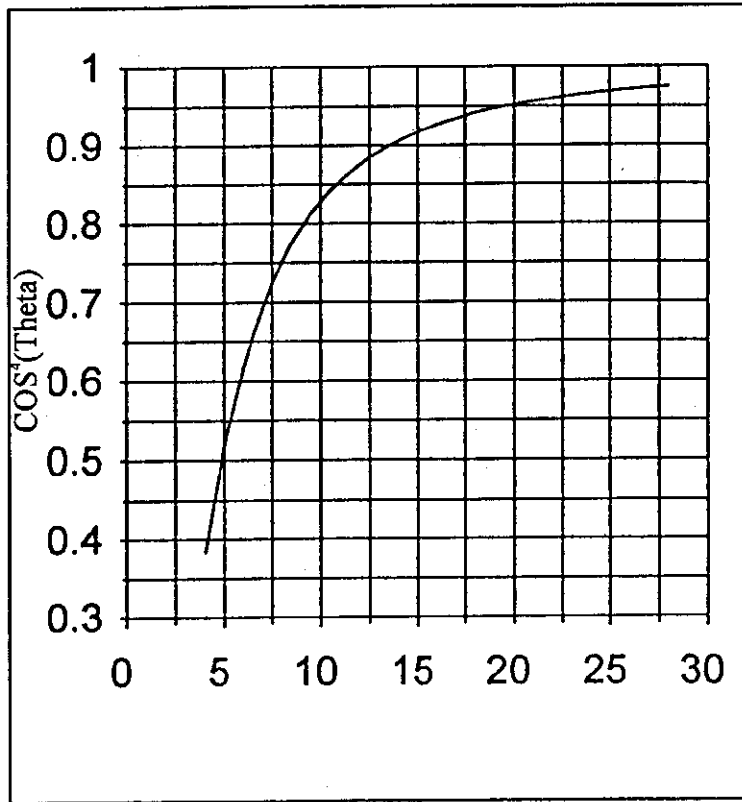




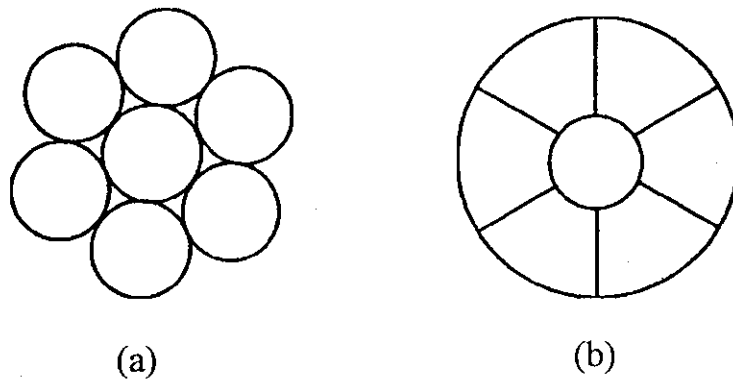
**Figure EC-3.2.3 (a): Six Strand Rope  
Wire Rope Construction**



**Figure EC-3.2.3(b): Thirty Six Strand Rope  
Wire Rope Construction**



**Figure EC 3.2.4: Lay angle vs L/d ratio**



**Figure EC 3.2.5: (a) Hexagonal packing of circular rods  
(b) Compression into solid wedge packing**

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	plus additional changes	jwsh	25 Nov '97
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## EC - 4. ROPE TERMINATIONS

### EC - 4.1 TERMINATION TYPES

#### EC - 4.1.1 END TERMINATIONS

##### EC - 4.1.1.1 Introduction

Termination is defined as the provision of a load transferring means on the end of a rope.

In Floating Production System (FPS) moorings the rope termination is as important as the rope material and rope construction in determining properties such as tensile efficiency and fatigue life.

The data referenced herein mainly applies to ropes smaller than those for FPS moorings because there is little public domain data on terminations at full scale. Recent (Norsk Hydro (1997)) and ongoing (NEL/TTI (1997 - )) studies are addressing the lack of data and some of the current perceived design issues for full scale terminations.

Figure EC-4.1.1 shows the principal types of terminations available for use on man-made fibre ropes. We believe that this tree includes all types of terminations which are presently used or are now publicly known to be under development for high-performance fibre ropes. There may be other feasible types of terminations.

The major categories are **grip** (with two sub-categories, **external** and **internal**, which themselves may be considered major categories), **pot**, **form eye**, and **knot**.

What follows is a general discussion of each category (other than knots), with references to examples. Usually only one prominent example will be given, but in some cases other examples could be referred to.

##### EC - 4.1.1.2 Gripping Terminations

Over half of the termination types listed fall into the major category of **grip**. All of these types are used on wire rope. Most are successfully used on small stranded or parallel element aramid ropes.

Grip type terminations are divided into two major sub-categories, **external** and **internal**. Various external and internal grip terminations are also used in combination. These combinations will not be discussed here.

##### EXTERNAL GRIP TERMINATIONS

There are many variations of **external** grip type terminations. Successful applications of most of these on small diameter high-performance fibre ropes can be identified. Only a few of these have been successfully applied to large diameter high performance fibre ropes.

The category of **wrap** external grip includes designs in which wires or strands are arranged around the outside of the rope in an appropriate gripping arrangement.

An example of the **spiral wire** is the Cable-Grip Termination (1986). Small diameter wires are preformed in a cork-screw pattern to fit tightly over the rope. It is efficient enough to break small wire, but the efficiency falls off with size. The spiral wire is used to terminate small instrumentation cables made of high-performance fibres, Strange and Green (1977). It is also used as a bending strain relief device in combination with other types of termination, Swart (1977).

The "Kellems grip" is a well known example of the **mesh sleeve** termination, Kellems (1928). It consists of a pre-assembled open wire or fibre braided collar with handle-like extensions which is placed over the rope. This is also known as the Chinese finger trap. Like the spiral wire, it is used to terminate small instrumentation cable and as a temporary stopper for pulling cables through conduits. It has been adapted as an aramid braided mesh sleeve for use on small aramid cables, Strange and Green (1977).

An example of the **over-braid** is the common rope stopper, used aboard ships to temporarily hold the end of a rope or wire during the mooring operation, Admiralty (1979). A short length of rope is passed around a bit or through a strong eye and then loosely wrapped or braided around the larger mooring rope or wire. Back tension is applied to the ends of this small rope to cause it to grip. In this form it is inefficient. However, when properly made up as a full multi-strand braid of high-strength fibres, it can be highly efficient on small ropes, Swanson (1979). An interesting variation is the use of aramid strands braided by this technique to provide intermediate pick-up points on long underwater lines and cables, May (1988)

The **clamp** can take many forms. The most common one in general use is the **swage**, a metal collar which is placed over the end of the rope and rolled or compressed to a reduced diameter. It is used on wire ropes. In its analogous form, the ferrule (see below), it is used to form eyes on small high-performance ropes.

The **collet** is a loose hollow cone which fits over the rope end and is itself enclosed in an outer tapered housing. It may be a **one-piece collet** with axial slots enabling it to contract, Electroline (1986a). It may be a **multi-piece collet**, essentially a hollow cone which is split in pieces, Electroline (1987, 1986b). In either case, tension on the rope forces the collet into the taper and causes it to grip on the rope. Usually the collet is forced into the housing by a screw thread or similar mechanism to preset it on the rope. There are many examples of the collet type of termination. Some of these have been successfully used on small aramid ropes.

The **wedge** is similar in function to the collet, but generally has straight sides, although the surface bearing on the rope may be semi-circular. The Carpenter's stopper is an example of a **one-side wedge**, Admiralty (1979). The Lucker Gripper is an example of a **two-side wedge** and is also an example of a **wedge with rollers**.

Wedges are used as grippers on some rope test machines. Thus ropes which are tested "without terminations" on a test machine have effectively been tested with this type of termination. With proper preparation and application, high efficiencies can be obtained on small ropes using such techniques.

#### INTERNAL GRIP : BARREL AND SPIKE

The **internal grip** termination is typified by the **socket and cone** type. This is also known as the **cone and spike** or barrel and spike type. It is a matter of viewpoint, but here the outer body will be called the socket because it is essentially the same as the socket used in potting.

The most familiar variation is the **round cone**, Admiralty (1981), Linear Composites, Kingston (1988), SEFAC, Strange and Green (1977). Several such designs have been successfully used on parallel element aramid and polyester ropes and are under intensive development to enhance fatigue life, Willes (1982), Reiwald et al (1986)

Other variations are possible. The **grooved cone** is used on wire rope, Electroline. The cone can be made of compliant material. Also, the cone can be combined with **potting**, Willes (1982).

#### EC - 4.1.1.3 Potted Terminations

Another common way of terminating is to **pot** the end of the rope in a tapered socket.

High performance fibre ropes have been successfully potted in the **conventional socket** commonly used for wire rope, Phillystran (1987 a,b). This has been effective on small aramid ropes. Improved performance on larger ropes has been obtained with a **custom socket**, designed specifically for use on the high performance rope, Phillystran (1987 a,b), Strange and Green (1977), Horn et al (1977).

There are many possible variations in the mechanical design of potted terminations. For example, as mentioned above, potting can be combined **with cone**, Willes (1982). Variations in the potting material and in the techniques used in assembling the termination are also possible. Research in these areas is continuing.

To date no public domain data is available on resin socketed ropes for FPS full scale ropes. Small scale development tests on polyester, Yeardeley (1996), have shown promising results with higher tensile and fatigue efficiency indicated compared to splice terminations. This work is ongoing and is being evaluated for larger sizes. Flory (1995a, b and 1997) demonstrated that the terminated breaking strength of 1-1/2in. six-strand aramid rope was increased by over 50% when the large potted socket is divided into smaller cavities This is further discussed in EC-4.5.2.

#### EC - 4.1.1.4 Splice / Eye Type Terminations

Another major category of terminations for high-performance ropes is to **form an eye**. This is commonly done by bringing the strands or parts of the rope back into the main body of the rope in a **splice**. There are many possible variations of the splice.

The most familiar way of making a splice is to **tuck strands**. In the sailmakers or Liverpool Splice the returning strands are tucked in the direction **with lay**, Admiralty (1981), Horn et al (1977). Each returning strand is continuously wrapped around one of the strands in the body of the rope, so that it proceeds in the direction of rope lay.

An alternative form of the tuck splice is the lock tuck or Admiralty splice, in which the returning strands are tucked back into the main rope body **against lay**, Admiralty (1979). Each returning strand is passed over one of the strands in the body of the rope and then under the next body strand, so that it proceeds against the direction of rope lay.

Initial attempts to apply the conventional Liverpool and Admiralty splices to stranded aramid rope produced poor efficiencies. It was then found that increasing the number of tucks beyond those commonly used on wire ropes, tapering the ends of the tucks, and other techniques increased the efficiency to acceptable levels, Fowler and Reiniger (1978). The performance depends greatly on how the splice is made. Torque performance of the splice and the rope structure are very important for some applications, Reiwald et al (1986). As a result of these findings, these splice methods have recently been used successfully on very large high performance fibre ropes, Koralek and Barden (1987).

Another way of splicing an eye into a high-performance fibre rope is to **braid strands**. One such method is to form the returning strands in a braided pattern **around rope**, Greening Donald, Fowler and Reiniger (1978, 1981). This is effective on small ropes. However efficiency falls off with increasing size. Another such method which is practised in some braided ropes is to braid the returning strands **into rope**, Admiralty (1979, 1981).

Another variation is to **wrap strands** around each other without either tucking or braiding. In the Flemish Eye splice, the strands are split into two groups and are then reformed in a **interwarp in eye** arrangement, Admiralty (1981). This technique is sometimes used together with the tucked strand splices. The strands can also be wrapped **around rope**, Hood (1976).

Hollow braid and double braid ropes can be spliced by **tuck one part of rope into another**. In the **hollow braid splice**, the end of the end of the rope is turned around, inserted through the braid and pulled back into the hollow of the rope, Admiralty (1981). This technique has been used in combination with inter-braiding on a braided aramid rope, Horn et al (1977).

In the **double braid splice** the core and cover are separated, the end of the cover is inserted in the reverse direction back into the core, and the original cover is pulled back over the exposed core to complete an eye, Admiralty (1981).

The eye can also be formed by a means to **grip end** of the returning rope or strand ends. This is commonly done by applying a **wire rope grip**. This is a special form of U-bolt with a plate to fit and grip the rope, sometimes called a bull dog clamp. It has successfully been used on aramid ropes applications in which bending fatigue and wear around sheaves is the principal concern and termination loads are not high, Whitehill (1982).

Another common means of securing the end to from a splice is to apply a compression **ferrule**, Admiralty (1981), Strange and Green (1977), Horn et al (1977). This is similar to the swage type grip which was mentioned above. In the same manner, many other of the grip type terminations can be adapted to secure the returning end alongside the body of the rope to effectively form an eye.

#### EC - 4.1.1.5 Custom Potted Socket For Pultrusions

The only type of termination so far proven for strands formed from pultruded rod is the custom potted socket.

The aim of this termination must be to obtain either an even hydrostatic pressure along the length of each rod, or a graded hydrostatic pressure which slowly increases from the nose to a maximum at the back of the socket.

It is very important to maintain symmetry within the socketing media and great care is needed to open up the rods in such a way that this is preferably maintained below the level of stress already induced by laying the rods in their shape in the main body of the product. The encapsulation should be of considerable length probably in the range of the product diameter, times 6 or even 10.

The encapsulating material should be filled to ensure the smallest possible shrink ratio to avoid the problem of creating a different angle between the cone and the socket into which it fits. This fill material also reduces the peak temperature of the exotherm if epoxy material is used and this is very desirable.

It is important to ensure that the socket neck area, in particular, does not generate any fretting points. At the other end of the cone, it is a good idea to expose the ends of the rod to enable movement of these rods to be easily spotted. If, for example, the cone is being produced separately to the socket, it is a good idea to cut the end squarely with a disc cutter so that the rod ends are flush with the top surface of the cone and any small movements can easily be seen particularly when first pulled into the socket. No wrappings of the rods should be encapsulated in the cone.

A further idea being considered is to coat the cone with a soft polyurethane for some 0.5mm before pulling it into the socket. This would then ensure very even loading of the whole cone when pulled into the socket.

#### EC - 4.1.2 IN-LINE JOINTS

No additional comments.

### EC - 4.2 MATERIALS

#### EC - 4.2.1 EXISTING SPECIFICATIONS

FIBRE TETHERS 2000 JIP (1995) tension-tension fatigue tests on fibre ropes revealed failures in the metallic part of both barrel and spike and steel sockets. This infers that the fatigue life of such



steel fittings may be inadequate for the longer lifetimes of fibre ropes and further work may be required to ensure compatibility between fibre rope and steel fitting.

#### *EC - 4.2.2 OTHER MATERIALS*

No additional comments.

#### *EC - 4.2.3 CLOTH PROTECTION FOR SPLICED EYES*

No additional comments.

#### *EC - 4.2.4 BEND RESTRICTORS*

No additional comments.

#### *EC - 4.2.5 BUSHES, THIMBLES AND PINS*

No additional comments.

### EC - 4.3 TERMINATION STANDARDS, GUIDELINES AND SPECIFICATIONS

#### *EC - 4.3.1 PROTOTYPE TESTING*

The philosophy of building and testing a prototype rope is described in the OCIMF (1987) hawser guidelines. Note however that termination techniques and testing methods for deepwater fibre mooring terminations will differ from those for marine hawsers.

#### *EC - 4.3.2 TERMINATION CONSTRUCTIONAL DIFFERENCES*

No additional comments.

### EC - 4.4 TERMINATION PROPERTIES AND DIMENSIONS

This section refers to only the termination types of current interest for FPS moorings: these are **Splice**, **Barrel and Spike** and **Resin Potting Socket** and they are illustrated in Figure EC-4.4.1

#### *EC - 4.4.1 STRENGTH*

Studies [such as the Norsk Hydro JIP (1997) and TTI US NAVY(1992)] on effects of terminations on rope strength have demonstrated failures clear of spliced terminations, proving that well designed splices were used. It should be noted that the Certified Breaking Strength (CBS) of the fibre rope assembly evidently takes account of termination efficiency.

Unless special precautions are taken, the efficiency of a termination will fall off as rope size increases. A full stress analysis, taking account of stress concentrations, is needed to deal with the problem in detail, but the general principle can be simply illustrated for a potted socket. For ropes of diameter  $D$ , the rope tensions under comparable loading conditions will increase in proportion to the area of the cross-section and hence to  $D^2$ . However this force has to be transmitted to the socket through the layer of resin, which will have an adhesive force proportional to the surface area and thus to  $D$ . The effect is only partially compensated by the increased length of the socket for a large rope.

Similar arguments apply to the frictional forces in barrel-and-spike terminations. The argument will also apply to splices, if rope is divided into the same number of strands for tucks, but can be overcome by using a larger number of tuck strands in large ropes, as well as by increasing the length of the splice.

The tensile efficiency of resin socket, spliced and barrel and spike terminations was assessed in the Fibre Tethers 2000 Study (1995) for parallel yarn, parallel strand and wire rope construction ropes in aramid, HMPE and polyester materials. Termination tensile efficiency was quoted as a percentage of aggregate material strength based on the fibre manufacturer's rated strength. Note that this also includes the effects of rope strength efficiency. A summary of the tensile efficiency is shown in Table EC-4.4.1 and highlights the extent of variability in termination efficiency. Note that these efficiencies are percentages of aggregate yarn strength and therefore they may relate to strength reductions in the rope itself, when breaks are clear of terminations, or in the termination for end breaks.

**Table EC-4.4.1**

**Summary of Fibre Tethers 2000 tensile test data  
( for aramid, HMPE and polyester ropes)  
shown as percentages of aggregate yarn strength.**

Rope Nominal Breaking Load (Tonne)	% Strength Efficiency		
	Splice	Termination Type Barrel and Spike	Resin Socket
• 5	50-83	26-57	32-72
• 120	50-77	Not Tested	37

#### *EC - 4.4.2 AXIAL STIFFNESS*

No additional comments.

#### *EC - 4.4.3 TENSION-TENSION FATIGUE LIFE*

Fatigue data for 5 tonne and 120 tonne manufacturers nominal strength (MNS) ropes is shown in Figures EC-4.4.2 through to EC-4.4.4 in aramid, HMPE and polyester materials respectively. The MNS is a calculated strength using a yarn in rope tenacity of 5.5 gpd (grams per denier) for polyester, 13.3 gpd for aramid and 18 gpd for HMPE. Tests were based on these MNS values to give approximately the same stress levels so that a comparison across material, constructions and terminations could be given. A full comparison is outside the scope of this document and the Fibre Tethers 2000 (1995) study report should be referenced for further information.

As above, Figures EC-4.4.5 through EC-4.4.7 show fatigue data comparison for 120 tonne MNS ropes compared also with steel wire rope. The comparison here is made on actual breaking strength (ABS) since the data exists for all these ropes. It is clear that at typical FPS loads the fatigue life of fibre ropes is greater than steel wire ropes.

FIBRE TETHERS 2000 JIP (1995) tension-tension fatigue tests on fibre ropes revealed failures in the metallic part of both barrel and spike and steel sockets. This infers that the fatigue life of such steel fittings may be inadequate and further work may be required to ensure compatibility between fibre rope and steel fitting.

EC - 4.4.4 FLEXURAL RIGIDITY

No additional comments.

EC - 4.4.5 FORCES AND MOMENTS AT CONNECTIONS

No additional comments.

EC - 4.4.6 SPLICED EYE HARDWARE

The effects of bending moments applied to a termination by VIV, current, wave induced motion or by any other mechanism should be assessed. Such effects include fibre induced axial compression in the legs of an eye splice or in the body of a splice or where a rope enters a resin socket.

As shown in Figure EC-4.4.8 an eye splice requires a pin and spool to connect to the next component in a mooring system. Due to bending moments applied to the termination, three possibilities for slipping around the pin/spool exist; no slip, rope slip around the spool, spool slip around the pin. In the no slip case a significant tension differential could be set up in the legs of the eye as shown in Figure EC-4.4.9.

In particular the tension differential will be sensitive to the torque arm in the eye that is dependent on the radius of the rope on the spool and the geometry of the eye as shown in Figure EC-4.4.10. The limiting conditions of slip should be calculated and any possibility of axial compression assessed due to the tension differential. For tensions below 10% the number of cycles should be determined and checked against the recommendation given in DPD 5.5.

EC - 4.5 TERMINATION SELECTIONEC - 4.5.1 'BARREL AND SPIKE' TERMINATIONS

On Barrel and Spike fittings assembly is extremely simple, and well designed terminations give frequent clear breaks in tensile testing in sizes up to 150 tonne.

Details on the first barrel and spike fitting are set out in Linear Composites and U.S. Patent 4,755,076 suggests poor and variable tensile and fatigue performance for this fitting on large rope and proposes rather marginal improvements by changes in barrel materials. Note, however, that the data cited in U.K. Patent GB 2091770D were on an early version of this fitting : considerable improvements have been made over the past decade as reported after exhaustive testing by Crawford and McTernan (1988), with tensile fatigue life at least a decade better than quoted in 4,755,076.

With few exceptions, tensile fatigue failures on Barrel and Spike fittings on the short lengths of rope used in tensile tests occur at the fittings regardless of design. Such failures are believed to be due to abrasion of the constituent yarns as they move over the spike and it has been proposed to eliminate this by resin impregnation, GB 2091770D or insertion of a malleable sleeve, UK Patent Application GB 2139659A. Other versions have been proposed including references UK Patent Application GB 2118583A and Norseman Marine.

In tension bending fatigue exceptionally good performance is recently reported, Burgoyne and Hobbs (1989).

#### EC - 4.5.2 'RESIN SOCKET' TERMINATIONS

Resin or Potted Sockets are commonly used on wire rope, Metcalf (1980). Potted sockets produce full strength efficiency on small high-performance fibre ropes, Phillystran (1987 a, b). They are compact and shorter than spliced terminations.

The strength efficiency of conventional potted sockets falls off on large high-modulus synthetic fibre ropes. The principal reason is that distortion of the resin potting material relaxes tension in fibres near the centre of the socket and thus increases tension in the outer fibres. This effect becomes greater as the size of the potting cavity increases.

The performance of potted socket terminations on large ropes can be improved by dividing the socket cavity into several smaller cavities in order to reduce this distortion of the potting material. Flory (1995 a, b, 1997) performed tests on 1-1/2 inch (38 mm) diameter six-strand aramid ropes which demonstrated that dividing the large socket into smaller segments increased the terminated rope strength by over 50%. Further work needs to be performed to demonstrate the strength efficiency of this improved potted socket termination on very large fibre ropes.

The failures of resin sockets in tension/tension fatigue tend to occur at the socket exit where the abrasion resistant fibre finish may have been removed due to solvent washing and where kink band formation is most prevalent. As stated above, the principal cause of the poor performance of large potted socket terminations is shear distortion within the resin. Careful graduation of the matrix material and appropriate pre-coating, (US Patent 04510202 etc.), and the use of bend restrictors, Swart (1977), are also reported to improve performance.

#### EC - 4.5.3 'EYE SPLICE' TERMINATIONS

Recent full scale splice development work, TTI/Dupont (1997), demonstrated a high strength efficiency of 56% on a Kevlar29, 136 mm diameter wire rope construction rope that achieved 1262 tonne breaking load.

The recent Norsk Hydro JIP (1997) completed on spliced polyester ropes of up to 1500 tonne and spliced Kevlar rope of 1200 tonne concluded that no effects were revealed that should discourage continued work towards the use of ropes for offshore mooring.

On Spliced Eyes it is also possible to obtain breaks clear of splices though a considerably greater degree of skill is required than for Barrel and Spike fittings. Thus, one survey reports that on 7/7 WRC Kevlar rope a reduction in splice tensile strength variability from 13% to 6% after suitable training was achieved, with mean efficiency rising from 89% to 97% of manufacturer's list strength in consequence. Other sources indicate a coefficient of variance between four experienced splicers of 12% for 3 strand Kevlar rope with a braided cover; at a mean of 94% manufacturer's list.

Flory (1987) reports 85% of failures on braid on braid rope at the splices, though with improvements to splice techniques that percentage can be reduced.

Most of the data reported on conventional construction man-made-fibre ropes are for spliced constructions and show fatigue lives; for polyester and aramid, well above that of steel wire rope at normal working loads.

#### EC - 4.5.4 FIELD EXPERIENCE

A summarised list of rope usage with spliced and barrel-and-spike terminations is shown below to illustrate the wide variety of engineered applications where fibre ropes have already been used. No public domain data is available for resin socket ropes used in offshore mooring applications.

Some of these fibre rope systems have been designed for 20 year life taking into account tension-tension fatigue, creep and hydrolysis. In some of the applications listed below, yarn or rope residual strength was measured and gave typically between 90-100% retained strength when compared with new average strength. Since there is a margin between minimum and average strength, if this data were compared on a minimum strength basis it could be stated that the ropes still meet their design strength.

#### BARREL AND SPIKE TERMINATIONS

- polyester parallel yarn 100 tonne break load riser arch tether with around 10 years usage to date in North Sea
- polyester parallel yarn raft mooring after 20 year service in Brixham harbour

#### SPLICED TERMINATIONS

- polyester parallel yarn, 200 tonne break load, riser arch tether, with around 1 year usage to date in North Sea
- US Navy third scale polyester parallel sub-rope, 40 tonne break load, platform mooring in 890 metres water depth, for over 2 years
- supply vessel mooring, polyester parallel sub-rope, 300 tonne break load, in 300 metres water depth, for nearly 3 years in Gulf of Mexico
- semi-submersible trials, polyester parallel sub-rope, 400 tonne break load, for one year in 220 metres water depth in Campos Basin offshore Brazil
- TLP riser protection net, polyester wire rope construction, 400 tonne break load, two separate TLPs, 2 and 3 year service to date
- semi-submersible trials, polyester 7-strand wire rope construction, 400 tonne break load, for one year in 115 metres water depth in Campos Basin offshore Brazil
- swamp barge mooring, polyester parallel sub-rope, 200 tonne break load, 7 years service
- numerous meteorological buoy moorings, various constructions, polyester, nylon, aramid and HMPE ropes, substantial service history
- semi-submersible mooring trial, aramid 36 strand wire rope construction, 450 tonne break load
- buoy mooring trial, aramid wire rope construction, 93 tonne break load
- oil flowline tether, HMPE parallel strand, 250 tonne break load, located West of Scotland

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- |                                      |        |  |
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**Figures**

Figure EC-4.1.1	Classification of Terminations for Man Made Fibre Ropes
Figure EC-4.4.1	Terminations
Figure EC-4.4.2	Comparative Load/Endurance Plot : 5 and 120 Tonne Twaron 1000/1020 (Aramid)
Figure EC-4.4.3	Comparative Load/Endurance Plot : 5 and 120 Tonne Dyneema SK60 (HMPE)
Figure EC-4.4.4	Comparative Load/Endurance Plot : 5 and 120 Tonne Polyester 785/855
Figure EC-4.4.5	Comparative Wire Rope- Fibre Rope Load/Endurance Plot; Aramid
Figure EC-4.4.6	Comparative Wire Rope- Fibre Rope Load/Endurance Plot; HMPE
Figure EC-4.4.7	Comparative Wire Rope- Fibre Rope Load/Endurance Plot; Polyester
Figure EC-4.4.8	<u>Eye Splice with Pin and Spool</u>
Figure EC-4.4.9	<u>Forces in Splice due to Bending Moments at Termination</u>
Figure EC-4.4.10	<u>Slipage of Rope on Pin and Spool Termination.</u>

**Tables**

Table EC-4.4.1	<u>Summary of Fibre Tethers 2000 tensile test data( for aramid, HMPE and polyester ropes)</u>
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**Appendices**

None

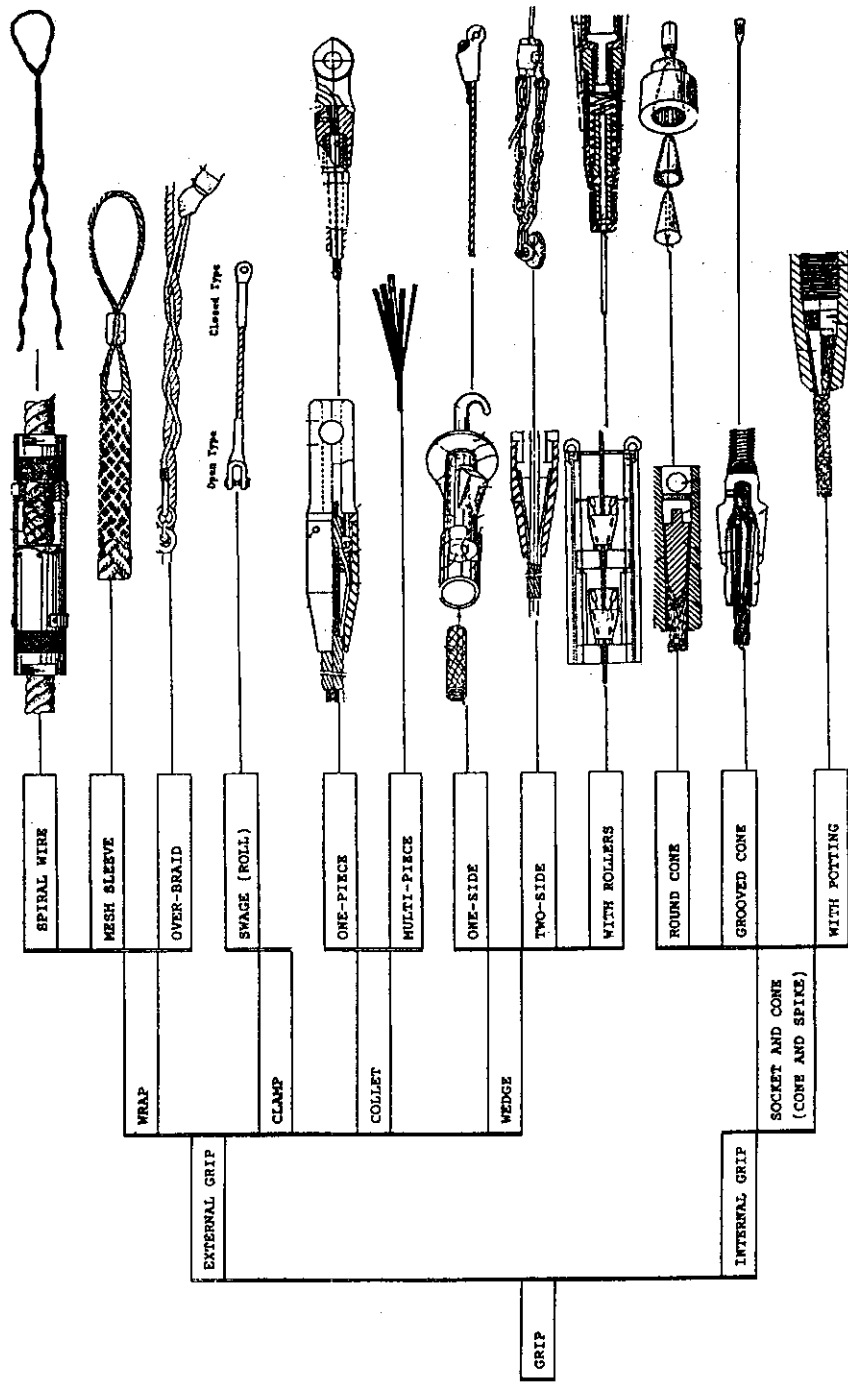


Figure EC-4.1.1(a) Classification of Terminations for Man Made Fibre Ropes

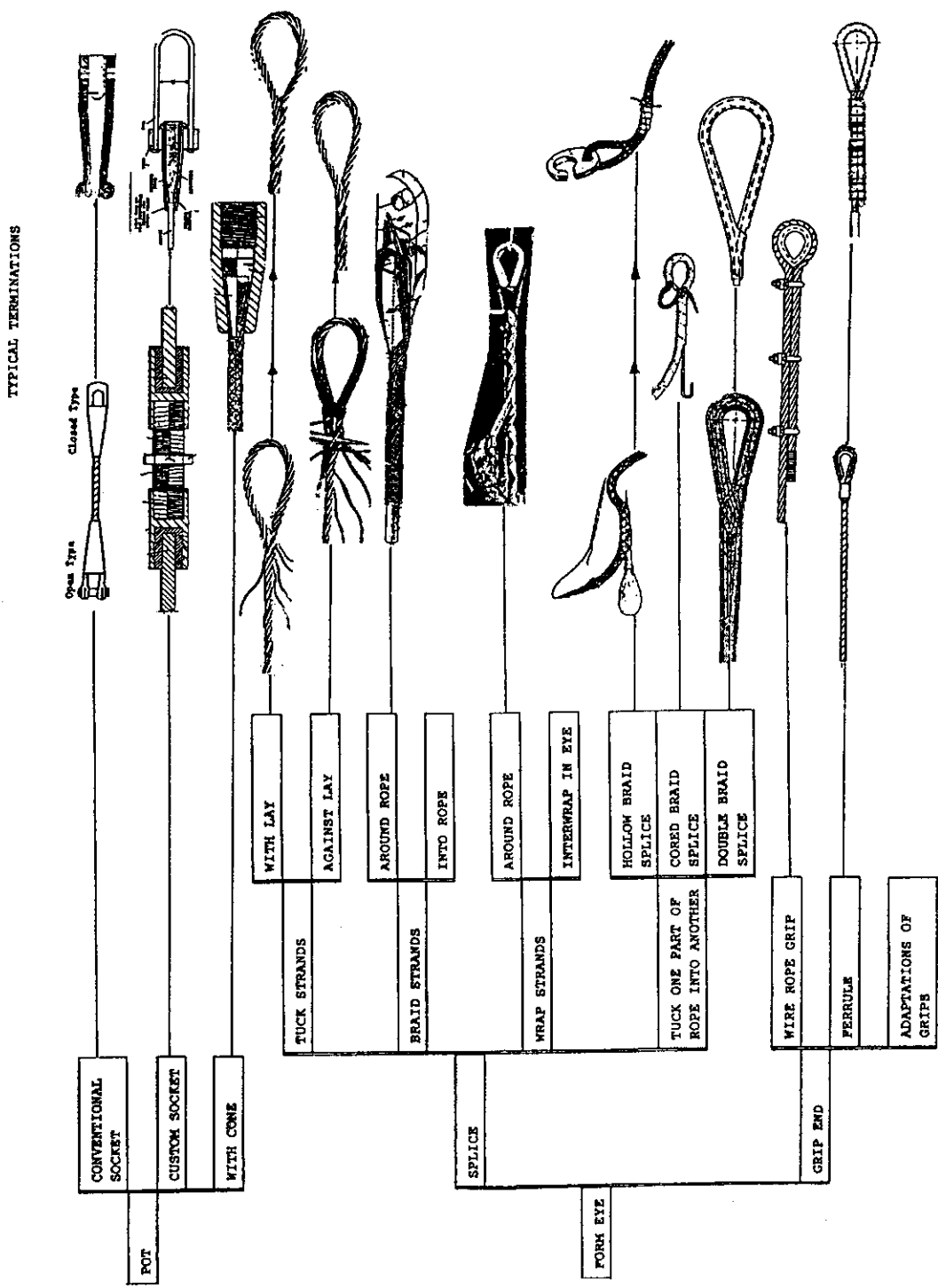
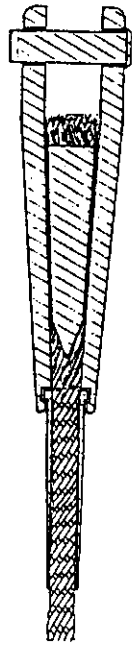
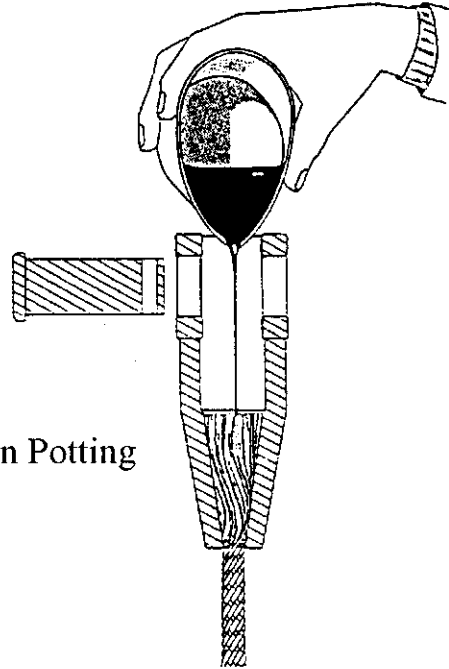


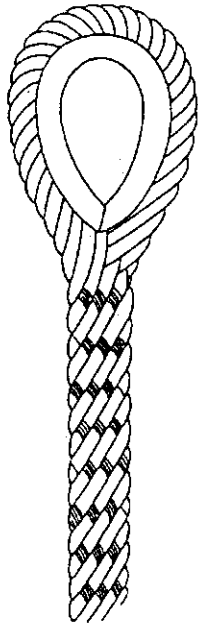
Figure EC-4.1.1(b) Classification of Terminations for Man Made Fibre Ropes (Cont.)



A - Barrel and Spike



B - Resin Potting



C - Splice

**Figure EC- 4.4.1: Terminations**

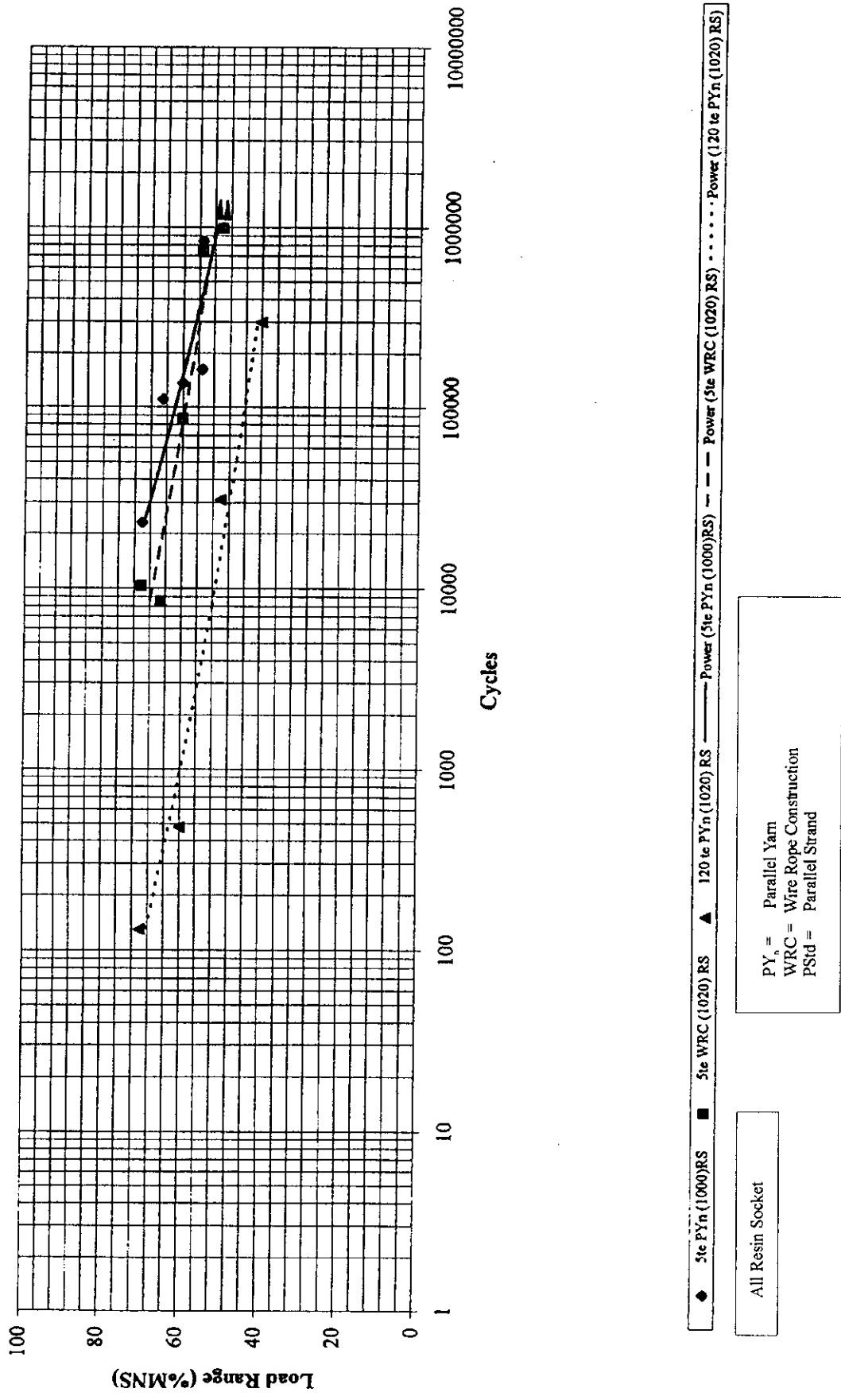
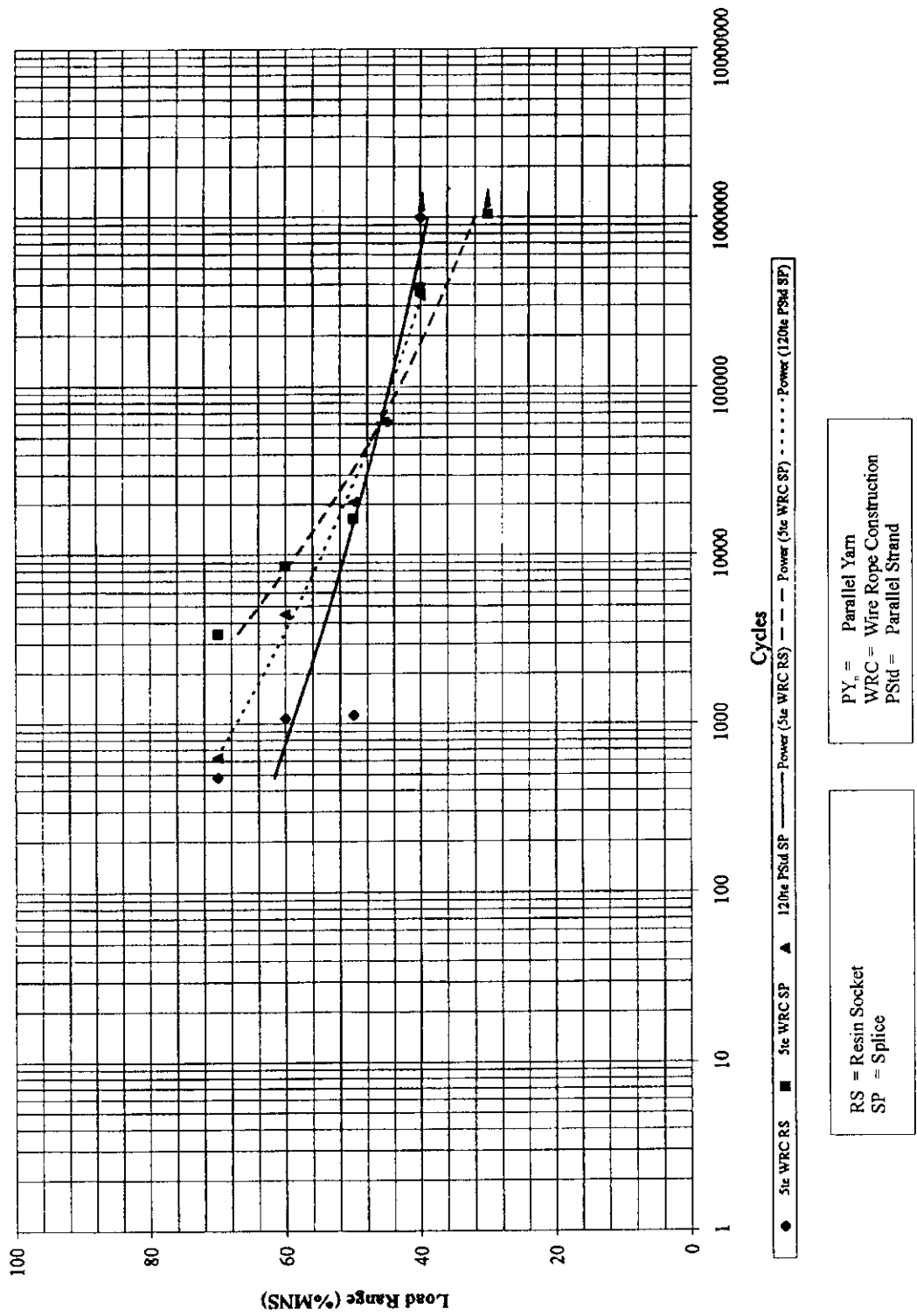


Figure EC-4.4.2: Comparative Load/Endurance Plot:5 and 120 Tonne Twaron 1000/1020 (Aramid)



**Figure EC-4.4.3 Comparative Load/Endurance Plot: 5 and 120 Tonne Dyneema SK60 (HMPE)**

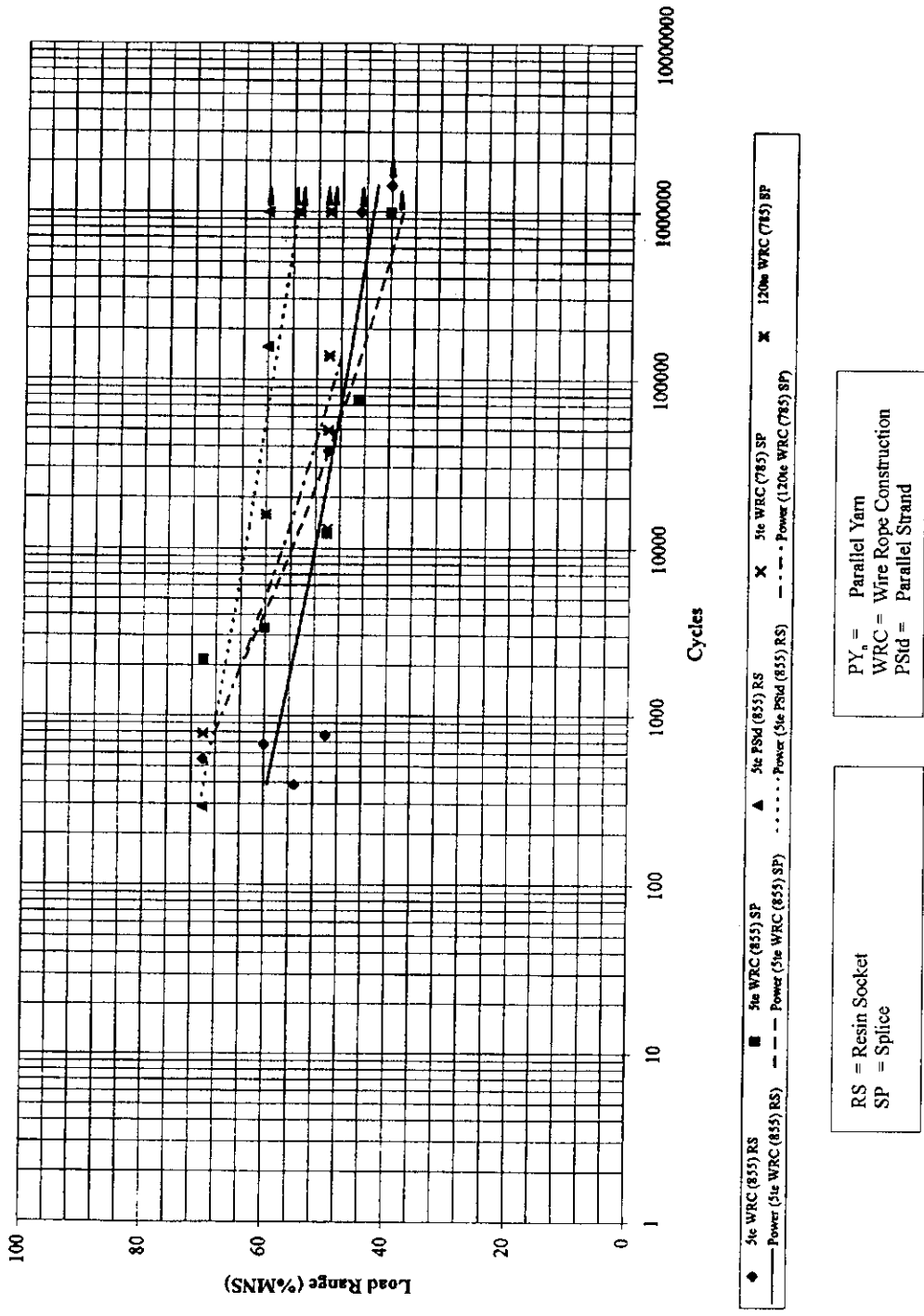


Figure EC-4.4.4 Comparative Load/Endurance Plot: 5 and 120 Tonne Polyester 785/855

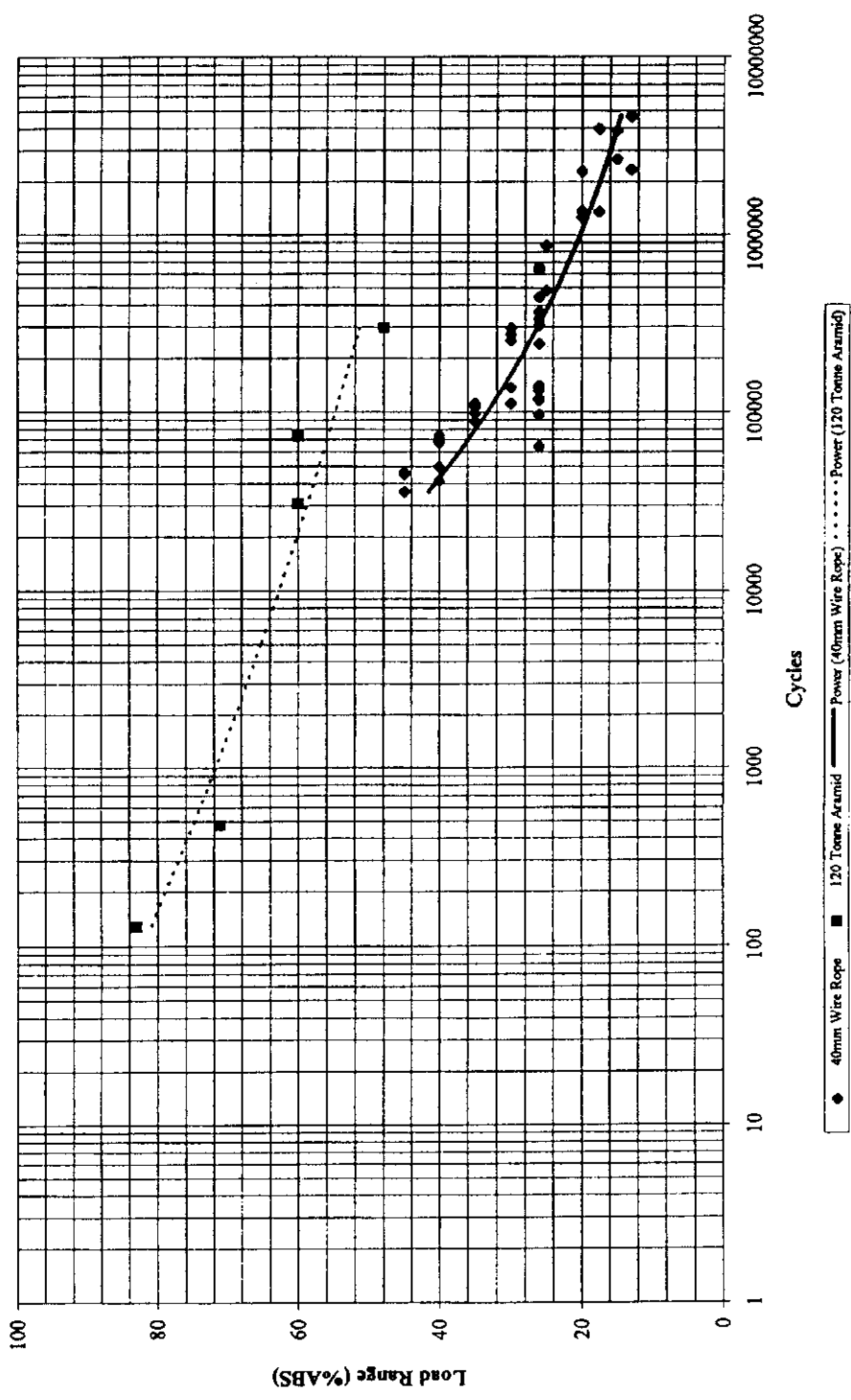


Figure EC-4.4.5 Comparative Wire Rope - Fibre Rope Load/Endurance Plot



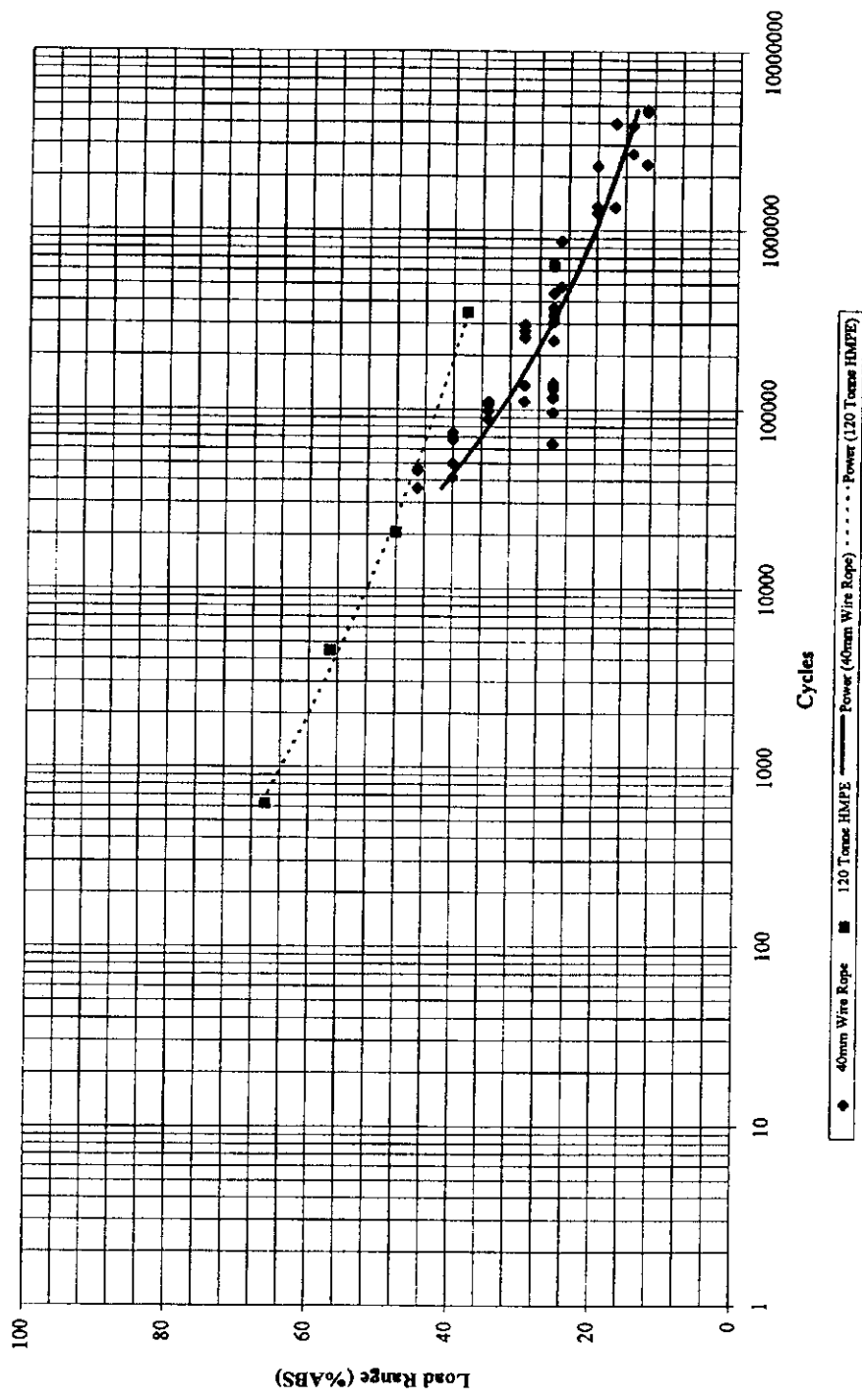


Figure EC-4.4.6 Comparative Wire Rope - Fibre Rope Load/Endurance Plot

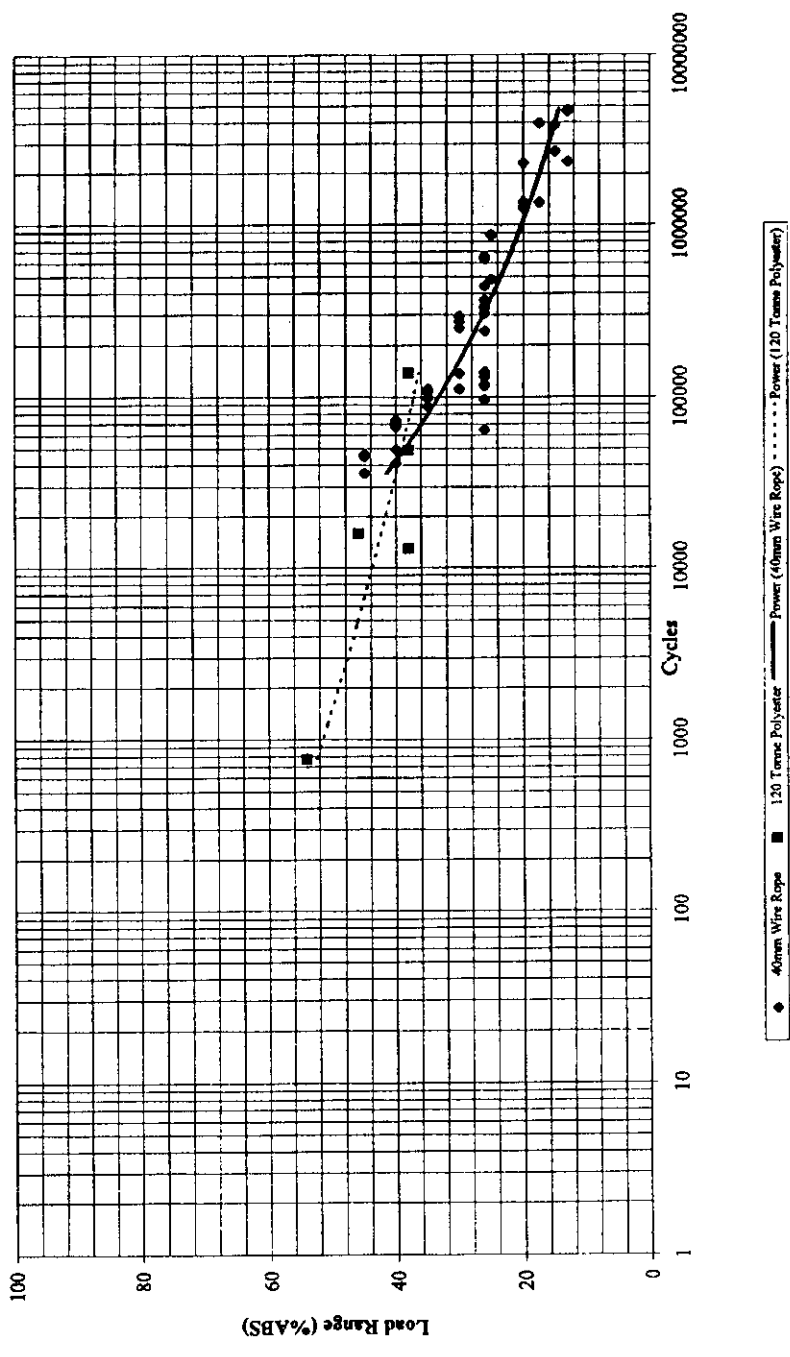
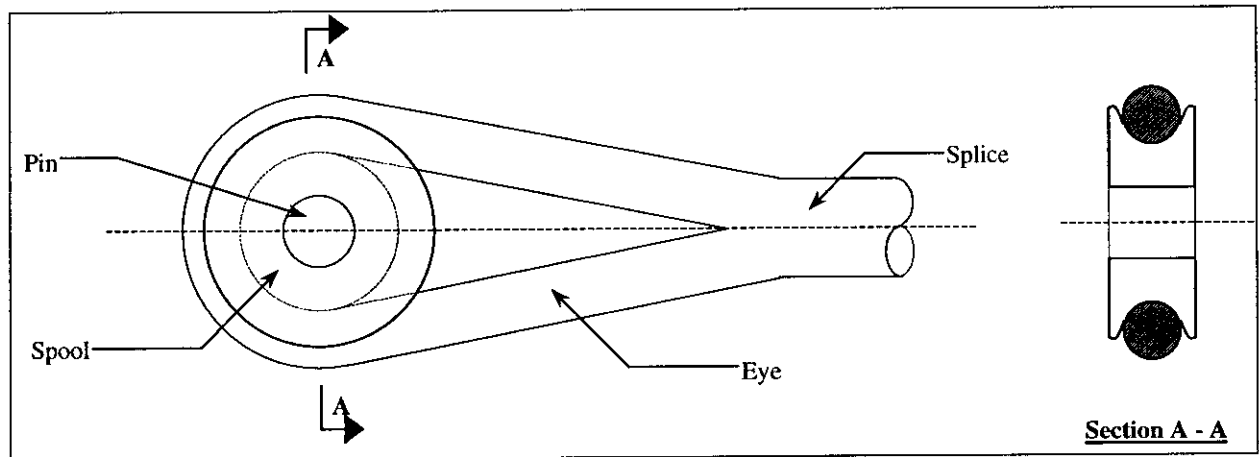


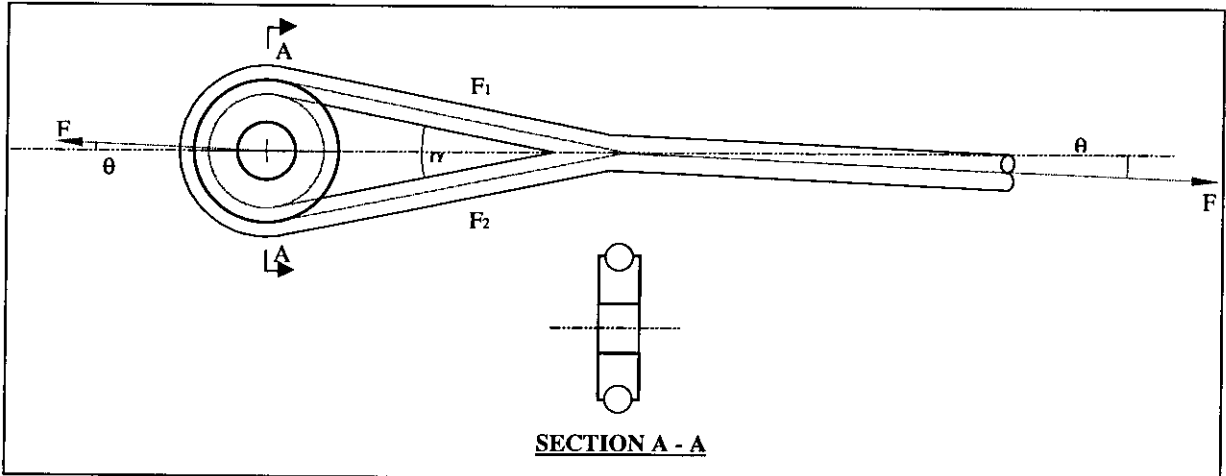
Figure EC-4.4.7 Comparative Wire Rope - Fibre Rope Load/Endurance plot



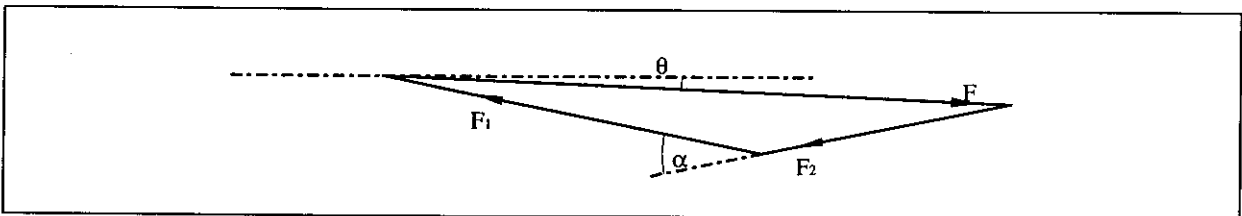
**Figure EC-4.4.8**  
**Eye Splice with Pin and Spool**



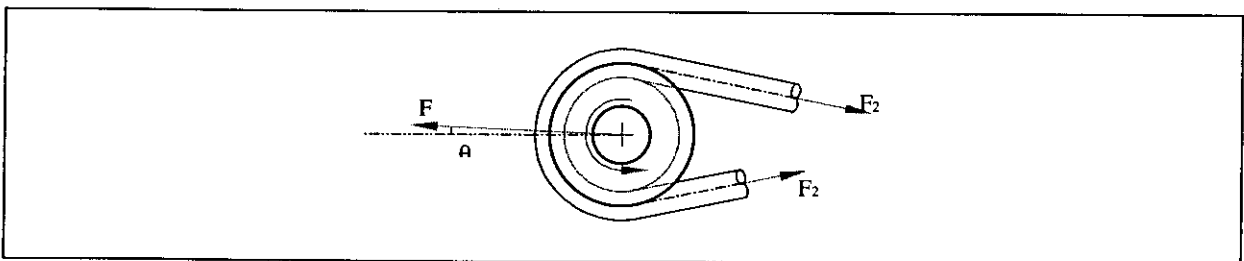
**Figure EC-4.4.9**  
**Forces In Splice Due To Bending Moments At Termination**



a) Spliced eye with line deviating from central alignment by  $\theta$  as a result of "No-Slip" at the Pin/Spool.

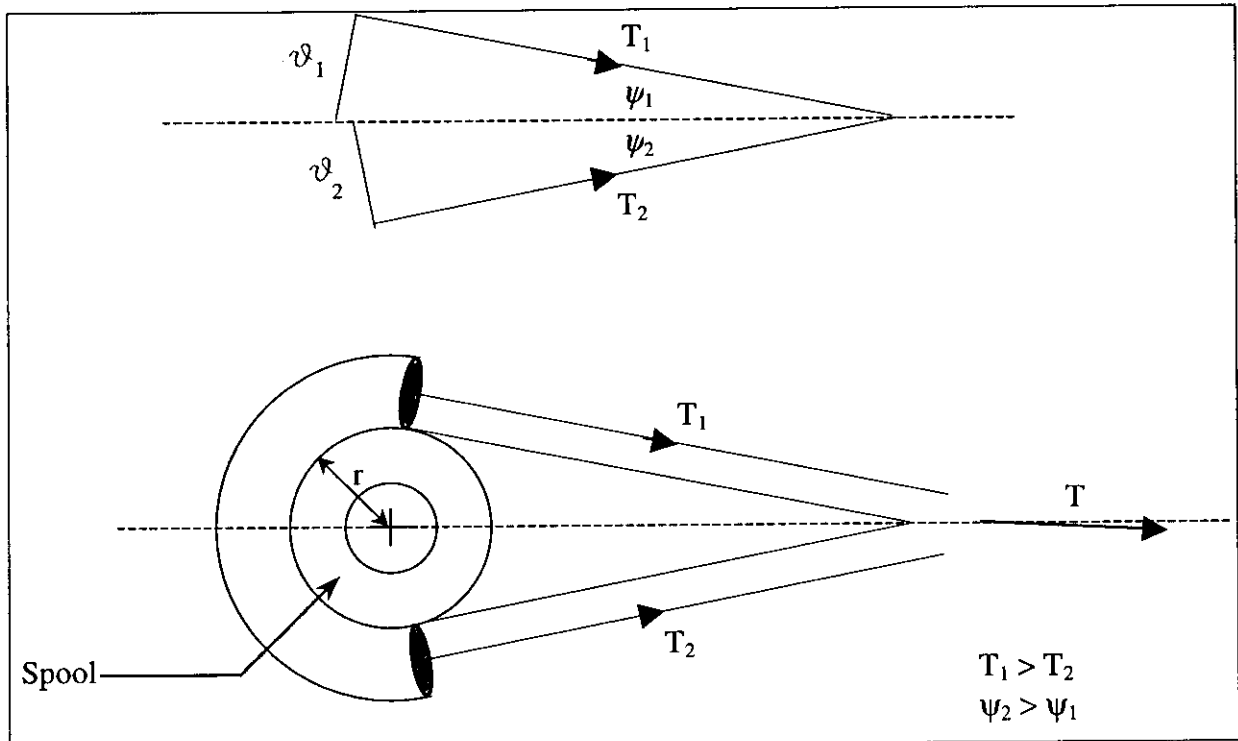


b) Force Diagram of Equilibrium Loads at splice.



c) Equilibrium Forces at Pin and Spool. Out of balance force in lines causes moment which must be carried by friction between rope and spool and spool and pin.

**Figure EC-4.4.10**  
**Slipage Of Rope On Pin And Spool Termination**



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**EC-5. ROPE ASSEMBLY PROPERTIES****EC-5.1 INTRODUCTION**

Rope assembly properties depend chiefly on rope properties, which have been referred to in basic terms in EC-3 and are treated in this Chapter in relation to practical use in deepwater moorings. Assembly properties are also influenced by terminations.

Yarn properties are the primary determinant of rope properties. However, the inherent yarn properties are modified in ropes due to the following causes, which were discussed in EC-3:

- off-axis orientation of yarns due to rope geometry
- effects of variability of yarn properties and interaction between components
- effects of internal transverse normal forces and axial frictional forces between fibres, yarns and strands
- packing of fibres, yarns and strands

**EC-5.2 SIZE AND STRENGTH**

Table EC-5.2.1 gives typical comparative values of rope weight in air and water and rope diameter for rope assemblies of 1000 tonne guaranteed minimum new wet breaking strength. These values are based on the assumption that the yarn-to-rope conversion efficiency is 65% for polyester and 50% for aramid and HMPE (conservative estimates), the packing factor is 0.7, and the yarn-to-rope contraction factor is 1.05. For other strength values, the core weights will scale with strength and the core diameter will scale with square root of weight. The sheath thickness will increase with rope size, but usually less than proportionately.

**Table EC-5.2.1  
Rope Weights And Sizes For 1000 Tonne Strength**

	polyester	aramid	HMPE	nylon
total weight in air (kg/m)	23	12	8.4	25
total weight in water (kg/m)	5.9	3.3	buoyant	2.5
typical overall diameter (mm)	175	120	125	200
nominal circumference (inches)	22	15	15.5	25

In addition to the effects of obliquity and variability referred to above, three other effects influence the effective strength of a rope. The strength/length effect and creep rupture are discussed below. The third possible effect is that strength would be reduced if substantial twist was imposed on the rope due to external torque forces. Other effects of torque are discussed in DPD-5.8 and EC-5.8.

**EC-5.2.1 STRENGTH DEFINITION**

No additional comment.

**EC-5.2.2 TYPICAL VALUES**

No additional comment.



EC-5.2.3     EFFECTS OF LENGTH ON STRENGTH

A rope will fail at its weakest place and, statistically, this must occur at a lower break load in a long length in use than in a short length as tested. A more extensive account of this effect, which has attracted the attention of theoretical statisticians and experimentalists, is given in Fibre Tethers 2000 (1995) SECTION 8.3. The conclusion is that the reduction in strength S from lengths L to NL can be estimated from coefficient of variation of strength:

$$[\text{mean } S(\text{NL}) \div \text{mean } S(\text{L})] = N^{(-\text{CV}/120)}$$

where     S(NL) is strength at effective length NL  
              S(L) is strength at test length L  
              N = factor on length  
              CV = coefficient of variation of available strength test results

If the coefficient of variation of rope strength were to exceed 3%, the reduction in strength would be likely to exceed the margin between actual break load and the manufacturers certified break strength (CBS). With good rope manufacturing practice, this variability should not be exceeded. An appropriate requirement on variability limits should be included in the rope specification.

EC-5.2.4     CREEP RUPTURE

Creep rupture occurs at lower loads than the measured new break load when ropes are subject to tension for times which are longer than the test time taken to measure new break load. This is a yarn property discussed in EC-3 and determined by a strength/time coefficient k. For the reasons mentioned in EC-5.7.2 in connection with HMPE ropes, creep is less in ropes than in yarns. A conservative estimate of rope creep rupture times will be given by the yarn equation which applies to most fibres. Rupture occurs under a load S after a time t given by:

$$S = S_g [1 - k \log(t/t_g)]$$

where  $S_g$  and  $t_g$  are the strength and time under given test conditions

Nylon is the only relevant material for which reliable values of k are in the literature. The value of k for aramid yarns is considered to be somewhat less than 0.05 and for polyester slightly greater. Table EC 5.2.2 gives values of k and times to fail at various percentages of a break load measured at 1 minute. These results indicate that creep rupture will be of negligible importance in polyester and aramid ropes under normal mooring loads. As would be expected, none of the polyester or aramid yarns tested in Fibre Tethers 2000 (1995) broke at the most severe conditions of 60% break load over many months. In modelling fatigue, creep rupture comes in as the final mechanism when the rope has been weakened, and some components broken, by other fatigue mechanisms.

The above equation does not apply to HMPE yarns, because it does not take into account the effect of plastic deformation.. The numbers of days to break in HMPE yarns in the Fibre Tethers 2000 (1995) tests are included in Table EC-5.3.2. Some HMPE yarns break in a few days at 30% of break load, but this behaviour is not representative of HMPE ropes used in moorings. As discussed further in EC-5.3.4.2, the amount of creep (1) varies considerably in different HMPE yarns, (2) depends strongly on temperature as well as load, and (3) is less in ropes than in yarns at the same percentage of break load. DSM (manufacturers of Dyneema) estimate a life of more than 35 years for a Dyneema SK60 Superline (parallel strand) rope at 30% of CBS at 10°C. Creep rupture in HMPE is further discussed in EC-5.3.4.2 in connection with creep extension.

For nylon, creep rupture is potentially a problem and the situation should be examined in the conditions applicable to any particular mooring. The value of k in Table EC-5.2.2 is for dry nylon; the creep is expected to be greater and creep rupture times may be shorter in wet nylon.

Table EC-5.2.2  
Creep Rupture (Yarn Properties)

yarn type	k	time to fail at percent of 1 minute break load			
		20%	30%	50%	80%
aramid	<0.05				
	0.05	2 x 10 <sup>10</sup> yrs	2 x 10 <sup>8</sup> yrs	2 x 10 <sup>5</sup> yrs	200hrs
polyester	>0.05				
	0.08	2 x 10 <sup>4</sup> yrs	1000 yrs	3 yrs	5 hrs
nylon	0.1	200 yrs	19 yrs	60 days	100 mins

### EC-5.3 ELONGATION AND STIFFNESS

#### EC-5.3.1 INTRODUCTION

(See also EC 3.2.1.5 EC 3.2.4)

Rope elongation depends on the current tension acting on the rope stiffness and the unrecovered elongation from prior loadings. Rope stiffness values (EA) are given as (tension/strain) in N or N/(m/m), which equals rope modulus x rope area or rope specific modulus x rope weight. The total elongation of a system will be given by multiplication by the total rope length.

The tensile properties of ropes involve two sets of complications. Firstly, the yarn stress-strain properties, as described for example in EC-2.2.1.8 for polyester yarns, are nonlinear and include combinations of instantaneous and time-dependent deformation, which may be recoverable (elastic) or non-recoverable (plastic). Secondly, as described above, the rope structure does not remain constant but is worked into new forms by loads imposed after it is made.

The precise response will depend on the choice of yarn type, rope construction and the elongation and loading pattern imposed on the rope. The study of cyclic responses has been limited to simpler sequences than are expected to be experienced by deepwater mooring lines, which will show elongation amplitudes of varying intensity, typified by moderate amplitudes over long periods interrupted by high amplitudes in storm conditions. Superimposed on the cyclic elongations, there will be mean loads which vary over time with wind and current conditions.

More research is needed on the responses of ropes under the loading conditions to be expected for deepwater moorings.

#### EC-5.3.2 STIFFNESS DEFINITIONS

Figure EC-5.3.1 illustrates schematically and approximately effects which are expected as a result of the changes in yarn properties and rope structure. The amplitudes and loads are exaggerated for clarity.

OA is the load-elongation curve for a rope as made. OBCPQ typifies pre-installation proving. The rope is loaded to B, held for a time with additional elongation to C, then unloaded to P and recovers further with time to Q. Installation would then follow QB and beyond towards A. DR is the first cycle of displacement controlled elongation about a mean load X. Continued cyclic elongation would give additional extension of the rope and eventually stabilise on the cycle ES with increased stiffness. FT is the first cycle under more severe conditions, which would go to GU after many cycles. On returning to less severe conditions, the cyclic response would settle between GU and ES.

Apart from the uncertainty and the costs of measurement for different ropes of the precise details of the tension/elongation relations shown in Figure EC-5.3.1, the complications are more than can easily be accommodated in a mooring analysis. The critical stiffnesses are therefore reduced to the minimum and maximum values shown in Figure EC-5.3.2. The minimum post-installation stiffness is an approximation to QB in Figure EC-5.3.1, and the maximum storm stiffness to FT or GU. In appropriate circumstances, when the rope has been subject to more severe cyclic loading, an intermediate stiffness value may be substituted for the minimum post-installation stiffness. Test methods for these stiffnesses are discussed in EC 9.2.3. The values should be taken as conservative estimates, which means that the post installation stiffness is the lowest expected value, since it is used in calculations of offset, and the storm stiffness is the highest expected value, since this is used in calculations of peak tensions.

Over the range of frequencies experienced by offshore moorings, frequency does not have an appreciable effect on stiffness values, except to a small extent for HMPE ropes.

EC-5.3.3 TYPICAL ROPE STIFFNESSES

Figure EC-5.3.2 is based on seven sets of experimental data on parallel yarn, parallel strand and wire rope construction polyester ropes. Table EC-5.3.1 also includes the stiffness values for aramid and HMPE ropes.

**Table EC-5.3.1**

**Typical stiffness values for parallel yarn, parallel strand, and wire-rope construction ropes  
(based on a 10,000 kN (≈1,000 tonne) Breaking Strength Rope)**

<u>rope material</u>	<u>Post-installed stiffness</u>	<u>Intermediate stiffness</u>	<u>Storm stiffness</u>
	<u>E.A(Post-Inst)/kN</u>	<u>E.A(Int)/kN</u>	<u>E.A(Storm)/kN</u>
<u>polyester</u>	<u>100,000</u>	<u>100,000-300,000</u>	<u>300,000-450,000</u>
<u>aramid</u>	<u>330,000</u>	<u>330,000-600,000</u>	<u>600,000</u>
<u>HMPE</u>	<u>350,000</u>	<u>350,000-700,000</u>	<u>700,000</u>

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EC-5.3.4 UNRECOVERED ELONGATIONEC - 5.3.4.1 Elongation And Creep

As described in EC-5.3.4.2, rope elongation, in addition to that due to bedding-in of the rope structure, is due to yarn elongation. This yarn elongation consists of: (1) instantaneous elastic extensions; (2) primary creep, which is recoverable in time; (3) secondary creep, which is not recoverable. Secondary creep can take two forms. It may be due to a pulling-out of local irregularities in the packing of the molecules. This is the reason for the creep under low loads in aramid fibres, which also causes the upward curvature in the initial slope of the stress/strain curve, and it does not lead to creep rupture. Plastic creep, which terminates in creep rupture, is due to whole molecules sliding past one another.

In most fibres the amount of creep is approximately constant in each equal interval of log(time) under a given load. Table EC-5.3.2 gives values for creep in one decade of log(time) at 15%, 30% and 60% of break load for yarns tested in Fibre Tethers 2000 (1995). Figure EC-5.3.3 shows how the extension of three typical yarns varies with time. For reasons discussed in EC-5.3.4.2 below in connection with HMPE, creep in ropes is expected to be less than in yarns.

**Table EC-5.3.2**  
**Creep Data for Fibre Materials**

Creep in one decade of log(time) from Fibre Tethers 2000 (1995)

at:

	15% break load		30% break load		60% break load	
	1-10	10-100	1-10	10-100	1-10	10-100
	days	days	days	days	days	days
<b>POLYESTER</b>						
• Diolen 855TN	0.240	0.166	0.093	0.034	0.195	0.172
• Trevira 785	0.119	0.069	0.165	0.009	0.298	0.266
• Seaguard IW81	0.216					
<b>ARAMID</b>						
• Kevlar 29	0.023	0.066	0.046	0.021	0.055	0.004
• Kevlar 49	0.011	0.030	0.041	0.009		
• Kavlar 129	0.050	0.010	0.027	0.022		
• Twaron 1000	0.051	0.022	0.061	0.029	0.029	
• Twaron 1111	0.026	0.036	0.042	0.020	0.056	0.072
• Twaron 1055	0.013		0.022		0.018	0.038
• Technora HM50	0.026	0.008	0.012	0.009	0.060	0.090
<b>HMPE: numbers in brackets are (time to onset of rapid creep; days to break)</b>						
• Spectra 900	1.7	13	=	=		
	(7 days; 182 days)		(17 hours; 4days)			
• Spectra 1000	1.1	6.3	8	=		
	(11 days; 331 days)		(1 day; 28 days)			
• Dyneema SK60	0.16	0.47	0.98	8		
	(70 days; > 354 days)		(7 days; 123 days)			

**EC - 5.3.4.2 Creep Of HMPE Ropes**

The estimates of creep rupture times in EC-Table 5.2.2. and the results of the Fibre Tethers 2000 (1995) tests on yarns in EC-Table 5.3.2 above shows very short rupture times and large creep extensions in HMPE. Figure EC-5.3.3 shows that, unlike the other yarns which show equal creep elongation in each decade of log (time), creep in HMPE yarns increases when plotted against log (time). After a critical time under a given load HMPE reaches a plateau creep rate at long times when plotted against time. However the practical situation in suitably selected HMPE mooring ropes is less severe than this suggests for the following reasons:

- As can be seen from the Tables, creep varies greatly among different HMPE yarns. Some of those introduced since Fibre Tethers 2000 study may have still lower creep. The creep properties of HMPE yarns selected for mooring lines should be verified with the fibre manufacturer.

- Creep of HMPE is very sensitive to temperature. This is illustrated in Figure EC-5.3.4. Note that the creep rate scale is logarithmic: creep at 20°C is 50 times faster than creep at 0°C. The Fibre Tethers 2000 tests were done at 20°C. In many deepwater moorings the temperature will be around 10°C and the creep will be less.
- Creep in ropes is less than in yarns under the same percentage of break load. This has been verified in tests on small Dyneema ropes by DSM, who report the following equation:

$$\text{creep of rope at } X\% \text{ of break load} = \text{creep of yarn at } (AX)\% \text{ of break load}$$

$$\text{where } A = \text{strength conversion factor}$$

$$= (\text{rope specific strength} / \text{yarn specific strength})$$

For the ropes recommended for deepwater moorings, A is given as 0.75 in Table EC-3.2.2.

The theoretical reason for this effect is most easily explained by reference to a simple twisted yarn as shown in Figure EC-5.3.5. The more complicated geometry of a rope will change the detail, but not the principles involved. When the yarn (or rope) is extended by a certain amount, the extensions of the individual fibres will vary. Partly this is due to obliquity: strain is proportional to  $\cos^2\theta$  and will vary from a value equal to the strain on the yarn for a straight fibre at the centre to a much lower value for the fibres following a highly inclined path on the surface. The other cause is constructional variability. Particularly in a rope, the strains will vary if components have been introduced at variable tensions, thus giving lengths which do not match those required by the geometry. For these two reasons, individual components will be under different tensile stresses in an extended yarn or rope. Those which are most highly tensioned would tend to creep more than those which are less tensioned. However the system has to extend as whole. It is not possible for some components to contribute a greater axial elongation in the system than others; all must extend together. Therefore the creep must be related to the average stress on the filaments in the yarn or rope. This will, at least approximately, correspond to that given by the use of the strength conversion factor.

Further information on reversible and irreversible elongation in Dyneema ropes is given in a DSM Technical Bulletin reproduced as Appendix 2.3. This states that the plastic creep only occurs above a threshold load dependent on temperature. In another communication, DSM say that, as a rule of thumb, there is negligible creep at 20°C up to 20% of ropes CBS (or approximately 10% in yarns), and at 10°C there is very small creep up to 30% CBS. A specific calculation for Dyneema SK60 Superline (parallel stand) at 10°C at 30% CBS gives an expected life of 38 years.

The extent of creep in HMPE ropes, if measured at intervals along the rope during retensioning operations, can be used to give a crude indication of when a rope is approaching its break point. DSM state that the real failure point of Dyneema ropes is at 25% extension. Ropes should be taken out of service at a safe interval before this value is reached.

## EC-5.4 HYSSTERESIS HEATING AND DAMPING

### EC-5.4.1 HYSSTERESIS HEATING

As shown in Figure EC-5.3.1, loading and unloading follow different curves and form a hysteresis loop. This has two important consequences for mooring lines: (1) the resultant damping influences the dynamic response of the system; (2) the energy loss is dissipated as heat, which raises the temperature and changes yarn properties.

Hysteresis is due to two causes. The major effect, at least in polyester ropes at small strain amplitudes, is the material inelasticity, which is described in EC-2.2.1.8. The other cause is frictional loss between components. This takes place between fibres in yarns, between yarns in strands, and between strands, and becomes important at large strain amplitudes in storm conditions. During deformation of twisted or braided structures, various forms of axial slippage or scissoring actions can occur. The simplest manifestation of this is the shear which accompanies the elongation of a helical structure and which can be relieved by slip between neighbouring components.

Leech et al (1993) describe how the normal loads, frictional forces and amount of slip occurring during elongation of twisted ropes can be computed. In a related paper, Hearle et al (1993) describe further computer programs, developed by TTI, which enable heat build-up to be predicted provided the right input data on energy loss parameters (see Note at end of Appendix 1.3) and thermal diffusivity (density  $\times$  specific heat / thermal conductivity) is available. The paper by Bosman (1996), referred to in EC-2.2.1.8 indicates that particular care is needed to get the correct value of  $\tan \delta$ . Figure EC-5.4.1 from Bosman (1996) shows that  $\tan \delta$  values for a small rope follow the yarn values, but are larger due to the frictional losses. There is also uncertainty about the thermal conductivity in ropes, any air pockets will have effectively zero conductivity, and the conductivity of the fibre materials is several times less than water.

Current industry studies are providing actual measurements of the increase of temperature during cyclic loading of large ropes and analysis of the factors involved. In addition to providing immediately useful data, these also give a way of checking the computer predictions. If the programs or the input are modified to fit real data, they can be used to provide good estimates in parametric studies of other ropes of similar construction. These studies will also indicate conservative estimates of the maximum levels of strain amplitude for which heating effects can be ignored. The general conclusion from the tests on large polyester ropes in Norsk Hydro (1997) studies is illustrated schematically in Figure EC-5.4.2. For strain amplitudes less than 0.25%, the damping factor is low and little heating will occur. At higher strain amplitudes, the damping factor increases rapidly and may cause considerable heating. If such conditions are expected, additional tests or analysis will be needed.

Some comments on the effect of temperature on yarns were included in EC-2. The consequences of an increase in temperature are as follows.

(1) Reversible factors, which will influence the mechanical response of moorings.

- Tensile stress/strain and other mechanical properties will change. As indicated in Figure EC-2.2.6, strength and stiffness decrease and extension increases.
- At the so-called glass transition, the modulus will decrease and the loss factor will go through a peak, as shown in Figure EC-2.2.7.

(2) Permanent changes.

- Secondary creep, leading to creep rupture, will increase in rate.
- Fatigue lives may be increased or decreased.
- Hydrolysis (see EC-5.10), or other reactions in chemically active environments, will become faster.
- At high enough temperature, melting or severe chemical degradation will destroy the fibres. As temperatures beyond about 100°C below the melting point, fibres become soft and will suffer major permanent deformation when forces are applied.

In addition to taking account of changes in strength and stiffness, as needed for mooring analysis, it is necessary to ensure that the yarns in ropes do not exceed safe working temperatures over long periods of time or exceed the higher limits acceptable for short times. Table EC-5.4.1 summarises the effects of temperature; the changes in strength and modulus are at near ambient temperatures.

Table EC-5.4.1

<b>Temperature limits: information from yarn manufactures and other sources</b>				
	polyester	aramid	HMPE	nylon
<b>safe working temperature</b>				
long-time	50°C		60°C	60°C
short-time	200°C		80°C	70°C
melting-point	258°C	430°C <sup>1</sup>	150°C	260°C
<b>approximate values for:</b>				
drop in strength per 10°C	2.5% <sup>2</sup>		6%	2.5%
drop in modulus per 10°C	3% <sup>2</sup>		4%	3%

## NOTES:

<sup>1</sup> does not melt; onset of rapid degradation<sup>2</sup> from Figure EC-2.2.6; additional data in Appendix 2.2EC-5.4.2 *DAMPING*

Available data is listed in Table EC-5.4.2.

Table EC-5.4.2  
Comparison of Line Hysteresis Damping Factors

Rope Material and Construction	Line Hysteresis Damping Factor
Polyester, parallel strand	0.03 <sup>1</sup>
Steel wire rope	0.06 <sup>2</sup>

Notes: <sup>1</sup> 20% Mean +/- 10% Load Range<sup>2</sup> 20% Mean +/- 14% Load RangeEC-5.5 *FATIGUE*EC-5.5.1 *FATIGUE EXCITATION MODES*

The various factors that lead to a deterioration in rope properties, particularly those liable to cause breakage, were discussed in the Fibre Tethers 2000 State-Of-The-Art Report and data on the most relevant effects were obtained in that joint industry study and are included in the Fibre Tethers 2000 (1995) Report and its Appendices.



This section is concerned with fatigue effects occurring within ropes under cyclic loading. Of the six mechanisms identified by Parsey and discussed by Hearle et al (1993), *creep* has been dealt with above. It is invariably involved in the final stages of failure when other mechanisms have caused yarns to fail, so that the residual tensions on the remaining yarns reach levels at which creep rupture becomes important. *Hysteresis heating*, which will reduce yarn strengths and is likely to accelerate other fatigue modes, has been dealt with in EC-5.4. The *tension-tension* fatigue mechanism in nylon and polyester fibres, when cycled down to zero load, should not occur in mooring lines maintained under tension. *Structural fatigue*, which results from disturbances of the internal rope geometry, is also unlikely in ropes kept under tension providing the installation guidelines in DPD 12 are strictly adhered to.

*Axial compression fatigue* was a major source of loss of strength and of failure during fatigue tests in the Fibre Tethers 2000 joint industry study and is discussed in full in EC 5.5.3.

Axial compression fatigue is a potential problem, and it is certainly a cause for concern with high-modulus fibres. Even with polyester ropes axial compression fatigue may develop in certain circumstances. The total system should therefore be designed and used so as to avoid its occurrence. As described in DPD-5.5.3.

*Internal abrasion* is the sixth fatigue mechanism. It is a severe problem in wet braided or highly twisted nylon ropes and occurs to a lesser extent with other fibres. Damage in the form of peeling away of the surface of fibres, or, in nylon, cracks running across the fibres at an angle of about 10°, is due to the shear stresses generated when fibres slide against another. The incidence of abrasion is therefore greatly affected by the finish applied to the yarn, and special low-friction finishes are applied to yarns for use in marine ropes. There is only limited information on how long such finishes will remain effective.

Internal abrasion will occur to some extent in mooring lines, but, with a suitable choice of yarn, is unlikely to be a serious problem in low-twist ropes under the comparatively low tensions acting during most of the design lifetime. The occasional higher tensions in storm conditions will not act for long enough to cause much greater abrasion. Pathological studies on polyester ropes after extended testing have shown internal abrasion to be negligible.

#### EC-5.5.2      *FATIGUE DESIGN LIFE*

Fibre mooring assemblies are subject to tensile fatigue loading due to wave action. Bend-over-sheave fatigue loading will be limited to any which occurs in deployment or retrieval operations. Free bending fatigue of ropes under tension will be minimal provided the terminations are properly articulated.

Data on the tension-tension fatigue performance of large spliced conventional polyester fibre rope were analysed by Marlow Ropes, NEL and TTI in the 1980's. The lower 95% confidence limit for all polyester fibre ropes from all those analyses is re-plotted in Figure EC-5.5.1 onto the API RP 2SK design curves.

Subsequent data on the newer low twist polyester constructions for FPS moorings shows that the mean fatigue life of properly spliced polyester low twist ropes exceeds that of wire rope at normal working loads. Tension-tension fatigue variability does not appear to be significantly greater.

Bend-over-sheave fatigue life is generally superior to that of wire ropes at loadings under 30% of break. Whereas polyester ropes outperform high modulus fibre ropes at a given D/d, their performance will usually be inferior over any given sheave because of their higher diameter. Nevertheless, calculations show that bending performance should be more than adequate in deployment for polyester ropes of up to 1500 tonne breaking load from pipe-laying vessels.

The more limited published work on tension-bend show that parallel filament ropes perform adequately at flex angles up to  $\pm 1.5$  degrees at terminations and that, indeed, failures occur clear of the termination.

Detailed references are set out in Appendix 5.1

### EC-5.5.3 AXIAL COMPRESSION FATIGUE

#### EC - 5.5.3.1 Axial Compression Fatigue In Rope

Axial compression fatigue was a major source of loss of strength and caused some failures during fatigue tests in the Fibre Tethers 2000 joint industry study.

Axial compression fatigue has also been a cause of failure in a splice in large rope test by Aker Omega, when the tension was always substantially more than 10% of break load. This failure is further discussed below under Terminations. Other data includes axial compression fatigue on basic yarns extensively referenced in Fibre Tethers 2000 (1995), on polyester tow lines (Parsey et al, 1989) and on aramid and steel rope (Whitehall and Whitehall, 1995).

Axial compression fatigue occurs when a rope component goes into compression, and causes buckling of fibres into sharp kinks. On the inside of the bends in the fibres, internal molecular kink-bands develop, and after repeated cycling these lead to rupture. Yarn buckling data in the Fibre Tethers 2000 Report (1995) show that the effect is very severe in aramids, which will begin to lose strength around 1000 cycles and will not survive more than about 20,000 cycles. HMPE, at 20,000 and 200,000 cycles, and polyester, at 50,000 and 1,000,000 cycles are much less severely affected.

Axial compression in the Fibre Tethers 2000 rope tests occurred in tension-tension cycling. There are two reasons why individual yarns or strands can suffer axial compression, even though the rope as a whole is always under tension. The first cause is rope twisting, which causes some components to follow shorter paths. This can occur either when a rope, which is not torque-balanced, develops torque under tension and twists against a softer termination, such as an eye-splice, or when torque is generated by a termination, or when there is variability along a rope that is not torque-balanced, so that one section twists against another (See below).

The second cause is when there is differential tension among the rope components. This can happen when strands or yarns are formed into the rope under different tensions, so that they have different natural lengths. At zero or low tension on the whole rope, some components will be in compression and some will be in tension. A particular case of the effect is when the jacket is under higher tension than the main rope, so that it forces the core into compression until enough tension is applied to the rope. This is the situation with an excessively tight braided jacket. The tightness of the jacket implies tension in the yarns of the jacket, so that the circumferential component of the forces grip the core tightly. However there must also be an axial component of the yarn forces, which provides the jacket tension. It is therefore necessary to achieve a suitable jacket tightness, since other problems would arise with jackets that are too sloppy. Another case is differential creep between core and outer yarns in consequence of the tension gradient between them, again forcing the core yarns into compression.

An analysis of such mechanisms and their modelling by a computer program (Tension Technology International, 1994) has been described by Hearle et al (1995) and Hobbs et al (1995). Following a model for the buckling of pipelines, the form of buckling of fibres and yarns within a rope has been analysed. The components, subject to axial compressive force, are restrained laterally by transverse pressure from the surrounding yarns but can slip axially against frictional forces. The pipeline model, which covers elastic buckling, was extended to cover elastic-plastic bending. The prediction is that sharp kinks can occur in groups separated by unknicked lengths. The predicted form is similar to that found in fibres and yarns in ropes which have suffered axial compression fatigue in Fibre Tethers 2000 (1995) tests.

EC - 5.5.3.2 Axial Compression Fatigue Near Or At Terminations

Axial compression fatigue frequently occurs near rope terminations due to localisation of twists and bending. It has also been observed within the terminations themselves.

Thus typical Resin Socket and Barrel and Spike termination and some types of splice designs grasp only the outer fibres of the rope or of the individual strands. Under high load, the inner fibres can move laterally relative to the outer fibres, causing a redistribution of stresses and increasing the stress in the outer fibres. When the load is then reduced, this maldistribution of stress is locked into the rope and into individually strands by internal friction. Then the less highly stressed inner fibres can experience axial compression when the load is reduced, even though tension remains on the rope.

In potted sockets on aramid ropes, this condition can occur when the potting material distorts, but it can be reduced or alleviated by dividing the potting socket into smaller segments, Flory (1995).

Axial compression fatigue was the principle cause of failure in the splices of aramid ropes tested in the "Deep Water Aramid Rope" tests by Aker Omega (1993). An investigation of those failures by Flory (1996) developed recommendations for avoiding this form of rope failure.

EC-5.6 STRENGTH FALL-OFF DURING DESIGN LIFE

Although experimental data is limited, in extent and duration the expectation is that, as with wire ropes, there would usually be little decrease in strength until the number of cycles was close to the final fatigue failure, when a rapid drop in strength would occur. One known exception to this in wet braided or highly twisted ropes where internal abrasion cuts through fibres and leads to a continuous reduction in strength.

Data on the retained strength of some polyester mooring ropes in both laboratory and field conditions as set out in Figure EC-5.6.1

EC-5.7 DELAYED ELASTIC RECOVERY

Delayed elastic recovery is a consequence of primary creep, which is recoverable in time. This means that after the application of a high load for a period of time, followed by its removal or reduction, fibres will contract in length - or, if the retraction is restrained, will increase in tension. This can lead to length decrease or tension increase in ropes after a storm

EC-5.8 TORQUE AND TWIST EFFECTS

A simple twisted structure will have a natural tendency to untwist and increase in length when it is put under tension. Alternatively, if it is held in rigid terminations, which cannot rotate, torque will be generated. The torque can be calculated from the circumferential components of the yarn tensions. In twisted ropes, with components at the same or different levels twisted in opposite directions, the effects are more complicated. Computer programs, such as OPTTI-ROPE, have facilities for calculating the full tension / torque / length / twist response. With suitable design, torque-balanced ropes can be produced in which the twist levels and directions are selected so that only minimal torque develops under tension.

EC-5.9 MINIMUM BENDING RADIUS

The simple analysis of bending of a circular rod under zero tension indicates that the material on the outside of the bend will be under tension and on the inside under compression, with a neutral plane in the middle. This model is changed for ropes for two reasons. Firstly, buckling under compression occurs at lower stresses than in equal extensions under tension. Consequently, the neutral plane will move towards the outside of the bend, relieve the tensions and increase the extent of axial contraction on the inside. Secondly, since components in a twisted structure run from one side to the other in the rope, or in individual rope components, stresses can be reduced by slippage with material on the inside, with excess length, being pulled towards the outside.

If the rope is under tension when it is bent, the compression will obviously be reduced and the tensions increased.

EC-5.10 OTHER ENVIRONMENTAL EFFECTS

Data on the loss of strength of polyester yarns due to hydrolysis is given in Table EC-5.10.1, based on studies by Burgoyne and Merii (1993). Long times at relatively high temperatures are needed to cause appreciable strength loss.

**Table EC-5.10.1**  
**Effects of Hydrolysis on a Polyester Yarn**

Temperature deg C	Time For Strength To Fall To :		
	90 % BL	70 % BL	50 % BL
	where BL = breaking load		
0	6310 years	25119 years	63096 years
20	200 years	794 years	1995 years
40	10 years	50 years	100 years
60	290 days	3 years	9 years
80	29 days	145 days	258 days
100	3 days	18 days	46 days

A comprehensive study of hydrolysis in aramid (Kevlar 29) fibres is reported by Knoff et al , who reference several field trials in sea-water where strength retention has been good. Their own laboratory experiments at various temperatures and pH values lasted for 3 years, and enabled them to develop a predictive formula. Figure EC-5.10.1 shows the expected loss of strength at 20°C and pH7. At lower temperatures the loss will be smaller, but it will be greater at higher temperatures and non-neutral pH. They conclude: "The expected strength retention of Kevlar aramid fibre in sea water at pH = 7 and T = 20°C is 78%. This value is in the range for successful long term underwater applications." On the basis, the effects of hydrolysis will be negligible for typical deepwater moorings to last 20 years at around 10°C.

A number of other possible causes of deterioration in rope properties, namely fish bites, external abrasion, UV-light degradation and other environmental effects, are dependent on the rope jacket and are discussed in EC-3.3.

EC-5.11 HEALTH, SAFETY AND ENVIRONMENTAL CONSIDERATIONSEC-5.11.1 SNAP BACK AT FAILURE

Ropes under tension store huge amounts of energy, which is released when they break. In uncontrolled conditions in air this causes high-speed snap-back which can and has caused serious injuries and death. The effects of energy release will be damped when break occurs in water.

EC-5.11.2 ENVIRONMENTAL POLLUTION

No additional comment.

EC-5.12 EFFECT OF WATER DEPTH

The question of whether the hydrostatic stress at large water depths influences the properties of fibre ropes has been raised by potential users. The hydrostatic stress at 1000 meters is 10MPa, which is about 1% of the strength of polyester or nylon yarns and a smaller fraction of other high performance yarns, and consequently there is likely to be a negligible effect on the fibre properties. However, there are other aspects of the influence of depth to be considered. The fact that a rope is close to being neutrally buoyant means that its weight does not have an appreciable effect on the overall tension in the rope, in the sense that no force would be needed at the top to support a freely hanging rope, but this does not mean that there is no effect on the variation of stress along the rope. A full analysis of these effects needs to be carried out, but the following arguments show what must be examined and predicted.

It is simplest to first consider the rope as a long, stretched, vertical tether attached to a rigid fixture at the seabed, as shown in Figure EC-5.12.1. If the rope weight per unit length is  $W$  and the tension at the top of the rope is  $T_1$ , then it is clear from the figure that the tension down the rope reduces to values at depths  $h$  according to the equation:

$$T = T_1 - Wgh$$

(If the rope had been hanging freely, there would be a hydrostatic pressure acting on the base of the tether, which would provide the compressive force indicated by the above equation when  $T_1$  is zero.)

For a tether of length  $H$ , equal to the water depth, there is necessarily a tension difference  $WgH$  between top and bottom. If the elongation of the rope is  $X$  and the rope stiffness (force/strain) is  $S$ , then if we ignored the weight of the rope, there would be a constant tension  $S(X/H)$  in the rope. However, if the tension is varying due to the weight of the rope, according to the above equation, it appears that, in order to increase the length of the rope by  $X$ , assuming linearity in the load-elongation relation:

$$\begin{aligned} \text{tension at top} &= S(X/H) + \frac{1}{2}WgH \\ \text{tension at bottom} &= S(X/H) - \frac{1}{2}WgH \end{aligned}$$

However, this ignores the direct effect of the transverse hydrostatic pressure on the deformation of the rope. The transverse stress leads to a transverse compressive strain. Poisson's ratio then gives an axial extension, which would contribute to the rope stretch and require a correction to the above equations. For an isotropic material, the relation would be:

$$\text{axial strain due to hydrostatic pressure} = 2\nu (\rho \cdot g \cdot h / E)$$

where  $\nu$  is Poisson's ratio and  $E$  is Young's modulus for the rope material, and  $\rho$  is density of water.

However fibres are anisotropic, so the true equation would involve the transverse modulus and two Poisson's ratios.

Since we are dealing with densities of water and rope of about  $1000 \text{ kg/m}^3$ , the order of magnitude of the stresses mentioned above will be  $1000gH \text{ Pa}$ , where  $g$  is approximately  $10 \text{ m/s}^2$  and  $H$  is the water depth in meters. At 1000 meters, this gives the value of  $10 \text{ MPa}$ , already mentioned. The strength of a polyester rope is about  $1000 \text{ MPa}$ , so that we are dealing with stresses of around 1% of break load. This begins to be comparable with minimum or mean tensions, if these are 10% or less of break load. The effects will become more pronounced at greater depths.

For a taut leg mooring at an angle of around  $45^\circ$ , there will be differences but the same factors will come into play. The forces involved are shown in Figure EC-5.12.2. Preliminary calculations indicate that the changes in stress will be of the same order of magnitude as for the vertical tether.

The simplest analysis of a taut leg mooring assumes that it follows a straight line. This would be true for a neutrally buoyant rope in still water. However, if the rope density differs from that of water, there will be a small catenary effect, which would cause the rope to bend. If currents are present, there will be additional lateral forces, which would cause bending, possibly associated with twisting. In view of the potentially damaging effects of axial compression and of disturbance of the rope structure due to bending and twisting, these effects should also be examined in detail.

In summary, it may be that the effects of water depth can be neglected at depths of around 1000 meters or even more. The bending and twisting may also not be large enough to cause a problem. However it is desirable that detailed numerical analyses, and any necessary experimental studies, should be carried out in to clarify the situation.

### References

- |   |   |
|---|---|
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| <u>Burgoyne, C.J., and Merii, A.L. (1993)</u> | <u>"Hydrolysis tests on polyester yarns", University of Cambridge, Department of Engineering Technical Report, CUED/D Struct/TR. 138.</u>   |
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| <u>Flory, J.F., (1996)</u>                    | <u>"Avoiding Fiber Axial Compression Fatigue in the Design and Use of Tension Members", Proceedings of Oceans '96 Conference, IEEE, Piscataway, NJ, 1996</u>  |

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**Figures**

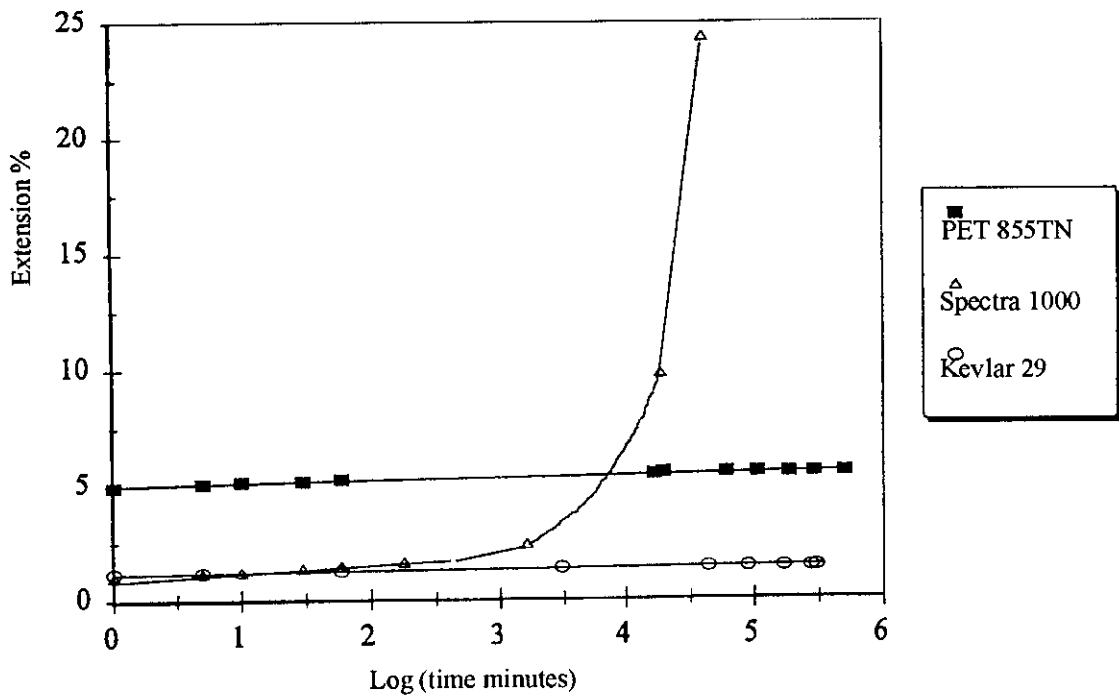
Figure EC-5.3.1	Schematic view of rope response under various loading regimes.
Figure EC-5.3.2	<u>Critical stiffnesses</u>
Figure EC-5.3.3	<u>Yarn Creep under 30% Break Load</u>
Figure EC-5.3.4	<u>Creep of an HMPE yarn, Dyneema SK60, at different temperatures</u>
Figure EC-5.3.5	<u>Idealised Twisted Yarn Geometry</u>
Figure EC-5.4.1	Tan $\delta$ in yarns and 17 mm three-strand ropes of polyester Diolen 855TN. After Bosman (1996).
Figure EC-5.4.2	Damping Factor for synthetic fibre rope increases with applied strain amplitude
Figure EC-5.5.1	Fatigue life of polyester ropes.
Figure EC-5.6.1	<u>Retained Strength of Polyester Ropes.</u>
Figure EC-5.10.1	Loss of Strength under temperature and pH. <u>(after Knoff)</u>
Figure EC-5.12.1	Forces on a vertical pillar in water
Figure EC-5.12.2	Forces on an angled tether

**Appendices**

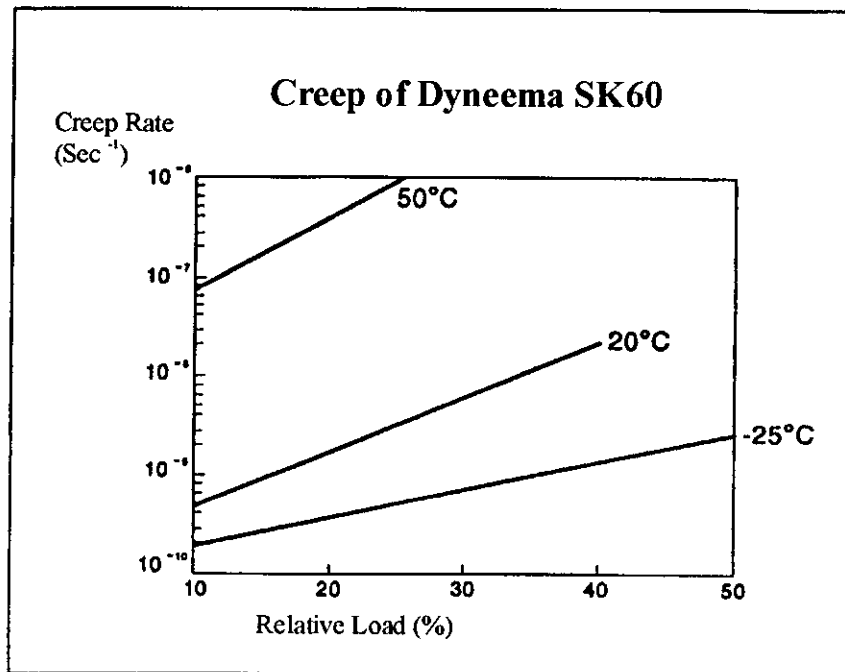
<u>Appendix 1.3 : Fibre Rope Modulus Definitions</u>
<u>Appendix 2.2 : Information from Fibre Producers</u>
<u>Appendix 2.3 : Technical Bulletin on reversible and irreversible elongation (DSM).</u>
<u>Appendix 5.1 : Fatigue References</u>







**Figure EC-5.3.3: Yarn Creep under 30% Breakload**  
 ■ Polyester    △ HMPE    ○ Aramid  
 (From Fibre Tethers 2000 (1995))



**Figure EC-5.3.4** Creep of an HMPE yarn at different temperatures.  
From Kirschbaum and van Dingenen (19XX)

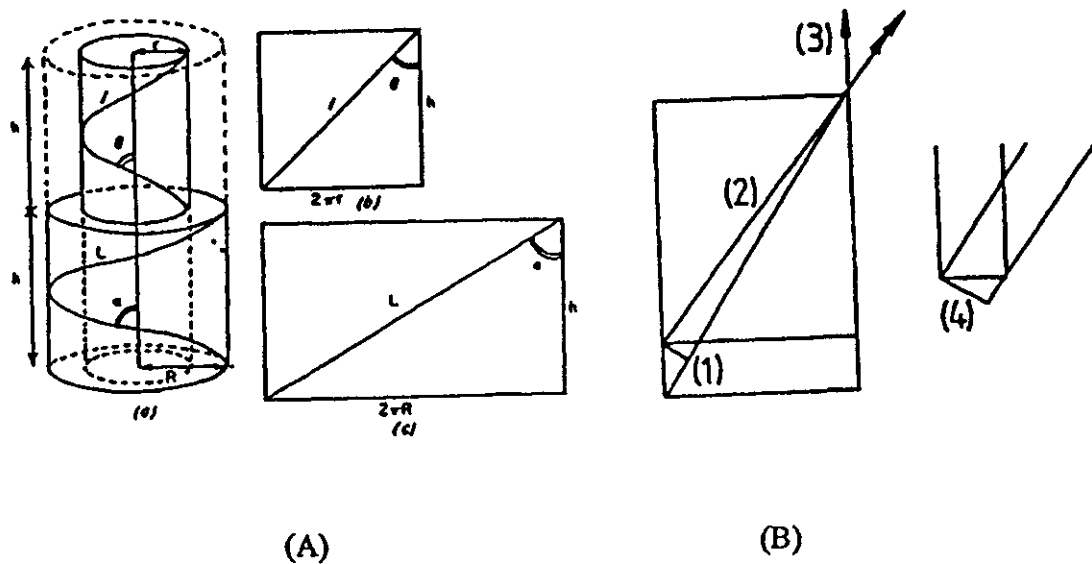


Figure EC-5.3.5

(A) Idealised twisted yarn geometry, showing obliquity in helical and opened-out diagrams. Helix angle  $\theta$  increases from zero at centre to  $\alpha$  at surface.

(B) Strain reduces as obliquity increases, because (1) elongation is less and (2) fibre length is longer. Hence stress will vary from a maximum value for the straight fibre at the centre to a minimum value for the most inclined fibre at the surface. This causes the differential creep tendency, which has to be averaged because the yarn must extend as a whole.

Note: Contribution to rope stress is further reduced because (3) a component of force acts axially and (4) it acts on a larger area. These two effects do not introduce the variability relevant to the difference in creep between fibre and rope.

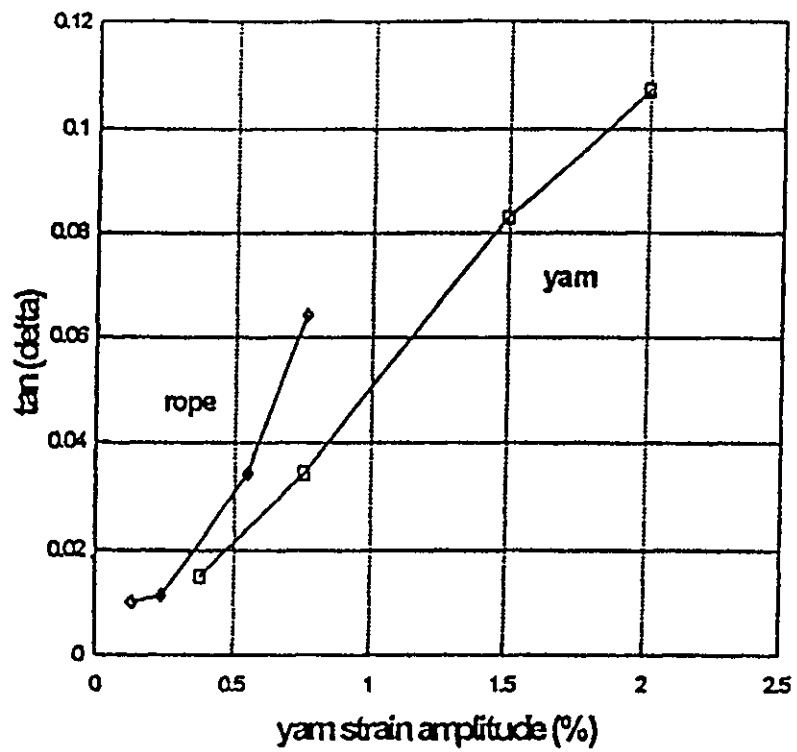
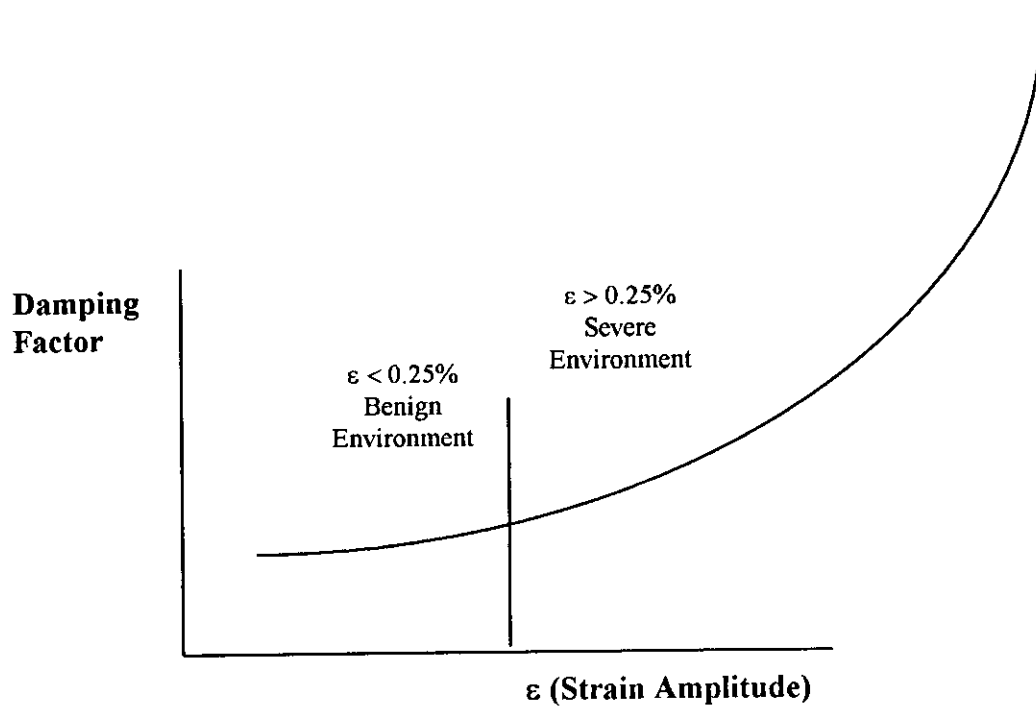


Figure EC-5.4.1

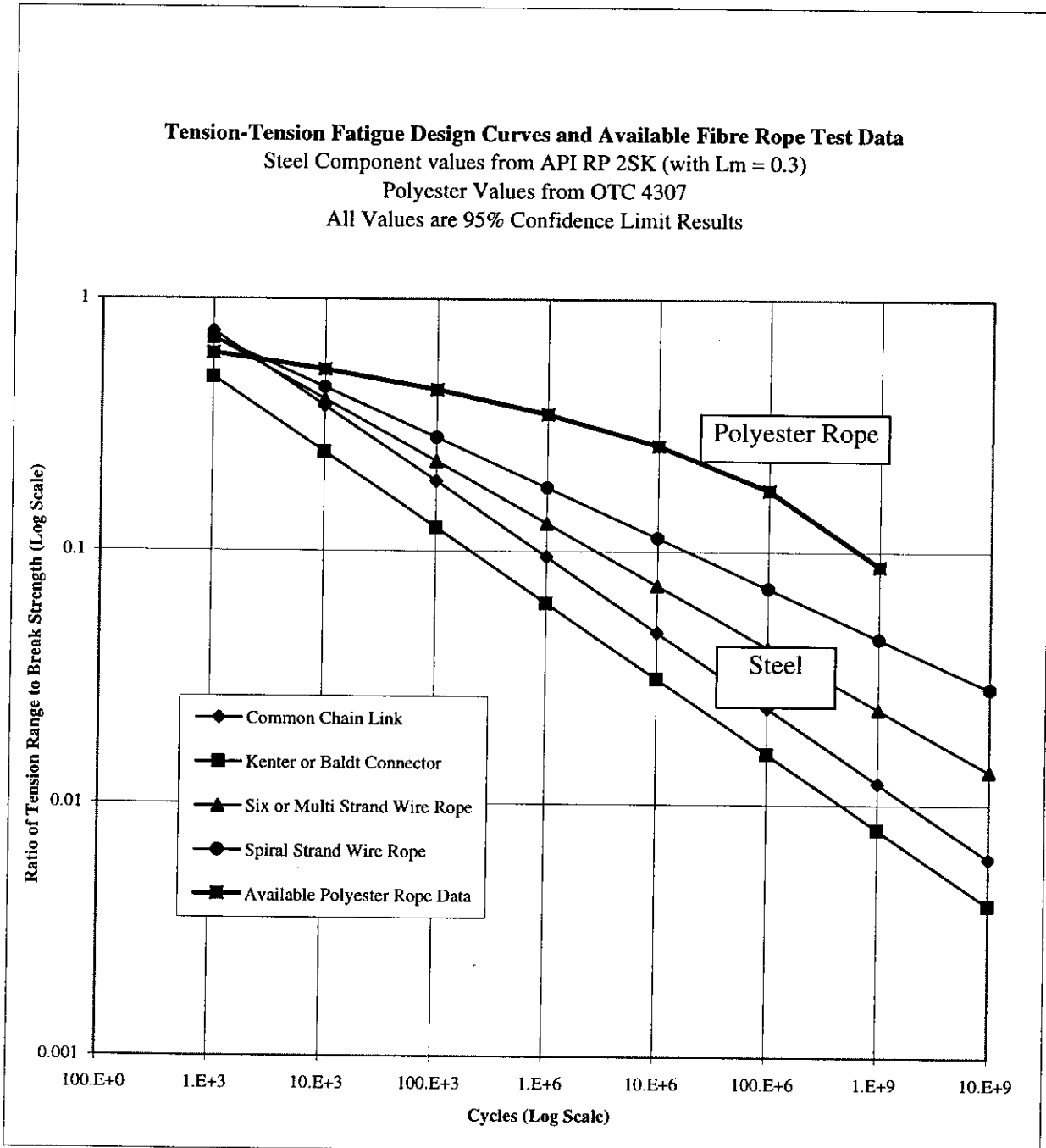
Tan $\delta$  in yarns and 17 mm three-strand ropes of polyester Diolen 855TN. After Bosman (1976)



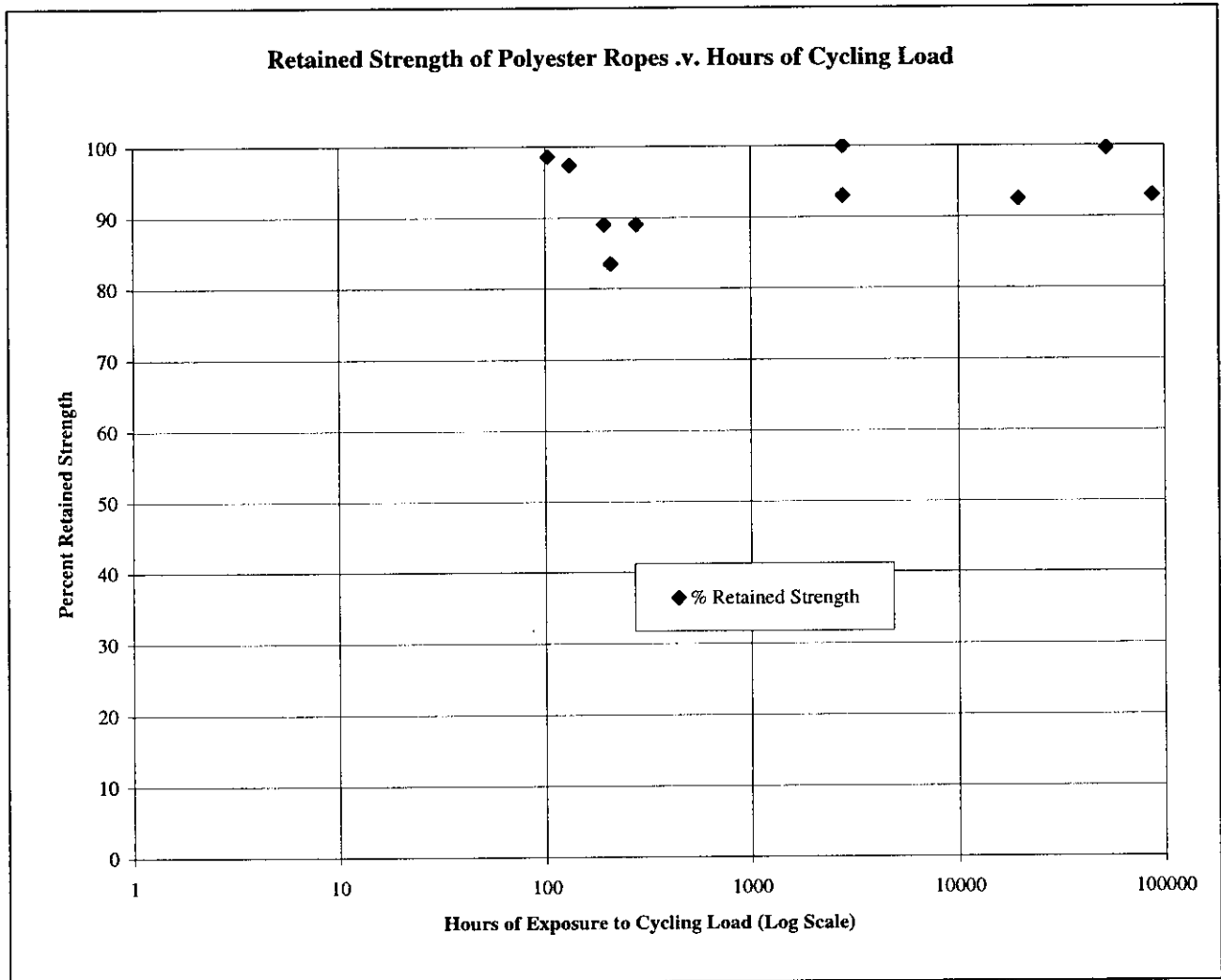
**Figure E C-5.4.2**

Damping factor for synthetic fibre rope increases with applied strain

**Figure EC - 5.5.1.**  
**Tension-Tension Fatigue Design Curves for Conventional Mooring Elements (as per API RP 2SK) compared with Available Test Data for Polyester Ropes**

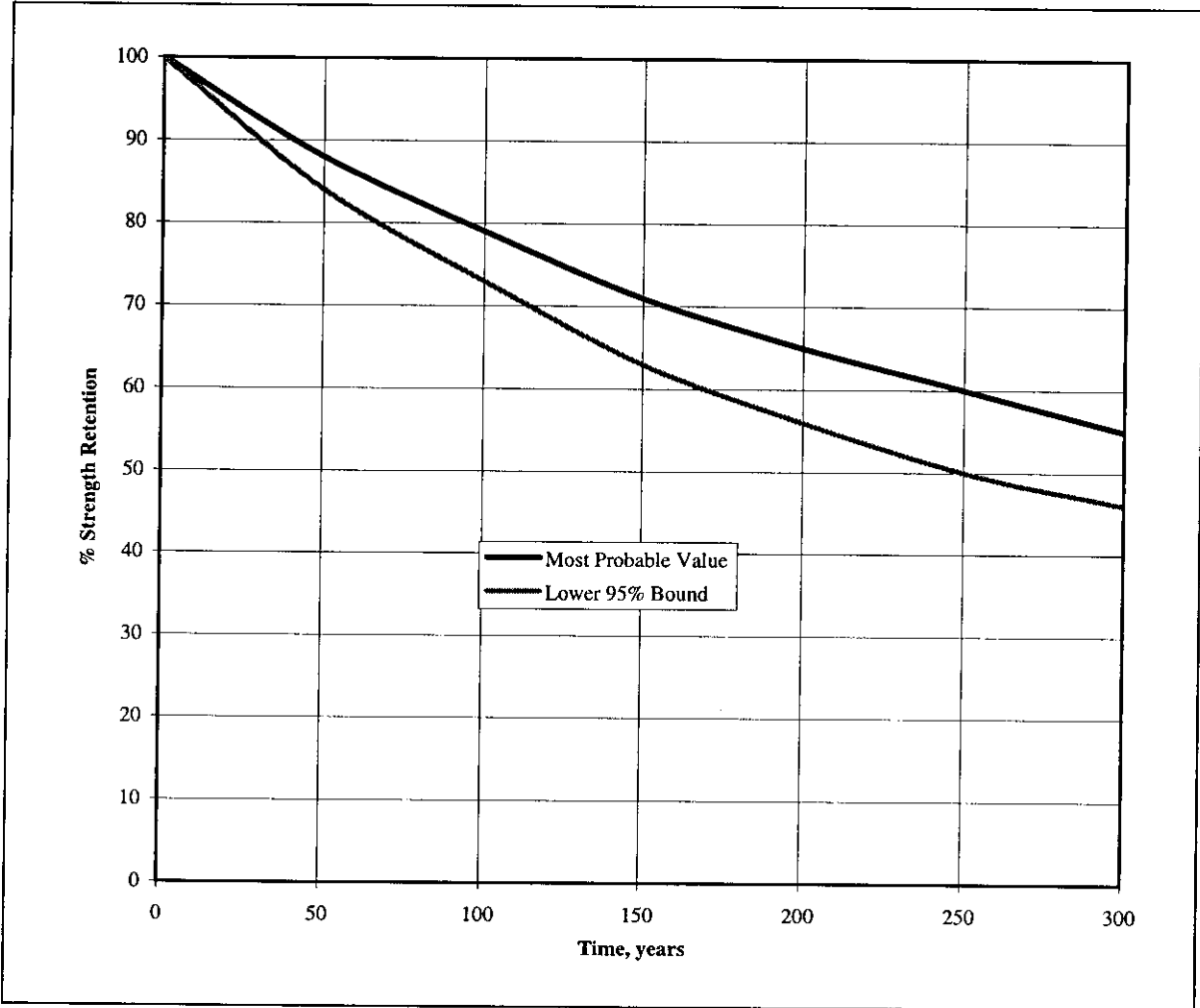


**Figure EC-5.6.1**  
**Retained Strength of Polyester Ropes**





**Figure EC-5.10.1 (After Knoff et al)**  
Percent Strength Retention of Kevlar® Aramid Fibers  
at 20°C in Neutral Water as a Function of Time



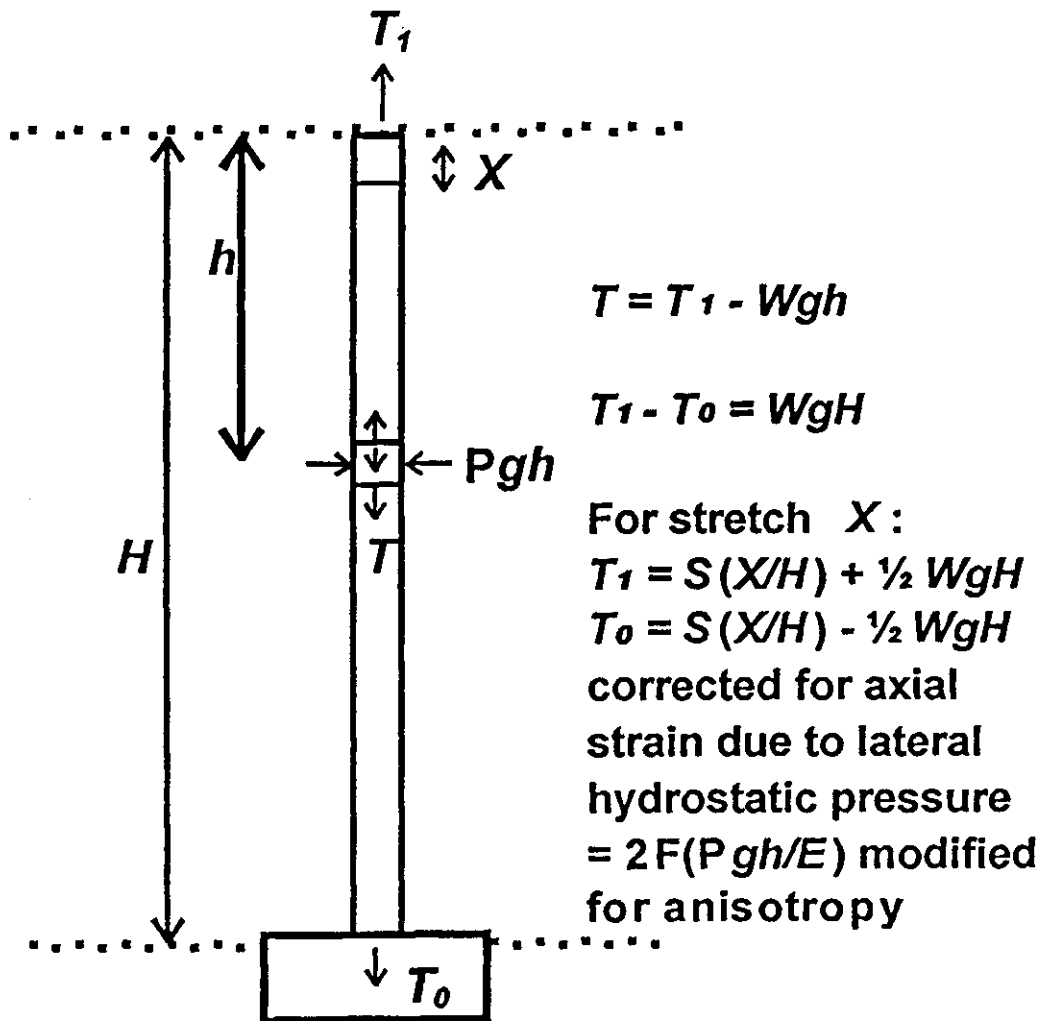


Figure EC-5.12.1 Forces on a vertical pillar in water

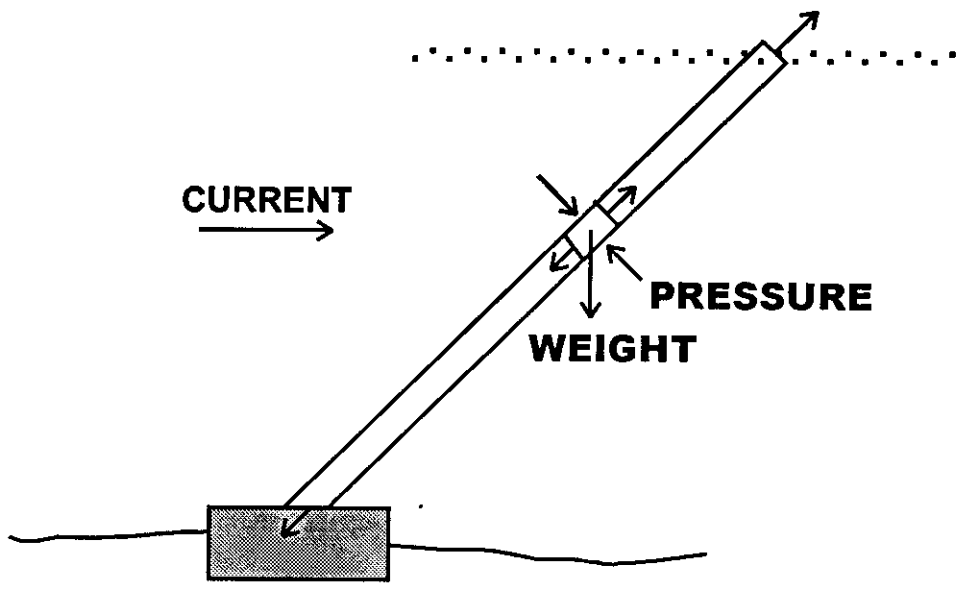


Figure EC-5.12.2 Forces on an angled tether

Document History

r2va	new	rwps	Oct 97
r3va	edited	rwps	29 June 98

**EC - 6. OTHER MOORING LINE COMPONENTS..... 1**

EC - 6.1 GENERAL..... 1

EC - 6.2 ANCHORS..... 1

EC - 6.3 CHAIN CABLE..... 2

EC - 6.4 STEEL WIRE ROPE..... 2

EC - 6.5 CONNECTING HARDWARE..... 2

EC - 6.6 CLUMP WEIGHTS..... 3

EC - 6.7 SPRING BUOYS..... 3

EC - 6.8 PENNANT LINES..... 3

**EC - 6. OTHER MOORING LINE COMPONENTS**

EC - 6.1 GENERAL

No additional comment.

**ANCHORS**

Table EC-6.2.1 lists anchor types that are currently in use or under development. All anchor systems depend on the local soil conditions and these notes are a general comparison of capabilities and currently available sizes:

**Table EC-6.2.1  
Anchor Types and Sizes**

Type	Typical Weight (in air)	Typical Holding Capacities	Comments
<b>Dead Weight</b>	-	-	These have very low efficiency as anchors and are not often used. However there has been some use of additional weights added to ground chain lengths in order to reduce anchor uplift forces.
<b>Drag Embedment Anchor</b>	15 - 30 tonne typical  65 tonne current maximum	100 - 500 tonne	Designed to resist horizontal load. Actual Holding capacity depends on soil conditions. Limited vertical load may be carried depending on the soil chain reverse catenary. Holding capacity depends on anchor weight and hence handling during installation requires substantial anchor handling equipment. Anchor requires to be dragged into position by tensioning from anchor handling vessel or a vertical tensioner. The final position and depth of the anchor is not easy to control. These anchors can be recovered.
<b>Pile Anchors</b>	any designed amount	any designed amount	Piles require substantial surface installation equipment such as crane vessels to stab and drive. Both vertical and horizontal loads can be resisted. Design capacity depends on pile size and soil conditions. They are not normally recovered. Critical installation aspect is orientation of the connection padeye.

<i>Suction Anchors</i>	typical designs to date: 40 - 100 tonne		Both steel and concrete types are possible. The anchor is not suitable for dense sand or stiff clay. The anchor is capable of taking a substantial vertical load. Installation relies on a suction pump powered by a surface umbilical which is re-usable. The anchor itself is not normally recoverable. Critical installation aspect is orientation of the connection padeye.
<i>Vertical Lift Anchors</i>	5 - 10 tonne	500 - 1000 tonne (target capacities - no published data)	Recent development with little published data. Deepstar has undertaken recent tests. Uses adjustable connector linkage to embed the anchor flukes deeply and then, after it has been tripped it is capable of resisting loads applied over a wide range of angles. Anchor installation is relatively quick and does not require pre-loading. Accuracy of positioning anchor is similar to drag embedment anchor. Anchor capacity based on fluke area hence minimising handling weight. Anchors can be installed using standard AHV and no special pre-tensioning is required.

Suction anchors are particularly suited to permanent installations where the cost of the installation activity can be more easily justified. The selection of the anchor geometry and weight will depend significantly on the available equipment for installation but trials have taken place demonstrating the practicality of deploying such anchors from supply-type vessels. In some cases this has been done with the addition of A-frame equipment to the deployment vessel.

Most suction anchors which have been considered to date are of the passive suction type - that is differential pressure is used to embed the caisson but is not permanently required during the lifetime of the platform. Active suction systems are also possible but in such a case the reliability of the anchor will depend on the continued operation of the suction pump.

The two types of Vertical Lift Anchors (also known as plate embedment anchors) which have been under recent development are the Vryhof "Stevmanta" - see Degenkamp (1996) - and the Bruce "Denla" - see Foxton (1997). These both operate on the principle that the fluke is pulled into the soil edgewise but the load is subsequently applied normal to the plane of the fluke.

For fibre mooring systems the installed location of the anchor directly affects the taut leg length of the mooring system. Pulling VLA's into the correct position is an area where there is little experience at present. Positioning of suction anchors is comparatively simple and depends mainly on the accuracy of the seabed surveying system.

For pile and suction anchors where the mooring line is attached by means of a side pad-eye the orientation of the anchor is important in order to minimise side loading (and high stresses) in the padeye connection detail.

EC - 6.3 CHAIN CABLE

No additional comment.

EC - 6.4 STEEL WIRE ROPE

No additional comment.

EC - 6.5 CONNECTING HARDWARE

No additional comment.

**EC - 6.6 CLUMP WEIGHTS**

No additional comment.

**EC - 6.7 SPRING BUOYS**

No additional comment.

**EC - 6.8 PENNANT LINES**

No additional comment.

**References**

- Foxton (1997) "Latest Developments for Vertically Loaded Anchors"; IBC 2nd Annual Conference - Mooring and Anchoring; 2 and 3 June 1997; Aberdeen
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**Tables**

Table EC-6.2.1 Anchor Types and Sizes

Document History			
r2va	new	rwps	Oct 97
	plus mods	rwps	Nov.97
r3va	mods after scm5	rwps	8 May 98
	tti edits from ec-3	rwps	28 June 98
	final tti edits	rwps	30 June 98

<b>EC - 7. SITE AND PLATFORM DATA</b>	<b>1</b>
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<i>EC - 7.3.1 FISHBITE DATA</i>	<i>1</i>
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**EC - 7. SITE AND PLATFORM DATA**

**EC - 7.1 SITE LOCATION DATA**

No additional comment.

**EC - 7.2 SITE ENVIRONMENTAL LOADING DATA**

Generally the type of environmental data to be gathered for a fibre rope mooring system will be very similar to that required for a conventional mooring. The greater depth that fibre ropes are expected to be designed for will affect the importance of some of the data required. In deepwater the current conditions will contribute more to the overall loading of the system than in shallower water. In addition the relative diameter of polyester ropes compared with steel will further increase drag loading on the lines.

Attention should be paid to the current profile and directions of currents at different depths. Current loading may be significant in terms of the size of the buoys required to provide temporary support before the lines are connected to the platform.

The current profile will also influence the propensity of the lines to develop vortex induced vibration behaviour.

**EC - 7.3 OTHER SITE DATA**

***EC - 7.3.1 FISHBITE DATA***

Some work has been conducted on ropes typically used for oceanographic buoy moorings and a maximum bite depth of 50 mm was recorded by Berteaux et al (1990). This work has shown that fishbite is localised by geographical area and depth. Indeed, recent work by Berteaux et al (1991) and Winkler and McKenna (1995) on larger ropes has shown no fishbite damage.

If necessary, pre-trials should be carried out or inspection routines established to check for jacket damage during the life of the mooring.

Information on monitoring fishbite activities and protecting deepwater fibre mooring ropes from fishbite damage is provided by Berteaux et al (1990).

#### EC - 7.3.2 MARINE GROWTH

There has not been any formal study of this phenomenon on fibre ropes, but general information is in a TTI (1991) report.

In general, the severity of fouling attack near the waterline depends on:

- Distance from shore
- Direction of prevailing current
- Temperature, salinity, and turbidity of the water near the surface

Algal type of growth will spread from quite small settlements of spores, when the environmental factors are favourable. Mussels, tubeworms, or barnacles can be imported from considerable distances by currents or tidal streams, as reported by Oldfield (1980) and West (1980). However, the composition, texture and roughness of the substrate (rope jacket) of the material influence the degree of fouling experienced. In particular, smooth surfaces or non-toxic anti-fouling coatings, such as rope coatings and vessel paints, are much less susceptible to settlement, as reported by Brady (1989).

Ropes removed from service, including a riser protection net after 6 years service, reported by TTI (1991), and a buoy mooring rope after 10 years service, reported by Linear Composites (1987) have shown negligible marine growth.

#### EC - 7.4 PLATFORM DATA

No additional comment.



**References**

- Bertaux, H.O., Prindle, B., and Putnam, S.S., (1990) "Monitoring Fishbite activities and protecting synthetic fibre ropes used in deep sea moorings", Woods Hole Oceanographic Institution, MA 02543, USA; Oceans '90 Conference 1990.
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**Figures Mentioned**

None

**Tables Mentioned**

None

**Appendices Mentioned**

None

Document History			
r2va	new	rwps	Oct 97
	plus suggestion on creep etc by jwsh + mods by	mrp/rwps	7.Nov.97
	plus editorial changes	rwps	13.Nov.97
	plus final changes	rwps	30.Nov.97
r3va	mods following scm5	rwps	8 May 98
	tti edits	rwps	30 June 98

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**EC - 8. MOORING DESIGN CRITERIA, ANALYSIS AND  
MODEL TESTING**

**EC - 8.1 GENERAL**

No additional comment.

**EC - 8.2 DESIGN CRITERIA**

***EC - 8.2.1 GOVERNING CRITERIA***

No additional comment.

***EC - 8.2.2 BASIC CONSIDERATIONS (API RP 2 SK SECT. 6.1)***

No additional comment.

***EC - 8.2.3 OFFSET (API RP 2 SK SECT. 6.2)***

No additional comment.

*EC - 8.2.4 LINE TENSION (API RP 2 SK SECT. 6.3)*

The safety factors against line failure in an intact system currently recommended by the major classification societies are summarised in Table EC-8.2.1.

**Table EC-8.2.1**

**Comparison of Published Safety Factors for Mooring Lines**

Authority	Factor of Safety against Break (assumes a dynamic analysis)	Notes
American Bureau of Shipping [ABS FPSS Guide (1995)]	1.67	This is value quoted for conventional mooring lines (chain or wire).
API [API RP 2SK (1997)]	1.67	This is value quoted for conventional mooring lines (chain or wire).
Bureau Veritas [BV Recommended Practice (1996)]	1.75	(assumes analysis omits line dynamics) This is value quoted for conventional mooring lines (chain or wire). It is understood that BV will require an additional factor of 1.25 for synthetic fibre ropes.
Det Norsk Veritas [Posmoor (1996)]	1.65	<u>Includes</u> 1.1 factor required by DNV for synthetic fibre ropes
Lloyds Register [Floating Offshore Production Installations at a Fixed Location (1995)]	1.85	This is value quoted for conventional mooring lines (chain or wire).
Lloyds Register [Ship Rules Part 7 (1996)]	1.8	(assumes quasi-static mooring analysis) This is value quoted for conventional mooring lines (chain or wire).

**EC - 8.2.4.1 Maximum Line Tension**

Note that increasing the size (cross sectional area) of a mooring line will not improve the 'safety factor' against breaking load if similar extension (strain) is applied. For practical moorings where the windward line resists both steady load effects (e.g. wind and current) as well as platform excursion effects (e.g. wave frequency motions) there can be expected to be a net improvement in the factor of safety between the maximum load in the line and the break strength of the line. However note the influence that such increase in rope size has on the minimum tension found in the leeward line (see EC-8.2.4.2)

**EC - 8.2.4.2 Minimum Line Tension**

Increasing rope size for a given set of platform dynamic excursions will result in lower minimum tension in the line as indicated by the argument in EC-8.2.4.1. The effect is considered in more detail in the Worked Example.

*EC - 8.2.5 STATISTICS OF PEAK VALUES (API RP 2 SK SECT. 6.4)*

The API method of defining peak value statistics is based on a Rayleigh distribution.

**[NDE to check whether other distributions are relevant or preferable**

*EC - 8.2.6 LINE LENGTH (API RP 2 SK SECT. 6.5)*

No additional comment.

*EC - 8.2.7 ANCHOR HOLDING CAPACITY (API RP 2 SK SECT. 6.6)*

Conventional practice for steel mooring systems often calls for test loading of drag embedment anchors to 100% of their storm load. For suction and pile anchors however this the requirement is not relevant. However if an anchor system such as a pile or vertical lift anchor contains a wire rope or chain which must be "cut" into the soil during installation to provide a reverse catenary profile and this loading is applied by the main (fibre) mooring line this loading effect should be considered in the design. The effect will generally be to help remove the constructional stretch from the fibre rope and thus result in a higher "post-installation" line stiffness. Obviously suitable winch capacity must be provided during installation.

The manufacturers of VLA's recommend that they are used with a seabed length of wire rope to allow the line to cut easily through the soil and thus allow the best embedment of the anchor. For fibre ropes it is generally considered that a chain length at the seabed is more satisfactory because of its torque free characteristics. This needs careful detailed consideration if fibre ropes are to be used with VLAs.

*EC - 8.2.8 THRUSTER ASSISTANCE (API RP 2 SK SECT. 6.2)*

No additional comment.

*EC - 8.2.9 FATIGUE LIFE (API RP 2 SK SECT. 6.8)*

Most of the data on fibre rope fatigue listed in Appendix 5.1 relates to tension-tension loading, which is the predominant loading mechanism for deepwater fibre moorings.

Much data is also published on Bend-over-Sheave fatigue (Karnoski and Liu, 1988; Hobbs et al 1984) but this is not relevant here.

Much less data is available on Tension-Bend fatigue, though work by Burgoyne et al at Imperial College (1987) showed that 60 tonne aramid parallel yarn ropes would resist well over 100,000 tension-bend cycles over +/- 1.5 degrees arc at a mean tension of 50% CBS. Ropes in the other constructions and materials considered in this guide would be expected to show much superior performance because of their lower and more consistent modulus and bend rigidity.

## EC - 8.3 MOORING ANALYSIS

*EC - 8.3.1 DESIGN ASSESSMENT*

No additional comment.

*EC - 8.3.2 BASIC CONSIDERATIONS (API RP 2 SK SECT. 7.1)*

No additional comment.

*EC - 8.3.3 DYNAMIC ANALYSIS (API RP 2 SK SECT. 7.2)*

No additional comment.

*EC - 8.3.4 DYNAMIC ANALYSIS NON-LINEARITIES (API RP 2 SK SECT. 7.2)***EC - 8.3.4.1 Fibre Rope Stiffness**

No additional comment.

**EC - 8.3.4.2 Changes in mooring geometry**

No additional comment.

**EC - 8.3.4.3 Fluid Loading**

For example with Polyester ropes the rope diameter (and resulting drag for equivalent relevant fluid velocities) will be greater than for steel wire ropes of equivalent strength.

**EC - 8.3.4.4 Bottom Effects**

No additional comment.

## EC - 8.4 EXTREME RESPONSE

*EC - 8.4.1 DYNAMIC ANALYSIS (API RP 2 SK SECT. 7.2)*

No additional comment.

**EC - 8.4.1.1 Review of Available Data**

No additional comment.

**EC - 8.4.1.2 Prototype Rope Data**

No additional comment.

**EC - 8.4.1.3 Upper Limit Stiffness Calculation**

No additional comment.

**EC - 8.4.1.4 Lower Limit Stiffness Calculation**

No additional comment.

**EC - 8.4.1.5 Mooring Sensitivity to Line Stiffness**

No additional comment.

**EC - 8.4.2 TRANSIENT ANALYSIS (API RP 2 SK SECT. 7.3)**

No additional comment.

**EC - 8.4.3 HULL SET-DOWN AND AIR-GAP**

No additional comment.

**EC - 8.5 CREEP RESPONSE****EC - 8.5.1 LINE CREEP ELONGATION: RETENSIONING**

The continuing increase of line length due to creep, described in DPD 5.7, should be estimated in order to plan a scheme for retensioning lines at intervals during the life of the mooring.

The creep elongation  $\Delta X$  of the line during a time  $t_0$  to  $t_1$  after installation or after re-tensioning the lines will be given by:

$$\Delta X = \int_{t_0}^{t_1} x(F) \delta t$$

where  $x(F) \delta t$  is the elongation in time  $\delta t$  under load  $F$  at the relevant temperature, taking account of the prior loading history.

An estimate of the tension decrease  $\Delta F$  is then given by:

$$\Delta F = S \Delta X = (EA/L) \Delta X$$

where  $S$  is the line spring constant and  $L$  is line length

When the increased line length due to creep leads to unacceptable positioning or when the tension levels become lower than is allowable, the lines should be retensioned.

In the absence of data on creep under varying loads, approximate values of  $X$  may be calculated by estimating the mean peak tension in the line (see Figure EC-8.5.1) and then taking values for the creep extension in each decade of log(time) under this load at an appropriate temperature, either from measured values on yarn or rope or from data such as that in Table EC-5.7.1. This may lead to retensioning intervals shorter than are strictly necessary, but should avoid undue loss of tension.

Note that HMPE yarns show a rapid increase in creep when plotted against log(time) beyond critical tension/time combinations, but such situations should have been ruled out on creep rupture considerations.

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*EC - 8.5.2 LINE CREEP RUPTURE*

The lines must have an adequate factor of safety against creep rupture.

Nylon ropes are subject to creep rupture under lower load/time combinations than polyester ropes. It is unlikely that this will be a problem at the loads used in deepwater moorings, but calculations of predicted creep rupture time should be made.

If it is considered necessary or desirable to make a prediction of creep rupture after time  $t$  under a load  $S$ , the following equation, previously given, should be used.

$$S = S_g [1 - k \log(t/t_g)]$$

where  $S_g$  and  $t_g$  are the strength and time under given test conditions.

In the absence of data on the effect of variable loading, the mean value of peak tension should be used for  $S_g$ . Some values of  $k$  for yarns are given in Table EC-5.7.1. Creep rupture times for ropes are expected to be greater than for yarns.

*EC - 8.6 FATIGUE ANALYSIS**EC - 8.6.1 BASIC CONSIDERATIONS (API RP 2 SK SECT. 7.5)*

No additional comment.

*EC - 8.7 MODEL TESTING**EC - 8.7.1 BASIC CONSIDERATIONS (API RP 2 SK SECT. 8.1)*

No additional comment.



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- ABS FPSS Guide (1995) "Draft Guide for Building and Classing Floating Production and Storage Systems"; American Bureau of Shipping; September 1995.
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- Lloyds FOI Rules (1998?) "Rules for Classification of Floating Offshore Installations - (provisionally as Part 3; Chapter 10 for mooring systems in general and synthetic ropes in particular); Lloyds Register; (expected 1998)
- API RP 2SK (1996) "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)
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- FPS-2,000 JIP (1992) Mooring Line Damping - Summary and Recommendations. Part 1.5 of FPS-2,000 Mooring and Positioning JIP
- Karnoski, S.R., and Liu, F.C.,(1988) "Tension and Bending Fatigue Test Results of Synthetic Ropes"; Offshore Technology Conference, Paper OTC 5720; Houston; 1988
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- Hobbs, R.E., Markussen, B.H. and Hunt, E.S., (1984) "Wear of Nylon Hawsers on Rollers, Pulleys and Fairleads"; Offshore Technology Conference, Houston, May 1984.

**Figures**

- EC-8.5.1 Illustration of "Mean" and "Mean Peak" Tensions used to estimate line creep during lifetime.

**Tables**

- Table EC-8.2.1 Comparison of Published Safety Factors for Mooring Lines

**Appendices**

- Appendix 5.1 References on Fatigue Loading

Time Tension Trace of Line Tension

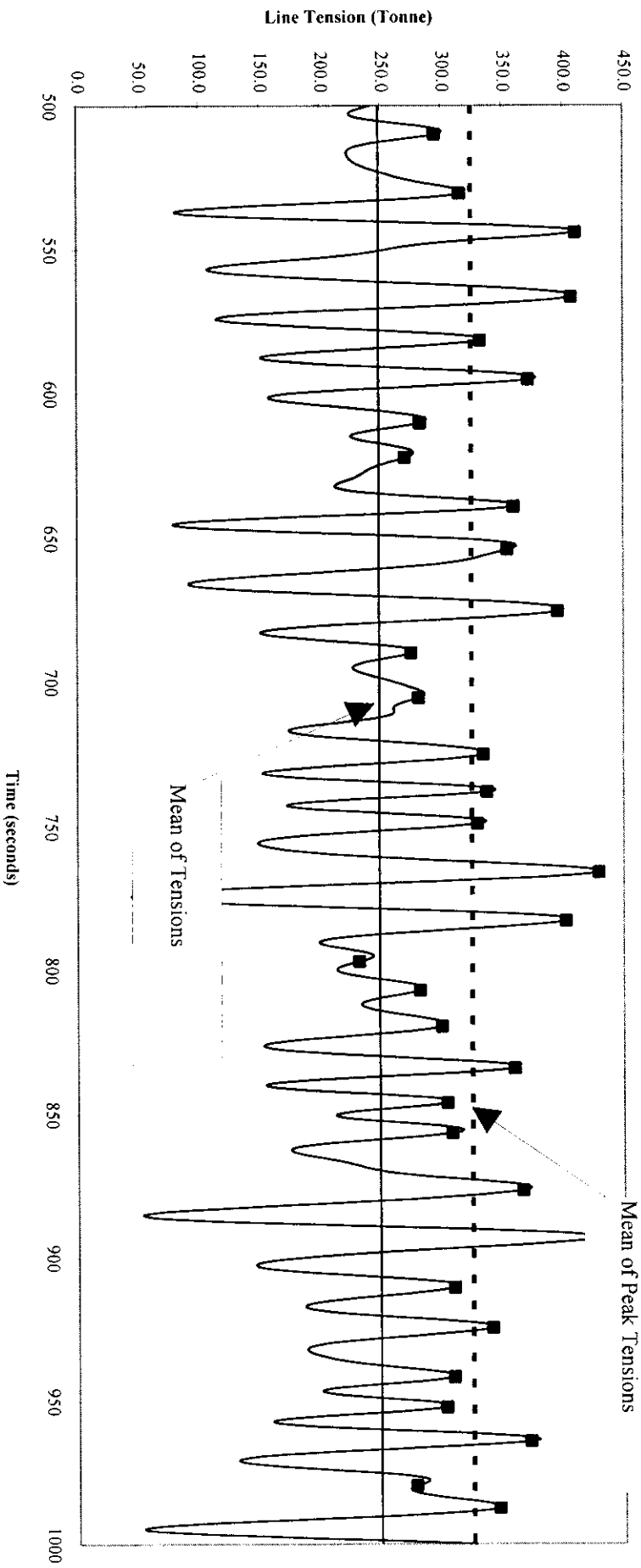


Figure EC-8.5.1 : Illustration of "Mean" and "Mean Peak" Tensions used to estimate line creep during lifetime.

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**EC - 9. SPECIFICATION 1**

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<b>EC - 9.2 SPECIFICATION AND TEST METHODS</b>	<b>1</b>
<i>EC - 9.2.1 ROPE ASSEMBLY LENGTH BETWEEN BEARING POINTS</i>	<i>1</i>
<i>EC - 9.2.2 CERTIFIED BREAKING STRENGTH OF THE TERMINATED ROPE ASSEMBLY</i>	<i>2</i>
<i>EC - 9.2.3 ROPE IN SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES</i>	<i>2</i>
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<i>EC - 9.2.7 SPLICED EYES OR BUTT SPLICES</i>	<i>2</i>
<i>EC - 9.2.8 SOCKETS AND OTHER TERMINATIONS</i>	<i>2</i>
<i>EC - 9.2.9 IDENTIFICATION</i>	<i>2</i>
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<i>EC - 9.2.11 PACKING</i>	<i>2</i>
<b>EC - 9.3 PERFORMANCE CRITERIA AND TOLERANCES</b>	<b>3</b>
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<i>EC - 9.3.4 AXIAL COMPRESSION FATIGUE RESISTANCE</i>	<i>3</i>
<i>EC - 9.3.5 ROPE WEIGHT AND SIZE</i>	<i>3</i>

**EC - 9. SPECIFICATION**

**EC - 9.1 INTRODUCTION**

*EC - 9.1.1 GENERAL*

No additional Comment.

*EC - 9.1.2 REQUIREMENTS*

No additional Comment.

**EC - 9.2 SPECIFICATION AND TEST METHODS**

*EC - 9.2.1 ROPE ASSEMBLY LENGTH BETWEEN BEARING POINTS*

No additional Comment.

*EC - 9.2.2 CERTIFIED BREAKING STRENGTH OF THE TERMINATED ROPE ASSEMBLY*

No additional Comment.

*EC - 9.2.3 ROPE IN SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES*

In addition to the test procedure provided in Appendix 9.1 "Proposed Prototype Rope Testing Procedure" other testing proposals have been suggested including that by Bureau Veritas (1997).

*EC - 9.2.4 TENSION-TENSION FATIGUE LIFE*

A fatigue testing procedure is contained in proposals by Bureau Veritas (1997).

The main body of fatigue data for tension-tension fatigue of fibre ropes suitable for deepwater moorings are those reported by FIBRE TETHERS 2000 (1995).

In addition other references dealing with tension-tension fatigue loading of fibre ropes are contained in Appendix 5.1 "References for Tension-Tension Fatigue Loading".

*EC - 9.2.5 ROPE JACKET*

No additional Comment.

*EC - 9.2.6 OVERALL FIBRE ROPE ASSEMBLY*

No additional Comment.

*EC - 9.2.7 SPLICED EYES OR BUTT SPLICES*

No additional Comment.

*EC - 9.2.8 SOCKETS AND OTHER TERMINATIONS*

No additional Comment.

*EC - 9.2.9 IDENTIFICATION*

No additional Comment.

*EC - 9.2.10 BEND LIMITERS*

No additional Comment.

*EC - 9.2.11 PACKING*

No additional Comment.

**EC - 9.3 PERFORMANCE CRITERIA AND TOLERANCES***EC - 9.3.1 ROPE ASSEMBLY LENGTH BETWEEN BEARING POINTS*

No additional Comment.

*EC - 9.3.2 CERTIFIED BREAKING STRENGTH OF THE TERMINATED ROPE ASSEMBLY*

No additional Comment.

*EC - 9.3.3 ROPE IN-SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES*

No additional Comment.

*EC - 9.3.4 AXIAL COMPRESSION FATIGUE RESISTANCE*

No additional Comment.

*EC - 9.3.5 ROPE WEIGHT AND SIZE*

No additional Comment.

**References**

Bureau Veritas (1997) "Guidance Notes For Certification Of Synthetic Fibre Ropes For Mooring Systems; Document Reference Ni 432 Dto R00 E, Bureau Veritas, Paris La Defense, 1997.

FIBRE TETHERS 2000 (1995) "Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.

**Figures****Appendices**

Appendix 9.1 "Proposed Prototype Rope Testing Procedure"

Appendix 5.1 "References for Tension-Tension Fatigue Loading".

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**EC - 10. MANUFACTURE**

EC - 10.1 GENERAL

The first assumption on which this section is based is that the manufacturer should be free to offer ropes of material and construction of his own choosing providing that the properties of the finished rope assembly meet the specifications set out in DPD-9.

It is further assumed that the important properties of the prototypes have been determined through tests conducted on prototypes having the same (+/- 10%) Certified Breaking Strength (CBS) Thus Rope assemblies subsequently purchased to the prototype specifications set out in DPD-9 can be expected to have the same properties, within agreed tolerances, without requiring further testing.

Manufacturer shall provide a rope product identical to that of the applicable Rope Design Specification and the rope shall be constructed in accordance with the applicable Rope Manufacturing Specification. Within these constraints the Manufacturer should be free to offer ropes of material and construction of his own choosing providing that the properties of the finished rope assembly meet the requirements set out by the purchaser and which are detailed in DPD-9.

The Manufacturer shall provide a quality assurance (Q.A.) procedure agreed with the purchaser and the appropriate Certification authority. Where specific procedures are not agreed those prescribed in the OCIMF (1987) -Procedures for Quality Control and Inspection during the Production of Hawsers - are recommended as a minimum level.

EC - 10.2 ROPE FIBRE MATERIAL

No additional comment.

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EC - 10.3 CONSTRUCTION

The manufacturer will have prepared a Rope Manufacturing Specification as described in DPD-11.2.2.3 corresponding to the manufacturing process utilised for the prototype rope covering aspects such as yarn twisting, twist levels, rope machine type and machine settings, manufacturing tension control and length measurement. The Specification should state whether yarn, strand or sub-rope joints are allowed and if so under what circumstances and frequency they are tolerated. It should detail jointing procedures to be adopted and these procedures should have been shown to be effective during the prototype evaluation exercise. A checklist of processes, processing parameters with measurable values and tolerances should be prepared. The checklist should function as a manufacturing tool and as a quality assurance document. It should be completed by the manufacturing Q.A. supervisor as a permanent record of the manufacturing process and the measured values of critical parameters. (see DPD-11.2.3.5). This document should be available for scrutiny by the purchaser's inspector. (see DPD-11.3.11).

Once the production process has begun the materials and part assembled elements of the ropes should be clearly identifiable and segregated from other materials in the factory. Under no circumstances should any elements be exposed to the weather. All materials should be stored under cover and laid into the final rope with the minimum of delay to minimise any environmental influence on the behaviour of the material.

Sub-ropes etc. should be stored on flanged reels and protected from damage by wrappings covering the exposed surface. Winding tensions on all reels should be identical and sufficiently high to allow the reels to be tensioned during the final assembly phase. It is important that all sub-ropes are equally tensioned during the final rope closing operation and the Rope Manufacturing Specification should describe how this is achieved.

A stripe should be applied down one side of the rope during the final laying, coating or extruding process. (see DPD-11.2.8.1)

## EC - 10.4 TERMINATION

Termination should only be undertaken by fully trained, competent personnel.

The termination procedures should include the treatment of the jacket. It is important that the end of the rope jacket is secured within the termination in such a way as to ensure that it will not separate from the termination when the rope is loaded to break or during cyclic loading.

In the case of spliced eyes or butt splices the procedures should include check marks to ensure that no length imbalances have been introduced by the splicing process. These marks should be checked by the Quality Assurance Supervisor. The number and length of tucks and method of splice finishing should match the prototype sample splices.

Spliced eyes can be connected to other mooring components by means of thimbles or by the use of bushes and shrouds connecting with a shackle pin.

Thimbles should be made of steel (unless some other material has been proven satisfactory) and can be in the form of castings or fabrications. They should conform to the design requirements set out in DPD-9.2.7.

Bushes and shrouds should conform with the design requirements in DPD-9.2.7.

Sockets may be chosen as the end terminations for the fibre mooring lines. These may be resin secured, barrel-and-spike or a combination of these. The Fibre Rope Assembly Specification shall specify fully the procedures to be adopted for attachment. The materials to be used and the quality control measures to be applied should ensure that the sockets perform as effectively as on the prototype ropes. As with spliced terminations it is vital that the rope jacket is secured effectively within the termination.

Sockets should conform to the requirements laid out in DPD-9.2.8.

Great care should be exercised in handling fittings to protect against damage to the surface of the fittings, particularly any area which may come into contact with the fibre rope. In the case of sockets, it is important to ensure that the fibre rope is not subjected to any severe bending at the mouth of the socket and does not become trapped beneath the socket. Under no circumstances should the rope be bent within 30 rope diameters of the mouth of the socket.

A suitable jig should be utilised to secure and ensure correct alignment of the rope and socket during the socketing operation. If resin is used as a socketing medium, the socket must be held vertically. The mouth of the socket must be sealed to prevent leakage as this can lead to voids in the resin cone or to loss of strength in the rope if resin is allowed to wick down into the fibre rope below the socket. The socketed rope must not be moved until the resin is fully cured. (This takes typically about one hour).

With-barrel-and-spike sockets it is important to establish pull-in loads and procedures for seating the socket which will not cause damage to the rope jacket.

A bend limiter or flex relief boot may be required at the point of entry into the fitting. This is particularly important in the case of a socket. This should preferably be a polyurethane elastomer of suitable hardness and thickness to provide support to the rope at the entry point into the heavy socket thus avoiding undue flexing fatigue. The boot material must be resistant to the effects of sea water immersion for the expected lifetime of the mooring. Boots may be cast directly onto the rope or take the form of separate sleeves threaded on prior to termination. In either case they should be securely attached to the end fitting.

## EC - 10.5 PACKING

Unless facilities exist allowing the rope to be produced directly onto the purpose designed storage tanks of an installation vessel the rope should be collected onto a substantial reel for transportation. The reel may be an installation reel or a transporting reel.

An installation reel can be taken straight from the production unit onto the installation vessel and used for the rope deployment. In this case, great care must be taken to ensure that the reel dimensions are suitably matched to the vessel and that the reel is designed to withstand the rope tensions involved in installation. The rope must be collected onto the reel with sufficient tension to prevent inter-layer jamming of the rope during installation. The reel should have a separate compartment to accommodate the end terminations as described in DPD-9.2.11. The end fittings should be individually wrapped with cloth or plastic sheeting prior to packing.

A transportation reel is used to carry the rope from the manufacturer to a storage yard or the installation vessel where the rope will be transferred to an installation reel. The reel should have two compartments as described in DPD-9.2.11. The end fittings should be individually wrapped with cloth or plastic sheeting prior to packing.

All reels must be sufficiently large to accommodate the complete length of rope and fitting without any material protruding above a flange.



The rope between flanges should be protected by wrappings of weatherproof material and finally by slats extending across the reel from flange to flange. The packing should be sufficiently robust to protect the rope against environmental damage during storage.

Reel sizes may be limited by the manufacturers machine capacity. In other cases land transport limitations may dictate the maximum size. It is unlikely that weight will be a limiting factor.

Direct production into the storage compartments of a cable laying vessel would overcome land transport limitations. In this case detailed stowage procedures would depend on the vessel involved. End fittings should be individually wrapped and great care taken to prevent the rope being kinked during handling.

### References

OCIMF (1987)

“Procedures for Quality Control and Inspection during the Production of Hawsers.”; Witherby and Co. Ltd., London 1987.

### Figures

### Tables

### Appendices

Document History:			
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## EC - 11. QUALITY CONTROL, INSPECTION AND CERTIFICATION

### EC - 11.1 INTRODUCTION

No additional comment.

### EC - 11.2 QUALITY CONTROL

#### *EC - 11.2.1 GENERAL PROCEDURES*

No additional comment.

#### *EC - 11.2.2 PRODUCT DESIGN DOCUMENTATION*

##### **EC - 11.2.2.1 Rope Design Specification**

No additional comment.

##### **EC - 11.2.2.2 Material Specification**

Methods of measuring both yarn-on-yarn friction and yarn-on-yarn abrasion are described in FIBRE TETHERS 2000 (1995). A full listing of yarn test methods is set out in Appendix 2.1

##### **EC - 11.2.2.3 Rope Manufacturing Specification**

No additional comment.

##### **EC - 11.2.2.4 Fibre Rope Assembly Specification**

No additional comment.

#### *EC - 11.2.3 QUALITY ASSURANCE PRACTICES AND REPORTING*

##### **EC - 11.2.3.1 Quality Assurance Manual**

No additional comment.

##### **EC - 11.2.3.2 Quality Assurance Supervisor**

No additional comment.

##### **EC - 11.2.3.3 Notification**

No additional comment.

**EC - 11.2.3.4 Quality Control Report**

No additional comment.

**EC - 11.2.3.5 Quality Control Check List**

No additional comment.

***EC - 11.2.4 ROPE FIBRE MATERIAL QUALITY*****EC - 11.2.4.1 Certification**

No additional comment.

**EC - 11.2.4.2 Material Testing by Rope Manufacturer**

Methods of testing of fibres to determine the type of fibre material include those provided in the OCIMF Procedures (1987) and include investigation of the following characteristics:

- melting point
- specific gravity
- solubility tests
- burning characteristic tests
- stain identification tests
- other tests

These tests are satisfactory for distinguishing between nylon and polyester and various lower strength yarn materials.

Aramid can be distinguished by its characteristic of not melting but decomposing at temperatures of about 500°C.

HMPE can be distinguished by its low specific gravity which allows it to float.

**EC - 11.2.4.3 Material Control Procedures**

No additional comment.

**EC - 11.2.4.4 Rope Manufacturer's Fibre Material Labelling**

No additional comment.

**EC - 11.2.4.5 Material Storage**

No additional comment.

**EC - 11.2.4.6 Intermediate Labelling and Storage**

No additional comment.

***EC - 11.2.5 ROPE PRODUCTION QUALITY*****EC - 11.2.5.1 Rope Making**

No additional comment.

**EC - 11.2.5.2 Setting of Rope Production Parameters**

No additional comment.

**EC - 11.2.5.3 Quality Control Checks**

No additional comment.

**EC - 11.2.5.4 Finished Rope Quality**

No additional comment.

**EC - 11.2.6 TERMINATION QUALITY****EC - 11.2.6.1 Spliced Eye Terminations**

Much work is currently going on in the development and proving of spliced terminations for large ropes and the potential user should identify the latest developments.

It is anticipated that splicing methods developed for the Norsk Hydro-JIP (1997) full scale deepwater fibre moorings may be adopted in the future as standards for the termination of fibre mooring assemblies.

**EC - 11.2.6.2 Socket Terminations**

Work is being undertaken in developing procedures for socketed terminations of large ropes Flory (a,b 1995 and 1997), but has not yet reached the stage of being ready for project utilisation. The situation may however change in the near future.

**EC - 11.2.7 FINISHED ASSEMBLY QUALITY**

No additional comment.

**EC - 11.2.8 IDENTIFICATION OF ROPE ASSEMBLY****EC - 11.2.8.1 Rotation strip**

No additional comment.

**EC - 11.2.8.2 Marker Tape**

No additional comment.

**EC - 11.2.8.3 Assembly Marking**

No additional comment.

**EC - 11.3 INSPECTION****EC - 11.3.1 GENERAL PROCEDURES**

No additional comment.

**EC - 11.3.2 ESTABLISHMENT OF INSPECTION CRITERIA**

No additional comment.

**EC - 11.3.3 MANUFACTURING QUALITY**

No additional comment.

*EC - 11.3.4 INSPECTION OF SAMPLE OF ROPE SECTION*

No additional comment.

*EC - 11.3.5 SELECTION OF SAMPLE ROPE SECTION*

No additional comment.

*EC - 11.3.6 WEIGHT OF SAMPLE ROPE SECTION*

No additional comment.

*EC - 11.3.7 CONSTRUCTION OF ROPE SAMPLE SECTION*

No additional comment.

*EC - 11.3.8 DETERMINATION OF ROPE STRENGTH*

The method of determining rope strength proposed in the DPD is by direct test measurement. (Indeed the importance of the mooring rope strength for the system reliability will justify the expense of a prototype testing programme as recommended in DPD-9.2.2). The alternative method of assessing large rope strength by the means of realisation is not generally deemed acceptable for ropes which will be used in such critical applications.

However, for completeness the realisation method is detailed below and in exceptional cases may be adopted under the agreement of all interested parties as a means of estimating rope strength.

- The approximate strength of the rope shall be determined by multiplying the aggregate strength of rope yarns, taken from the sample rope section, by a rope strength factor determined from the prototype tests.
- The total number of rope yarns in the rope shall be determined (see DPD-11.3.7).
- If all the yarns are of a uniform size, a number of rope yarns equal to half the number giving the nominal diameter in millimetres of the load bearing core shall be selected at random and subjected to the test.
- If the yarn sizes are not uniform, the number of each different yarn size shall be determined and at least 10 samples of each different size tested, the total number of tests being at least equal to the number for equal sized yarns.
- Each sample yarn shall be tested to determine breaking strength as described in ISO 2062 (1995), or an equivalent method. The average yarn breaking strength shall be determined.
- For each yarn size the total yarn breaking strength shall then be determined by multiplying each average strength by the number of such yarns in the load bearing core and summing the totals.
- The calculated breaking strength of rope shall then be determined by multiplying the total yarn breaking strength by the rope strength factor for that particular size and design of rope as given in the Rope Design Specification.

*EC - 11.3.9 FIBRE MATERIAL IDENTIFICATION TESTING*

No additional comment.

***EC - 11.3.10 ASSEMBLY INSPECTION***

It is unlikely that facilities will be available for tensioning the complete rope assembly. Problems associated with providing such a facility include:

large size of loads that need to be applied even to reach 30% CBS of large mooring lines

the large stroke of the loading piston required to deal with the bedding-in extension and initial rope creep

the problems associated with snap-back and safety of people and property when testing such a rope which will store very large amounts of energy

One advantage of such testing is that it would remove the bedding-in strain of the rope prior to installation and this might benefit the installation contractors by simplifying the installation procedures. However it is not clear whether subsequent re-reeling of the rope for storage and deployment may not re-create the bedding-in strain. Thus the benefits of such pre-tensioning would be greatly reduced.

***EC - 11.3.11 INSPECTION OF TERMINATIONS*****EC - 11.3.11.1 Inspection of End Fittings**

No additional Comment

**EC - 11.3.11.2 Spliced eyes**

If cloth is used to protect against chafing, it should be securely sewn in place over the completed eye. If a thin cover of elastomeric material is used to protect against chafing, then it should be highly elastic such that the rope is not constrained from stretching or bending. If a thick cover of elastomeric material is used to encapsulate the eye to protect against chafing, it should be applied over a non-porous tape or cloth which covers the eye and prevents direct adherence to and penetration into the rope.

**EC - 11.3.11.3 Sockets**

The Inspector will review the Socketing Procedures and witness at least one socketing operation. The procedures as described in DPD-10.4 should include minimum bending radius of rope during handling, control and distribution of individual rope elements and alignment control of rope and socket.

In the case of resin secured sockets the Inspector will witness material tests on samples of resin to verify hardness, compressive strength and compressive modulus. These tests to be carried out on 40 mm test cubes poured immediately after mixing from resin used for the first three, last three and middle three socket pours.

**EC - 11.3.11.4 Bend Limiters**

The Inspector will verify that any bend limiters have been manufactured and fitted in accordance with the Fibre Rope Assembly Specification.

## EC - 11.4 CERTIFICATION

*EC - 11.4.1 GENERAL*

Due to the novelty of fibre ropes for offshore mooring systems not all classification societies currently have certification schemes developed.

The following schemes have been identified but discussions with the classification societies or other certification organisations may be needed in order to identify specific certification methods appropriate for fibre ropes for deepwater moorings.

- Bureau Veritas Certification of Synthetic Fibre Ropes for Mooring Systems (Guidance Note NI-432-DTo-R00-E; 1997)
- DNV Conformity Certification Services
- Lloyds Register
- ABS

**References**

- |   |  |
|---|--|
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| <u>FIBRE TETHERS 2000 (1995)</u>                  | <u>Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.</u> |
| ISO 2062 (1993)                                   | “Textiles - Yarns from packages - Determination of single-end breaking force and elongation at break”; ISO (1993)  |
| OCIMF Procedures (1987)                           | “Procedures for Quality Control and Inspection during the Production of Hawsers”; Witherby and Co., London (1987)  |
| <u>Flory, J.F., H.A. Mckenna, and P.T. Gibson</u> | <u>“Improvements in Potted Socket Terminations”, Proceedings of Oceans '95, IEEE. Piscataway NJ, 1995</u>  |
| <u>Flory, J.F.</u>                                | <u>“Rope Termination With Constant-Cross Section”, US Patent 5415, 490. May 16, 1995</u>   |
| <u>Flory, J.F.</u>                                | <u>“Tension Member Termination With Segmented Potting Socket and Central Passage”, US Patent 5,611,636, March 18, 1997</u>   |



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## **EC - 12 INSTALLATION OF FIBRE ROPE MOORING SYSTEMS**

### **EC - 12.1 INTRODUCTION**

Potential installation methods for fibre ropes are bounded by their handling characteristics. These vary for the different fibre materials and rope constructions. It is important to take proper cognisance of these characteristics, and develop suitable installation methods for the particular fibre rope mooring system that is being installed. There have been some notable failures of fibre ropes during their installation, largely due to a failure to pay adequate regard to their handling characteristics.

This section summarises the handling characteristics that must be considered during installation. It also reviews other factors that will affect the method for installation, such as the make-up of the mooring system, including anchor type, vessel and equipment type and availability.

A summary of the current installation methods is provided with notes on applicability for fibre mooring systems. Modifications to these methods, or alternatives, are suggested, where appropriate.

### **EC - 12.2 FIBRE ROPE HANDLING CHARACTERISTICS**

#### ***EC - 12.2.1 MATERIAL AND CONSTRUCTION***

The fibre rope elements to be used in mooring systems may consist of any one of a number of different types of materials and constructions (including sheath types). The various materials and constructions are described in detail in DPD 2 and 3 respectively. These will display different handling characteristics and also differ from steel wire rope. It is therefore imperative that the handling characteristics used as the basis for development of the installation methodology and procedures, are appropriate for the fibre rope material and construction chosen.

#### ***EC - 12.2.2 END FITTINGS***

The end fittings for fibre ropes are discussed in DPD 4.

Bend restrictors may be fitted to limit any rope bending damage at the termination and to assist in handling the rope near the termination.

Based on current technology, the terminations of fibre rope elements will most likely be spliced with a thimble made of steel. Light weight end fittings (high strength metals or composites) may be desirable for simplifying handling during installation.

#### ***EC - 12.2.3 WEIGHT AND SIZE***

Sizes and weights of typical comparable breaking strength mooring lines are listed in DPD-5.2.2. (Table 5.2.1).

When compared with wire rope of the same breaking strength, polyester and nylon fibre ropes are significantly larger in diameter, while aramid and HMPE are comparable to steel wire. All fibre ropes of similar breaking strength are significantly lighter in weight than wire rope. The fibre rope materials also have a specific gravity approximately equal to, or slightly over 1.0, i.e. fibre rope elements are almost neutrally buoyant. HMPE is buoyant.

These characteristics for polyester and nylon fibre ropes, imply the need for large deck space, hold volume, and/or reel size, for storage, transportation and deployment. Required craneage should not however, be adversely affected. The almost neutral buoyancy may present requirements for additional weights during deployment; restrictions on surface vessel movements/operations during deployment; and/or additional requirements to thruster guards.

The large diameter of polyester and nylon ropes will also have a direct impact on the size and weight of the end fittings that are required.

#### *EC - 12.2.4 BENDING RADIUS*

This guide assumes that fibre ropes will not be permanently deployed around sheaves or bollards.

The minimum bending radius for fibre rope while it is being deployed under nominal load levels is dependent on the fibre material, rope construction, and rope sheath type.

Minimum bend radius values are needed to design:

- termination thimbles around which the rope is bent to allow a splice to be formed.
- arrangements for storing the rope on reels for transport and deployment, which should be under very light levels of tension.
- methods of overboarding ropes over installation vessel stern rollers or specially provided sheaves or shoots - in these cases significant levels of line tension may be acting depending on the weight of the equipment suspended. Features that may be relevant here are the number of bending cycles, the construction of the rope, the type of the jacket, the friction forces between rope and roller and the tension in the line.

The first case is specific to termination design and is dealt with in DPD-4.4.6 (Table 4.4.1)

The second case is generally dealt with by the rope manufacturer. Indicative values are provided in DPD-12.2.4 (Table 12.2.1) but only limited information is currently available.

The last case is the most difficult to answer and only limited data is currently available. Until more data is forthcoming the recommendations of DPD-12.2.4 (Table 12.2.1) are recommended as a guide.

In general terms, the minimum bending radius for fibre rope, when expressed as a ratio to the rope radius, is comparable to that for wire rope and may be smaller. However, if fibre ropes of large size are used for new deepwater locations the diameter of the ropes being handled are likely to be greater than is currently typical. Thus there may be a requirement for larger winch drums, fairleads, sheaves, stern rollers, and other deck equipment.

*EC - 12.2.5 TWIST AND TORSION*

Torque or twist should not be applied to fibre rope elements, as degradation in the fatigue life may occur. This is outlined in DPD-5.8 which recommends that all components in a mooring line should be torque balanced.

*EC - 12.2.6 CUTTING DAMAGE*

Fibre ropes are susceptible to mechanical damage arising from frictional or shear contact with deck equipment such as fairleads or stoppers. High friction may potentially lead to shearing of the rope sheath or jacket. Fibre rope should therefore, not be dragged across rough surfaces. Similarly fibre rope should not be brought into contact with sharp edges.

The rope sheath fulfils a number of functional requirements such as preventing ingress of particles and maintaining the fibre bundles in a compact geometry. Damage to the sheath is not therefore acceptable.

To prevent abrasion or chafing damage, frictional contact surfaces encountered during deployment should be relatively smooth. "Coarse Grade Shot" as defined by ISO 8503 Part 1 (1988) is probably acceptable. A shot cleaned surface will produce a much less abrasive surface than one cleaned by grit blasting.

Care should be exercised if running rope quickly over a stationary surface which is well insulated (by for instance a significant coating of paint) as this may result in the rope heating up more rapidly than anticipated due to the thermal insulation of the paint film.

*EC - 12.2.7 SHEARING FORCES*

The controlling feature may be the shear resistance of the jacketing material. The paper by Firth and Sefton (1997) describes the way in which polyurethane jacketing of steel spiral strand ropes controls the allowable radius such ropes can be bent to under tension.

*EC - 12.2.8 HEAT DAMAGE*

Fibre ropes are susceptible to strength degradation when their temperature is raised to a sufficiently high level. The following precautionary measures should therefore be taken with regards to reducing the potential for thermal damage:

- Fibre ropes should be stored away from sources of heat. Strong sources of heat should not be used to dry out wet fibre ropes.
- Hot work, such as welding, in the vicinity of fibre rope should be avoided, or sufficient thermal protection provided.
- Frictional heat from excessive slippage of the fibre rope over a capstan, drum, or other rope, should be avoided. Hauling in and paying out operations should therefore be carefully monitored.

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#### *EC - 12.2.9 CHEMICAL AND UV DAMAGE*

Fibre ropes are susceptible to strength degradation in varying degrees when exposed to certain chemicals. For a comprehensive review of this, see Bridon Fibres (1980) and Morton and Hearle (1993).

#### *EC - 12.2.10 GENERAL CARE*

Fibre ropes will inevitably become soiled during handling unless special measures are taken. Soiling by sharp grit which may penetrate the fibre rope and cause strength reducing internal damage should be avoided. Ropes soiled in this way should be washed with water as soon as possible.

Fibre ropes are susceptible to strength degradation following long term exposure to sunlight. For long term storage, fibre ropes should therefore be kept covered.

#### *EC - 12.2.11 SNAP BACK BEHAVIOUR*

The energy available for snap-back depends on the length of the line under tension, the tension in the line and its elasticity where the line elasticity depends on the material type and the rope construction. Some rope constructions may have less tendency to fail suddenly and instead allow part of the stored energy to be absorbed in heat during failure.

### EC - 12.3 MOORING SYSTEM TYPES AND EXAMPLES

#### *EC - 12.3.1 GENERAL*

The make-up of the complete mooring system, not just the fibre rope elements, affects how the system will be installed. The make-up of typical mooring systems, incorporating fibre rope elements, is briefly described here, with particular emphasis on the anchor systems.

The mooring systems briefly described here are independent of the type of moored vessel under consideration.

The mooring systems being considered for fibre rope systems are:

- taut leg fibre moorings
- fibre rope insert catenary moorings

#### *EC - 12.3.2 TEMPORARY MOORINGS*

No additional comment.

#### *EC - 12.3.3 PERMANENT MOORINGS*

No additional comment.

### *EC - 12.3.4 ANCHOR TYPES*

Anchor types that have been commonly used on catenary line moorings include drag embedment anchors, and anchor piles. Other anchor types in use include gravity anchors and suction anchors.

Existing conventional drag embedment anchors can only resist relatively small uplift loads. They are therefore unsuitable for taut leg moorings where the uplift is of similar magnitude to the horizontal load. New drag embedment anchors are under development that will accept substantial uplift loads.

Anchor piles, gravity anchors and suction anchors are all capable of withstanding uplift loads, although gravity anchors are comparatively not very effective in resisting horizontal loads, and are therefore not discussed further.

### *EC - 12.3.5 CONNECTION TO ANCHORS*

No additional comment.

## **EC - 12.4 INSTALLATION PLANNING**

### *EC - 12.4.1 GENERAL*

In order to give guidance on the most appropriate installation methods for moorings incorporating fibre rope elements, the current methods for installing conventional moorings (i.e. not incorporating fibre rope elements) are summarised, including the installation methods for the various anchor types. Requirements specific to the installation of fibre rope moorings are then presented. The applicability of the current installation methods to fibre rope moorings is then reviewed.

Alternative installation methods, not conventionally used for moorings, but potentially suitable for fibre rope moorings are also reviewed.

#### **EC - 12.4.1.1 Anchor Installation Methods**

Drag embedment anchors are typically deployed by lowering the anchor from the stern of an anchor handling tug/supply vessel. The anchor is either lowered using a pennant wire that will ultimately be attached to the anchor pennant buoy, with the mooring line attached to the anchor being paid out from the moored vessel or from a second anchor handling vessel; or the anchor is lowered by its mooring line.

When the anchor is on the sea-bed, the mooring line is tensioned, either by the moored vessel, or by the anchor handling vessel, to a pre-defined installation tension to bed in the anchor. This installation tension is typically set to a level, such that at the design intact tension no further dragging of the anchor will occur. The anchor's position is typically set by positioning the deployment anchor handling vessel, either relative to the moored structure, or by a global position fixing system. Inaccuracies in the final anchor position will therefore depend on the accuracy of the position fixing system, the relative position of the anchor to the deployment vessel, and the accuracy to which the drag length during bedding in can be predicted.

Variations on this scenario may include the use of specialist mooring installation vessels, although these essentially fulfil the same function as the anchor handling vessel.

Piled anchors are typically deployed from crane barges. The anchor pile is lowered to the sea-bed with the mooring line attached, but slack. The pile is driven through a guidance template using an underwater hammer to a target penetration. The mooring line is then tensioned, using an anchor handling vessel, not for bedding in and testing as with a drag embedment anchor, but to pull the sub mudline section of the mooring line into a reverse catenary, thereby taking out the slack in the line.

Variations on this scenario include the use of drilling vessels instead of crane barges, with the pile and hammer lowered on the drillstring. A further variation is the installation of the pile by drilling and grouting. This requires the use of a drilling vessel, and associated equipment.

Suction anchors are typically deployed by lowering the suction pile to the sea-bed using either a crane barge, or an anchor handling tug/supply vessel fitted with an A-frame or similar. The mooring line is attached to the pile with the line slack. A subsea pump then evacuates the water from the pile until a target penetration is reached. As with a piled anchor, the mooring line is then tensioned to pull the sub mudline section of the mooring line into a reverse catenary, also taking out the slack in the line.

#### EC - 12.4.1.2 Conventional Mooring Installation

For shallow water applications, the entire length of the mooring lines is typically stowed on winch drums or in chain lockers, with the anchors on racks on the hull, actually on the vessel to be moored. The vessel moves to the mooring location either under its own steam, or towed by tugs. The anchors will then be passed to anchor handling tugs, which will then deploy them as outlined in Section 15.4.2. Tensioning of the anchors for bedding in is carried out by the moored vessel cross-tensioning opposite anchors.

For deeper water applications, it is less practical for the entire lengths of mooring chain or wire to be stowed on board the vessel to be moored during transit, because of weight and space restrictions. Also for moorings, where anchors other than the drag embedment type are to be used, there is an increased installation period. For the vessel to be moored to be on location during this period is both costly, and places the vessel at risk. These moorings are therefore typically pre-deployed prior to the vessel arriving on location.

The anchors are deployed as outlined in Section 15.4.2, and then tensioned for bedding in, or setting up the sub mudline reverse catenary, using the anchor handling tug/supply vessel. The length of mooring line being pre-deployed, is then buoyed off for later connection to the moored vessel. The length of mooring line being pre-deployed may be connected directly to the buoy, or the entire line may be laid out on the sea-bed with a pennant line connecting the mooring line to the buoy, or some intermediate arrangement.

When the vessel to be moored arrives on location, anchor handling tugs retrieve the buoys (and pennant lines), and make the connections to the mooring line elements that have been passed from the vessel. The mooring line elements on the vessel are relatively short, sufficient to allow the connection to be made. The vessel then pre-tensions the mooring lines as appropriate.

#### EC - 12.4.1.3 Alternative Installation Operations

Some typical fibre rope mooring line elements have bending radii that are comparable with those for flexible risers and flowlines. The installation procedures, vessels and equipment used for flexible risers and flowlines may therefore be appropriate with some adaptation for fibre ropes.

Flexible risers and flowlines are typically transported to location on large reels, each reel containing a segment of the line. A reel drive is connected to each reel in turn to deploy the line. The line is then typically passed through a set of tensioners (or linear winches). The line is over-boarded either horizontally, passing over a stinger type arrangement of appropriate radius, or vertically, in which case the line will have been turned over a sheave through to the vertical prior to the tensioners. Handling of connectors is by crane or A-frame. The vessels that are used for the installation of flexible risers and flowlines, have often been converted for this application, but much of the equipment is readily demountable.

A further alternative installation methodology, together with the vessels and equipment, that may be appropriate for fibre rope mooring lines, is cable laying. On a cable laying vessel the cable is stowed in a large horizontal basket. The cable is placed in the basket by unreeling it from the quayside. This method will introduce one revolution of twist for each lap of rope paid out. The rope construction should be capable accepting this additional twist without damage or reduction of strength.

#### *EC - 12.4.2 INSTALLATION ACCURACY*

##### **EC - 12.4.2.1 Anchor Positioning**

Accurate control and monitoring of the anchor positioning will be required, in order to ensure that the lengths of the mooring line elements connected to the moored vessel are within the design limits. Accurate control and positioning will be required during lowering, set-down, and for drag embedment anchors, during bedding in. If the anchors are positioned too close to the moored vessel, then there may be interference problems between the vessel mooring hardware and the fibre rope elements. If the anchors are positioned too far from the moored vessel, then the fibre rope elements are not being used efficiently. To optimise the fibre rope mooring system design, the designers will need to use anchor position parametric limits that can realistically be achieved by the mooring system installation contractors.

#### **EC - 12.5 INSTALLATION OPERATIONS**

##### *EC - 12.5.1 GENERAL*

Based on the fibre rope handling characteristics presented in DPD-12.2, the following specific requirements for the installation of fibre rope mooring systems should be noted.

##### **EC - 12.5.1.1 Bending Sheaves, Fairleads, Roller Drums**

The required minimum diameter for any item of deck equipment that may be used to turn a fibre rope, should be determined for the rope in question.

For some typical fibre rope mooring elements, the combination of these factors may produce a required minimum bending diameter considerably in excess of the size of the stern rollers and winch drums on typical anchor handling tugs/supply vessels, or of commonly available sheaves. In these cases special arrangements must be made.

The use of these vessels for installation of a fibre rope mooring system, whereby the procedure requires deployment over the stern, will not therefore be feasible without either a change to the fibre rope over-boarding arrangement, or revising the specification of the fibre rope elements. The latter is, of course, only an option at the design stage of the fibre rope elements. To change the over-boarding arrangement, a number of alternatives exist. For example, a static guide of approximately quarter circle section, of the required radius, and a suitable width, could be mounted over the stern roller for deploying the fibre rope elements. If the diameter of the winch drum is inadequate, then again a number of alternatives exist. A linear winch could be used deploying the fibre rope directly from its transportation reel. The gripper details of the linear winch may however also need to be modified to be suitable for the fibre rope elements.

As the extent of modifying and/or re-equipping existing anchor handling tugs/supply vessels increases, the use of alternative installation methods and vessels may become more appropriate.



**EC - 12.5.1.2 Winch Drum Capacity**

The required winch drum capacity for fibre rope elements for deepwater applications may be greater than is available on typical anchor handling tug/supply vessels for some combinations of material type and breaking strength. This would be exacerbated if the fibre rope construction was one of large minimum bending radius.

Alternatives may include deployment from the transportation reel using a linear winch as noted in DPD-12.5.2, driven reels, or the use of alternative installation methods and vessels.

**EC - 12.5.1.3 Sea-bed Contact Point During Temporary Pre-deployed Condition**

In order to avoid problems with abrasion, and/or kinking of the fibre rope, the fibre rope elements should be kept clear of the part of the mooring line where it touches the sea-bed in its pre-deployed condition. The fibre rope element can either be laid down completely on the sea-bed, in which case cover design should prevent particle ingress or be suspended from the temporary buoy above the sea-bed. The element where the mooring line touches the sea-bed should be either wire or chain. Due consideration should be given to environmental effects (tide, current, waves, wind, etc.) changing the position of the touchdown point.

**EC - 12.5.2 LINE CONTROL DURING DEPLOYMENT**

No additional comment.

**EC - 12.5.3 AVOIDANCE OF FIBRE COMPRESSION FATIGUE DAMAGE**

In order to avoid problems with structural or axial compression fatigue, the criteria set out in DPD 8.2.9.3/DPD 12.5.3 should be met.

**EC - 12.5.4 MINIMUM INSTALLATION TENSIONING**

There may be a requirement to carry out a fibre rope tensioning routine in order to eliminate some of the constructional bedding in that may otherwise occur during subsequent periods of bad weather, and to ensure that the stiffness of the mooring lines is within the system design limits. This could be carried out either during pre-deployment of the mooring lines or during connection to the moored vessel. The timing is dependent on various parameters such as the duration between and the likely fibre rope loading regime during pre-deployment of the mooring lines and connection up of the moored vessel, which both affect the potential relaxation of the fibre rope that may occur, and the capabilities of the installation vessels.

The tensioning routine recommended for fibre ropes in DPD-12.5.4 (Table 12.5.1) in which an initial load of 30% CBS is applied for at least one hour is recommended.

**EC - 12.5.5 NORMAL PRE-TENSIONING**

No additional comment.

**EC - 12.6 FIBRE ROPE PRE-DEPLOYMENT****EC - 12.6.1 GENERAL**

No additional comment.

*EC - 12.6.2 SURFACE BUOYED LINES*

No additional comment.

*EC - 12.6.3 BOTTOM LAID LINES*

No additional comment.

*EC - 12.6.4 MID SPAN SUSPENDED LINES*

No additional comment.

*EC - 12.7 TYPICAL FIBRE ROPE MOORING INSTALLATION SCENARIOS**EC - 12.7.1 INTRODUCTION*

In order to illustrate some of the aspects that need to be considered during the installation of a fibre rope system some examples are presented below. These are not fully developed installation schemes but represent feasible approaches to the problem of installing deepwater fibre mooring lines. The water depth assumed for the examples is 1,000 metres and the vessels are scaled accordingly.

The sequences for two typical but different mooring systems are shown. It is emphasised that these are typical for illustrative purposes only, and do not necessarily represent best practice, or the commercially most viable solutions.

*EC - 12.7.2 TEMPORARY INSTALLATION - INSERT CATENARY MOORING*

The first fibre rope mooring system is a taut leg mooring system in 500 m water depth, with vertically loaded drag embedment anchors. The fibre rope elements are made from aramid of 1000 tonne certified breaking strength. The mooring system is being used to moor a semi-submersible platform.

This illustration considers the platform being moored on arrival. Alternatives would include the pre-installation of the lines. The installation sequence is illustrated in Figures 12.7.1(a) through (e).

- a) On arrival of the platform at the site the anchor chain end is disconnected and the anchor taken by the first Anchor Handling Vessel (AHV). The second AHV connects the chain line to the fibre rope line stowed on its winch drum or spooling reel.
- b) The fibre rope is reeled out by AHV(2) while AHV(1) moves over to the target anchor location.
- c) When AHV(2) has finished reeling the rope out it connects the end to the platform fairlead chain length and overboards the connection.
- d) AHV(1) lowers the anchor using a deployment wire and positions the anchor just beyond the target anchor position while AHV (2) maintains tension on mooring line to prevent it contacting the deployment line.
- e) The anchor is lowered to the seabed and the line tensioned by the platform. AHV(1) deploys a marker buoy to suspend the anchor recovery line.

The use of aramid rope means that the minimum bending radius does not create a problem, and each mooring leg can thus be deployed in an almost conventional manner from an anchor handling tug using its winch. The aramid mooring elements have been transported to location on reels on the stern of the tug. They are then in turn each reeled on to the tug's main winch, and the vertically loaded drag embedment anchor attached.

The anchor is over-boarded using an A-frame on the tug stern, and the aramid rope element is deployed along a gutter laid along the tug's deck, to minimise any potential problems regarding cleanliness. Deploying the anchor using the aramid rope should not exceed the allowable number of low load cycles. The anchor position is monitored during deployment, using a positioning system. The mooring line is tensioned, and the anchor is embedded.

A clump weight is attached to the end of the aramid rope element, and this is then deployed with a pennant wire and surface buoy attached. The clump weight is lowered to the sea-bed using the pennant wire, and the buoy over-boarded, and disconnected from the tug winch. The clump weight ensures that the aramid rope element is left in a stable position on the sea-bed, prior to arrival of the vessel to be moored.

These operations are repeated for all mooring legs.

Once the vessel arrives on location the anchor handling tug collects the end of the mooring line element attached to the vessel. The tug then proceeds to the first pennant buoy, picks it up using the pennant line, and retrieves the clump weight and end of the aramid rope element onto the tug deck. The aramid rope element is attached to the mooring line element from the vessel, and the connection carefully over-boarded. This is repeated for all of the mooring legs.

The required aramid rope tensioning routine is carried out by winches on the vessel itself, with the assistance of its towing tugs, if necessary.

### *EC - 12.7.3 TEMPORARY INSTALLATION - TAUT LEG MOORING WITH SUCTION ANCHOR*

The second fibre rope mooring system is a taut leg mooring system in 1000 m water depth, with suction anchors. The fibre rope elements are made from polyester of 1000 t certified breaking strength, and with an extruded sheath. The mooring system is being used for a turret moored FPSO.

In this example shown in Figure 12.7.2 (a) through (c) the platform arrives at the location while the mooring lines are being deployed.

- (a) The fibre line is connected to the suction anchor and reeled out by one AHV while the other vessel deploys the suction anchor and umbilical.
- (b) The suction anchor is located and activated while AHV(2) connects the top end of the fibre rope to the fairlead chain from the platform and overboards the connection.
- (c) After installing the anchor AHV(1) retrieves the suction equipment and umbilical and the platform test loads and pretensions the line.

The minimum bending radius requirement, together with the winch drum capacity, would necessitate significant modification to most anchor handling tugs. The use of suction anchors, and the subsequent need to deploy and connect up the risers has led to the use of a vessel equipped for flexible riser installation, to which only minor modification is required. The polyester rope elements have been transported to location on reels on the stern of the installation vessel.

The first suction anchor is connected up to the sea-bed chain. The polyester mooring element is deployed through the vessel moonpool, cross-hauled and attached to the sea-bed chain. The anchor is over-boarded and deployed to the sea-bed using the vessel's crane. The polyester rope element is kept slack, as it is deployed through the moonpool using the linear winches. The anchor position is monitored during deployment using an acoustic positioning system.

Once the anchor has reached the sea-bed and is being installed, the weight of the sea-bed chain is supported by the polyester mooring element, and the linear winches. When the anchor has reached its target penetration, the pumping skid is returned to the installation vessel. The remaining length of polyester rope is deployed, and the required rope tensioning routine is carried out.

A clump weight is attached to the end of the polyester rope element, and this is then deployed with a pennant wire and surface buoy attached. The clump weight is lowered to the sea-bed using the pennant wire, and the buoy over-boarded, and disconnected from the installation vessel winch. The clump weight ensures that the polyester rope element is left in a stable position on the sea-bed, prior to arrival of the vessel to be moored.

These operations are repeated for all mooring legs.

Once the vessel arrives on location an anchor handling tug collects the end of the chain attached to the vessel. The tug then proceeds to the first pennant buoy, picks it up using the pennant line, and retrieves the clump weight and end of the polyester rope element onto the tug deck. The rope element is attached to the chain from the vessel, and the connection carefully over-boarded. This is repeated for all of the mooring legs.

#### *EC - 12.7.4 PRE-DEPLOYED MOORING - STORED ON SEABED*

The example shown in Figure 12.7.3 (a) through (d) illustrates how a fibre rope can be safely laid on the seabed to await subsequent connection to a platform.

- (a) AHV (1) connects the fibre rope it has stored on its winch drum onto the suction anchor on AHV(2). The Suction anchor is overboarded and lowered to the seabed while AHV(1) reels out the rope.
- (b) After the anchor is positioned it is installed by the suction equipment run from the umbilical from AHV(2) while AHV(1) continues to reel out rope.
- (c) With the suction anchor fully installed AHV(2) disconnects and retrieves the umbilical. AHV(1) continues to deploy the line including an end weighted section which is lowered to the seabed by a recovery line.
- (d) When the mooring line is on the seabed AHV(1) marks the top of the recovery line with a buoy. The line is then left on the seabed until it is required when it is recovered by reversing the last step and connecting the top end of the fibre rope to the arriving platform fairlead chain.

#### *EC - 12.7.5 PRE-DEPLOYED MOORING - SUSPENDED BY MID LINE BUOY*

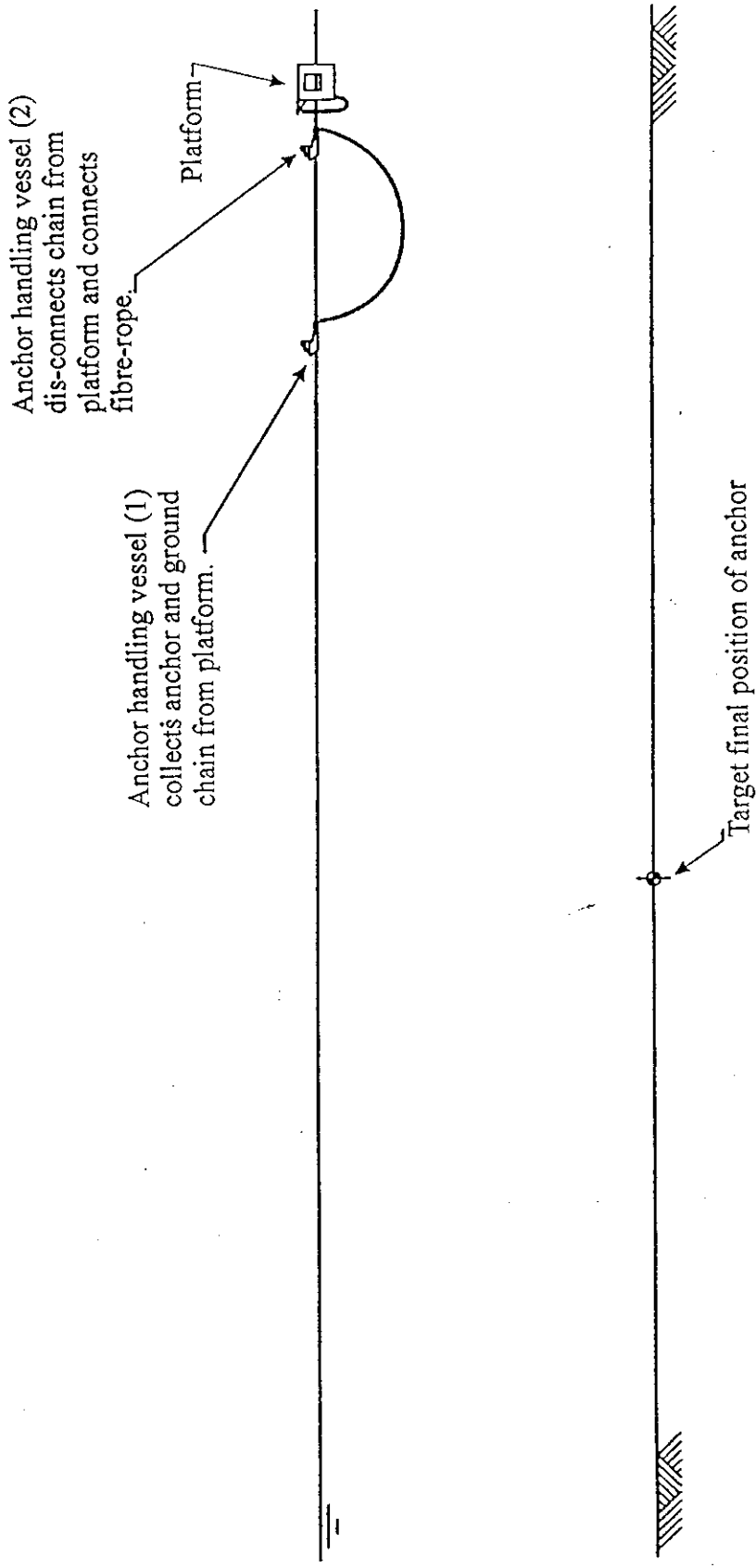
The sequence is illustrated in Figure 12.7.4 (a) through (c).

- (a) As in Figure 12.7.3 AHV(1) unreels a fibre rope while AHV(2) deploys a suction anchor. However at the mid length of the fibre rope a spring buoy is inserted and the deployment continued.
- (b) AHV(1) completes reeling out the fibre rope and then pays out a weighted end which is part of the eventual fairlead chain length.
- (c) The weighted end of the line is lowered to the seabed by AHV(1) using a recovery line which is buoyed-off. This leaves the fibre rope buoyed at mid length.

The advantages of this system are that the fibre rope avoids prolonged contact with the seabed and consequent possible incursion of sand and grit into the rope. The ends of the fibre rope are kept clear of the seabed and chain used at the thrash zone. Suspending the line well below the surface will avoid the rope being subjected to wave action although it will be affected by currents. The recovery operation requires the weighted top end to be lifted from the seabed and connected to the fairlead chain of the incoming platform.

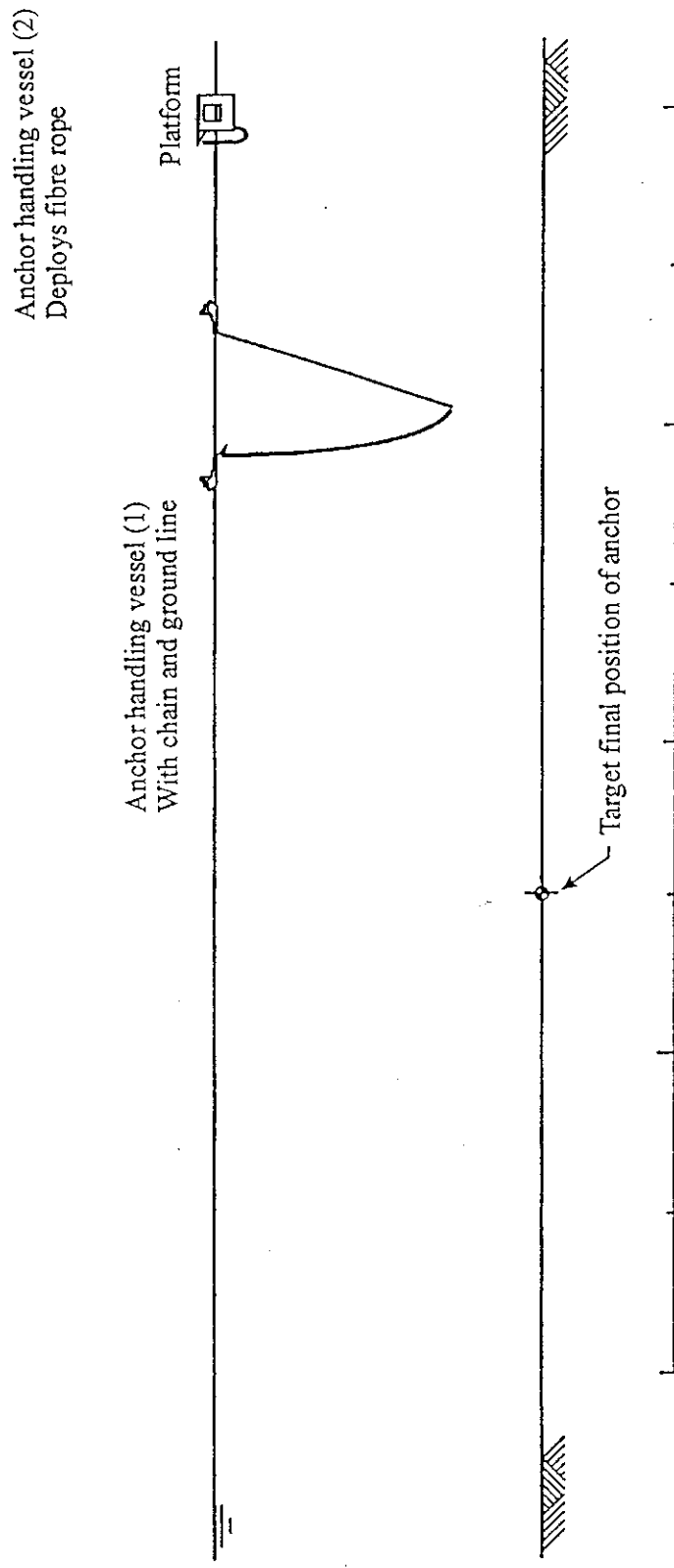
#### **REFERENCES**

- 
- Bridon Fibres (1980) "Ropes Made From Man Made Fibres - Section E - Chemical Resistance, Bridon Fibres and Plastics, London 1980
- Morton, W.E., and Hearle, J.W.S., (1993) "Physical properties of textile fibres"; 3rd edition; The Textile Institute, Manchester, 1993
- Firth, K.M., and Sefton, S.L., (1997) "The installation of Spiral Strand Mooring Cables in Deep Water"; Bridon Structural Systems, Technical Report, Bridon, Doncaster, October 1997
- ISO 8503-1 (1988). "Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates - Part 1 : Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces".



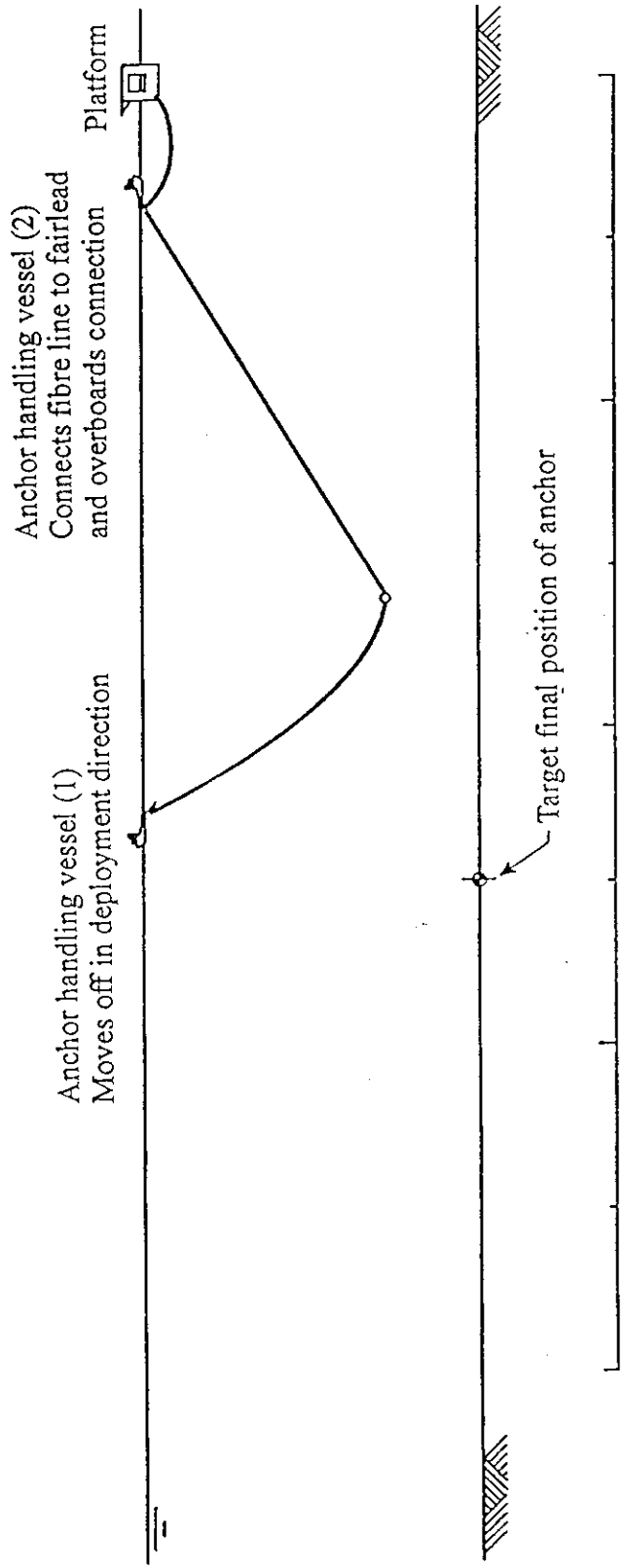
A) Arrival of platform and dis-connection of anchor section

**Figure EC 12.7.1 a**  
**Installation of a Fibre Rope Insert Catenary Mooring**



B) Fibre rope deployment commences

**Figure EC 12.7.1 b**  
Installation of a Fibre Rope Insert Catenary Mooring



C) Fibre rope connected to platform

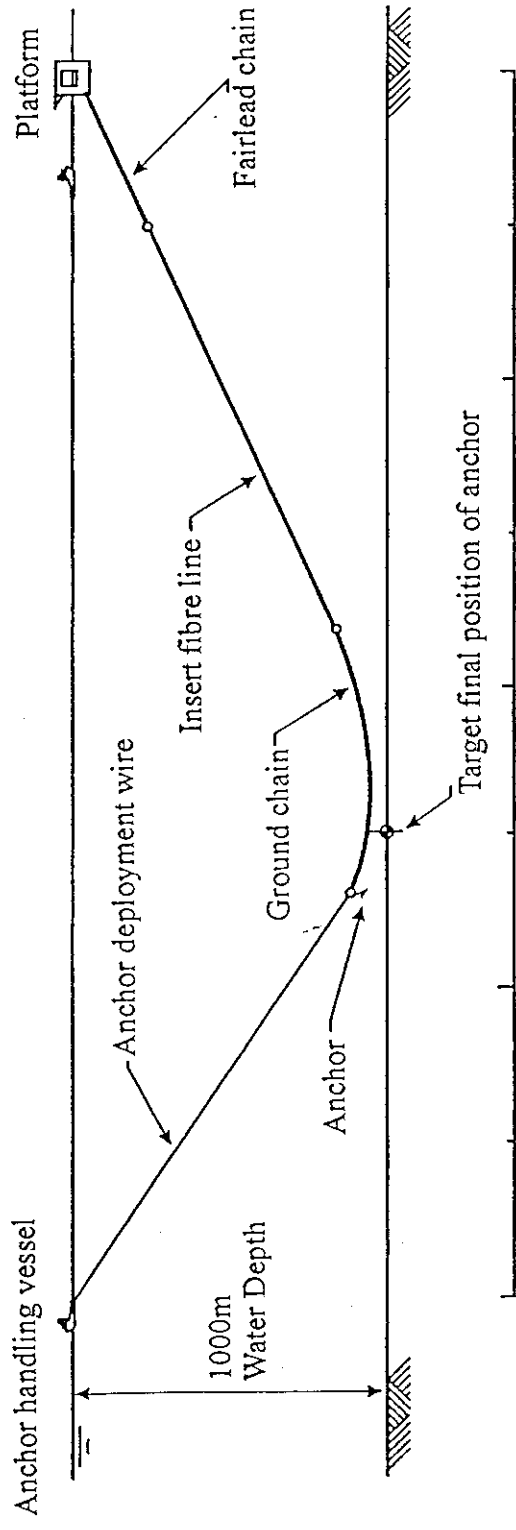
**Figure EC 12.7.1 c**  
**Installation of a Fibre Rope Insert Catenary Mooring**



NOTES:-

- a) The AHV should not use a chaser running over the fibre rope.
- b) The platform fairlead chain must be long enough to avoid the fibre line running over the fairlead.
- c) The ground chain should be long enough to keep the fibre line clear of the sea-bed.
- d) The Anchor must resist up-lift of the ground chain and must be heavy enough to remove the uplift of the fibre line.

Anchor handling vessel used to place anchor so it can be pulled into the target position by the floating platform

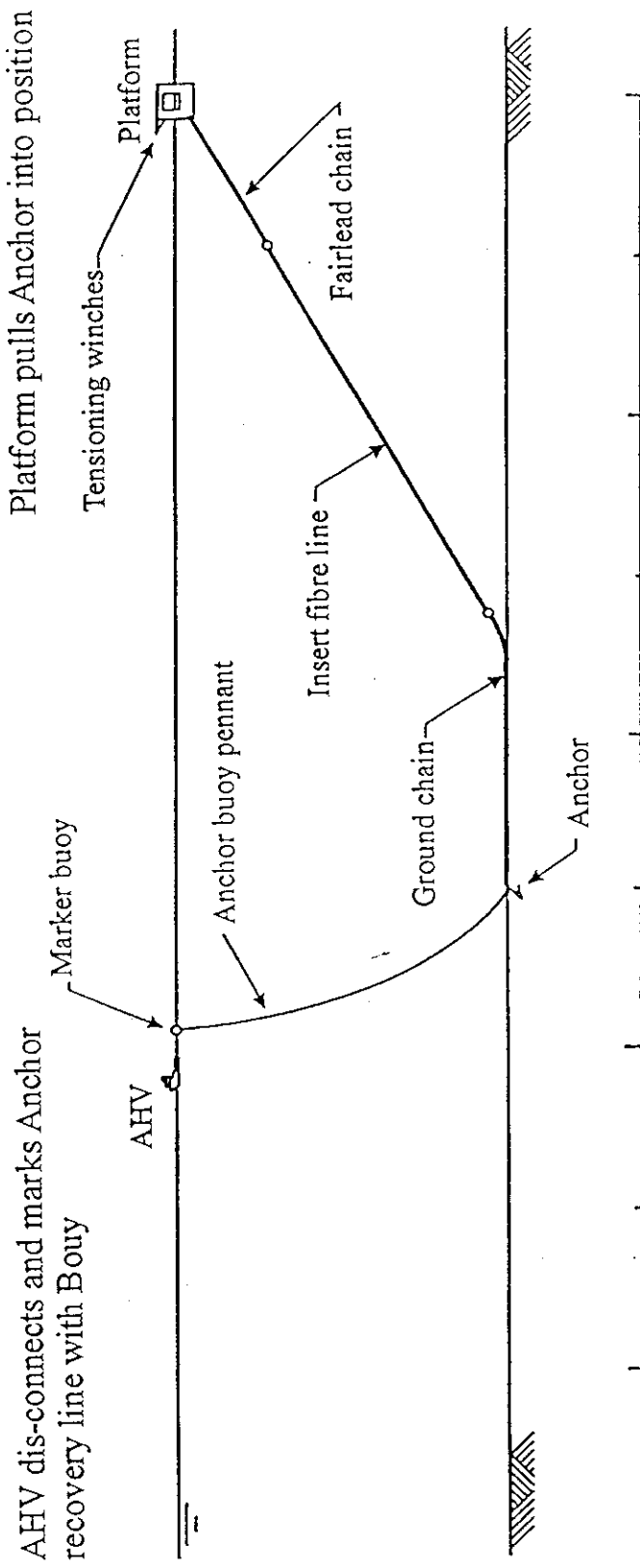


D) Anchor positioned

Figure EC 12.7.1 d  
Installation of a Fibre Rope Insert Catenary Mooring

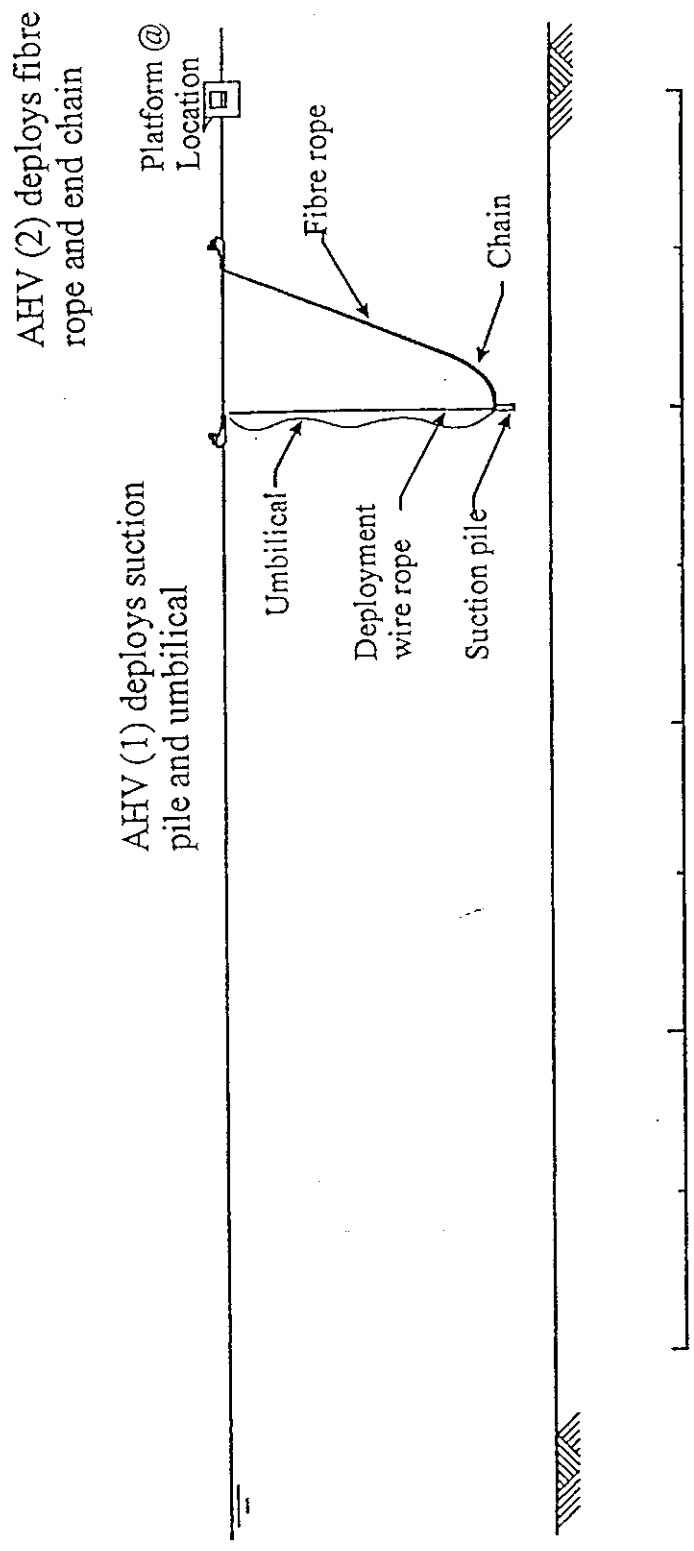
NOTES:

- A) Large buoy needed to support AHV wire connection to anchor
- b) Platform based winches must be capable of tensioning Anchor into target position



E) Anchor tensioned and buoyed off.

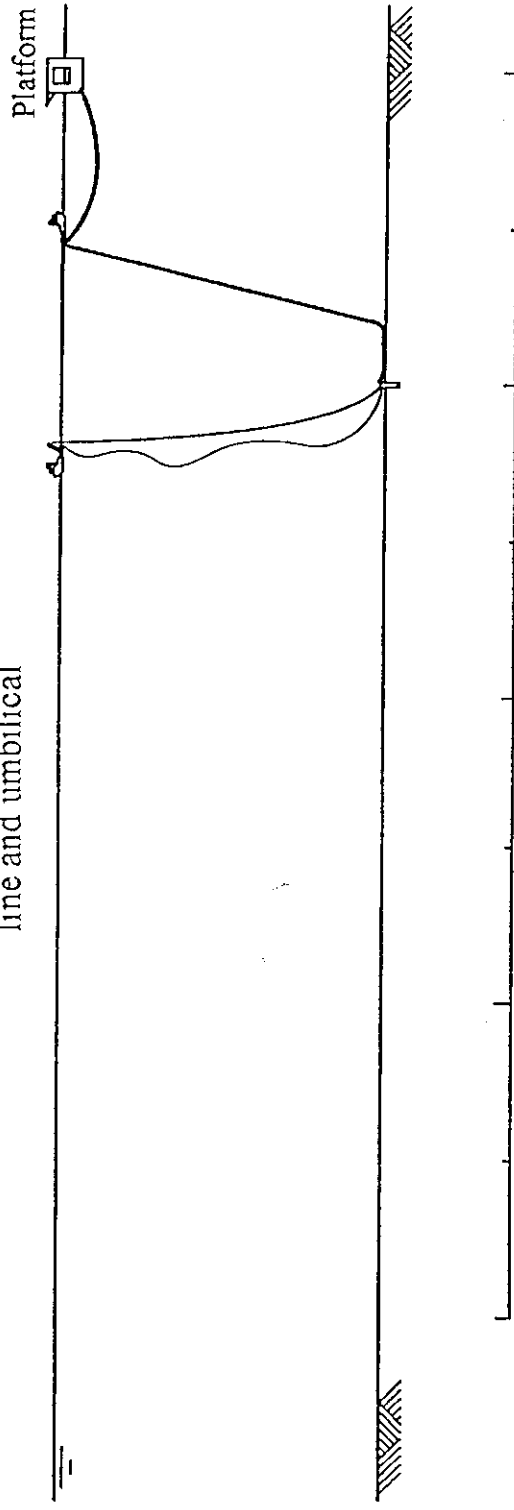
Figure EC 12.7.1 e  
Installation of a Fibre Rope Insert Catenary Mooring



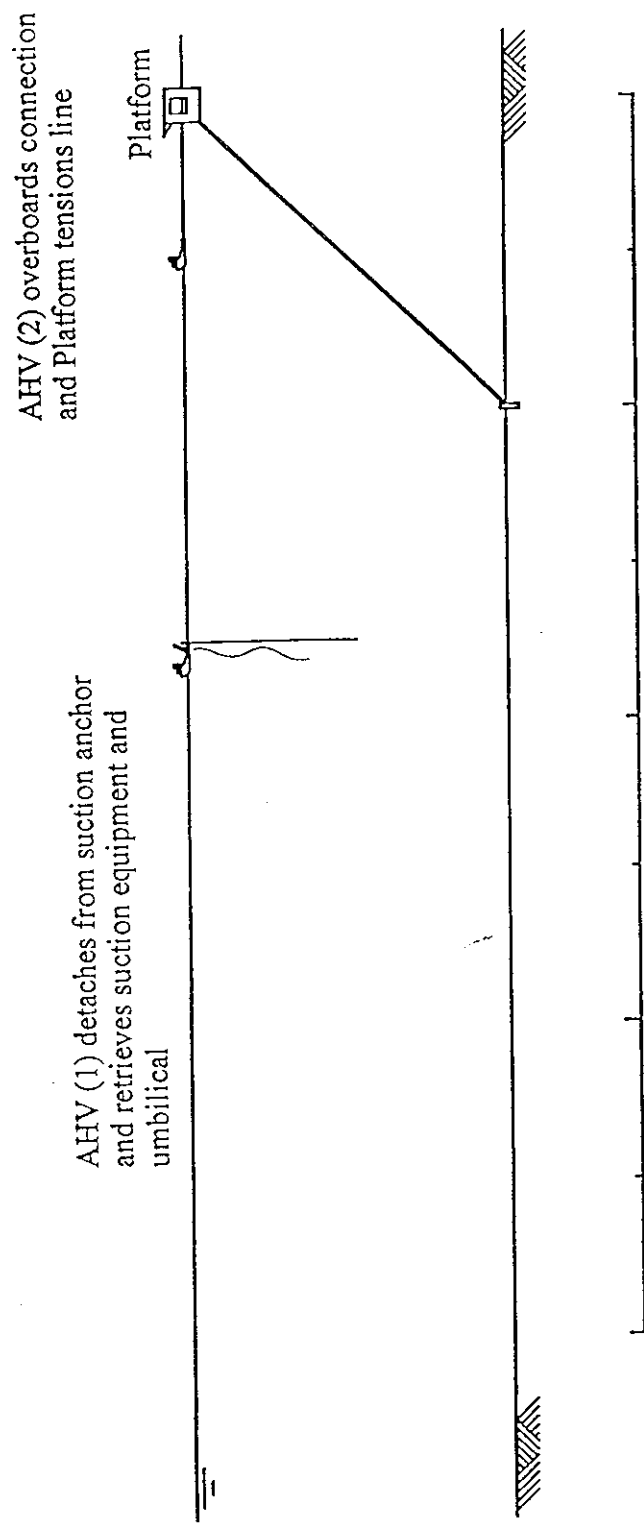
**Figure EC 12.7.2 a**  
**Installation of a Fibre Rope Insert Catenary Mooring**

AHV (2) completes reeling out fibre rope and makes connection to fairlead chain

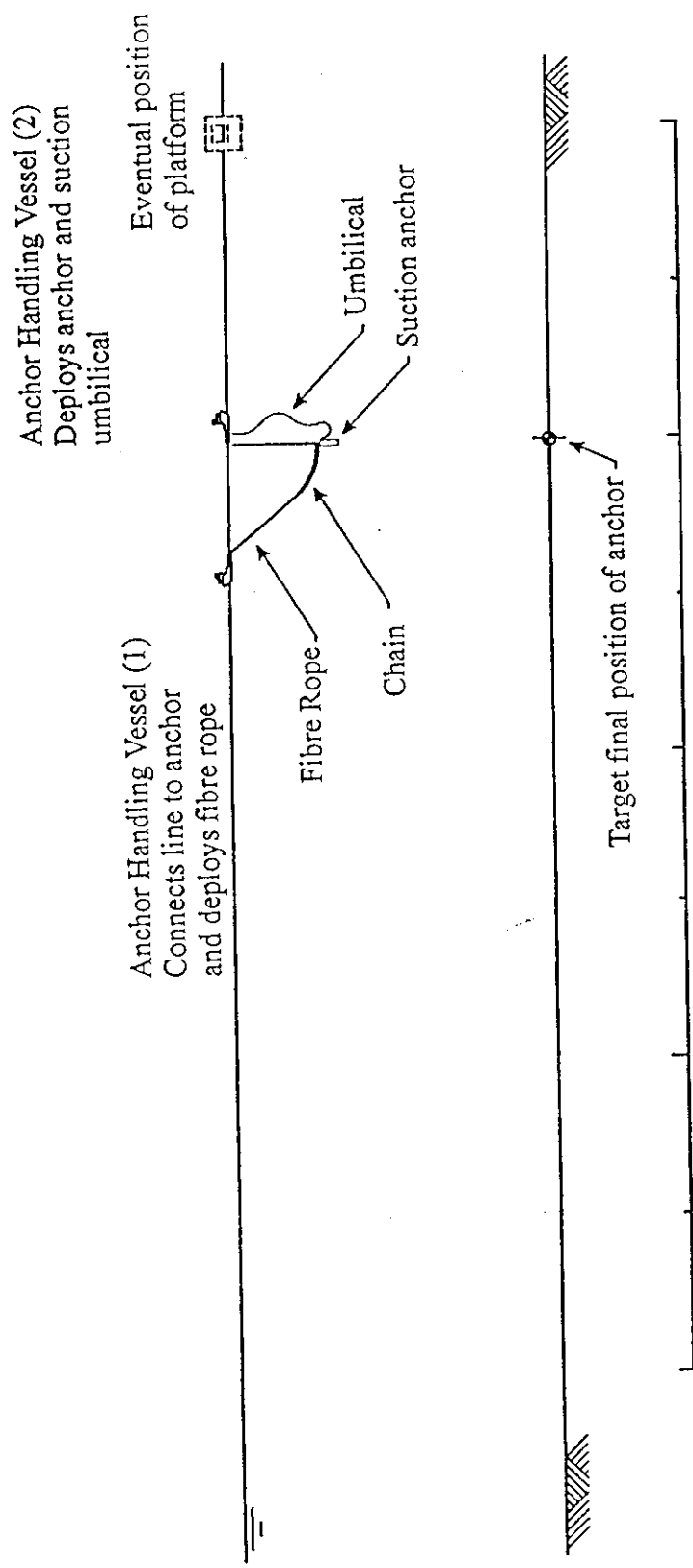
AHV (1) empaces suction anchor and removes deployment line and umbilical



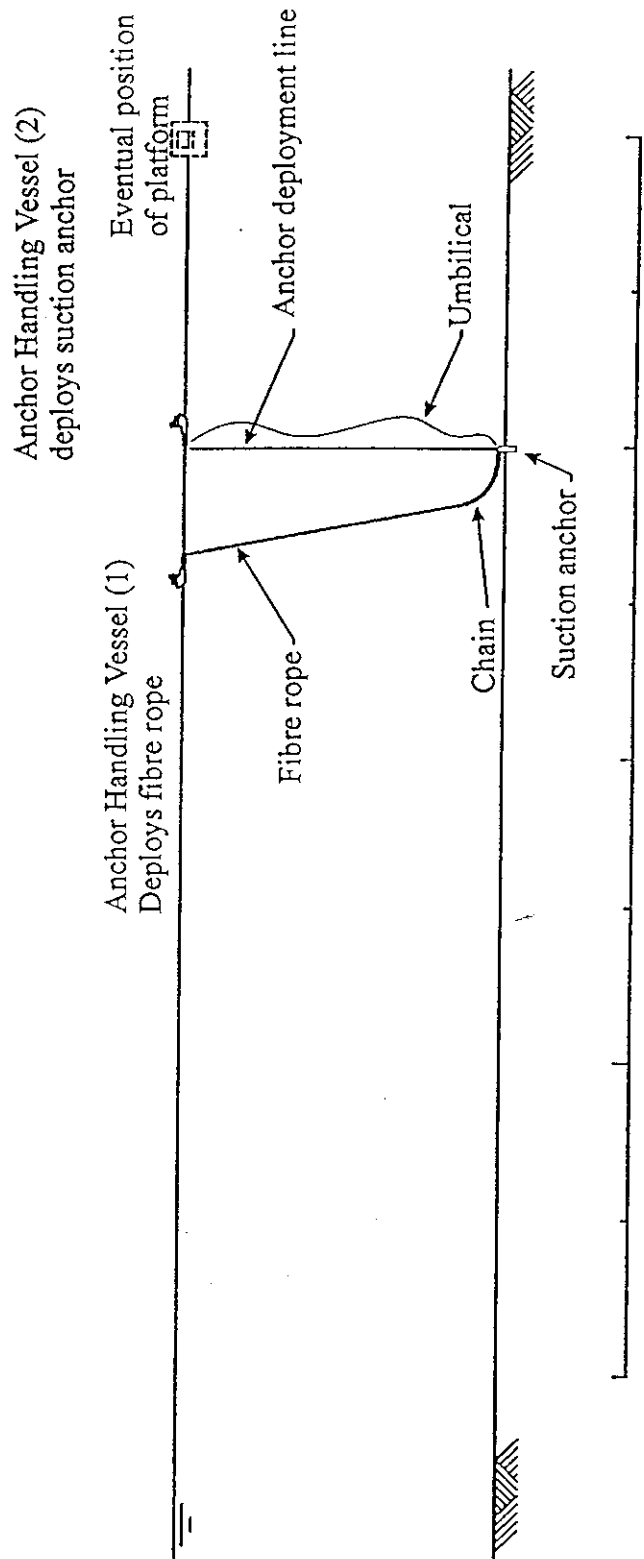
**Figure EC 12.7.2 b**  
Installation of a Fibre Rope Insert Catenary Mooring



**Figure EC 12.7.2 c**  
**Installation of a Fibre Rope Insert Catenary Mooring**



**Figure EC 12.7.3 a**  
**Installation of a Fibre Rope Insert Catenary Mooring**



**Figure EC 12.7.3 b**  
Installation of a Fibre Rope Insert Catenary Mooring

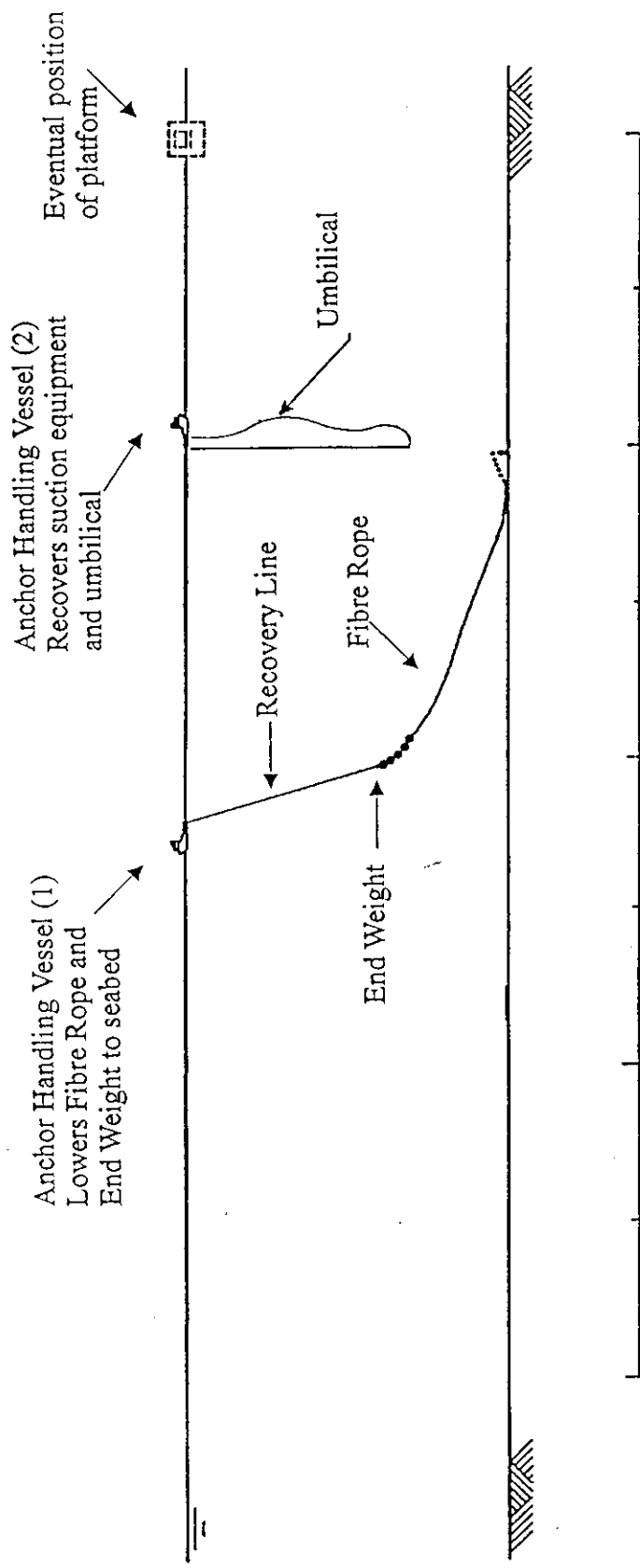
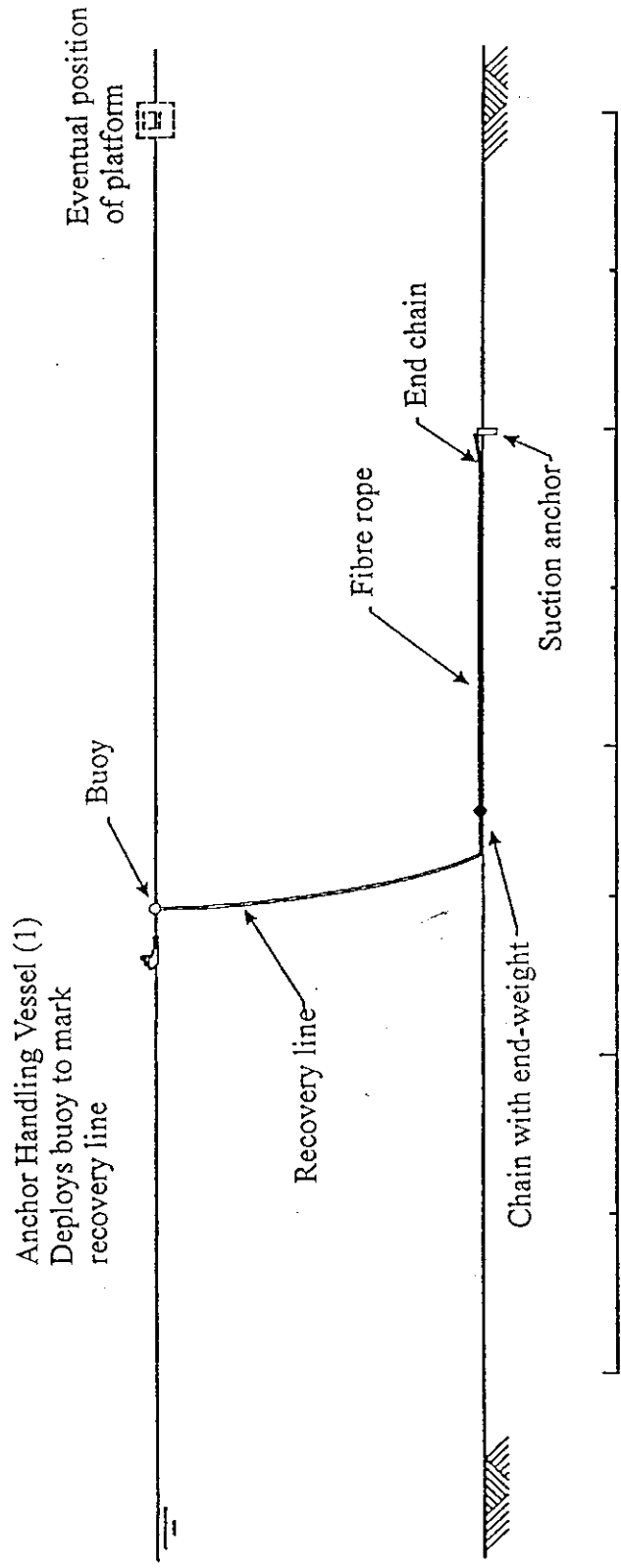


Figure EC 12.7.3 c  
Installation of a Fibre Rope Insert Catenary Mooring





**Figure EC 12.7.3 d**  
**Installation of a Fibre Rope Insert Catenary Mooring**

Anchor Handling Vessel (2)  
Deploys suction anchor  
and umbilical

Anchor Handling Vessel (1)  
Connects line to anchor  
and deploys fibre rope with  
mid-length buoy

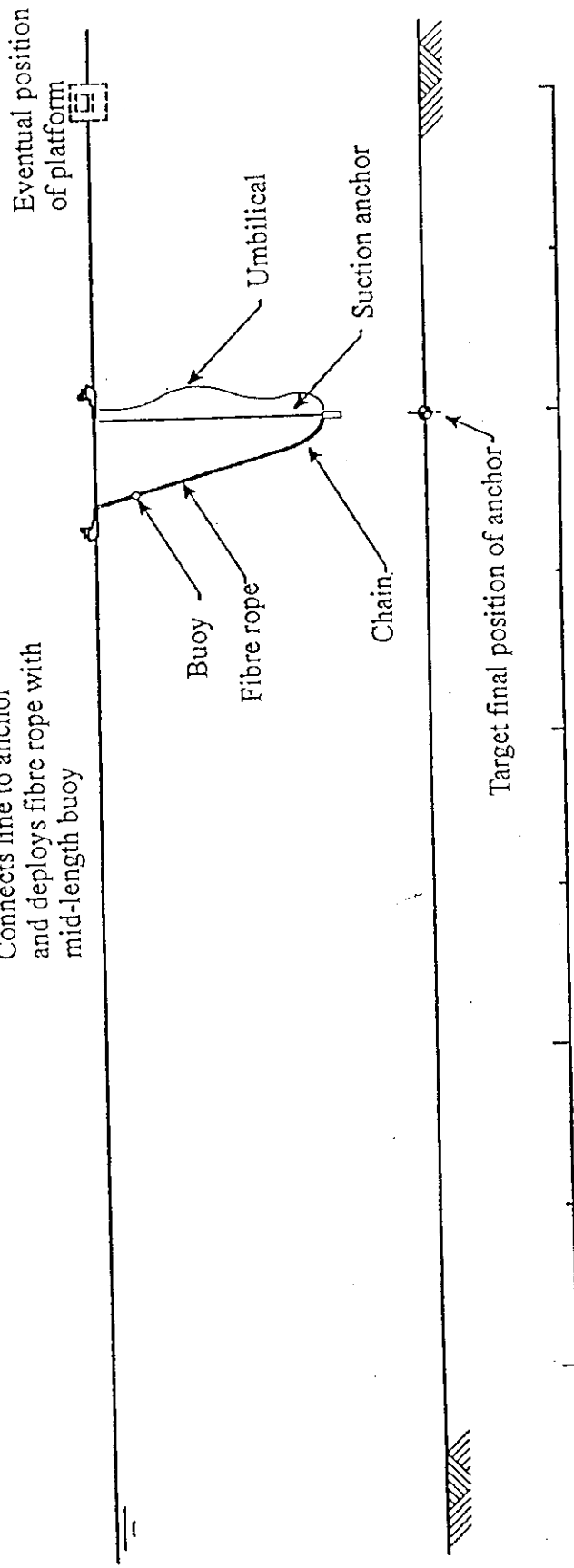
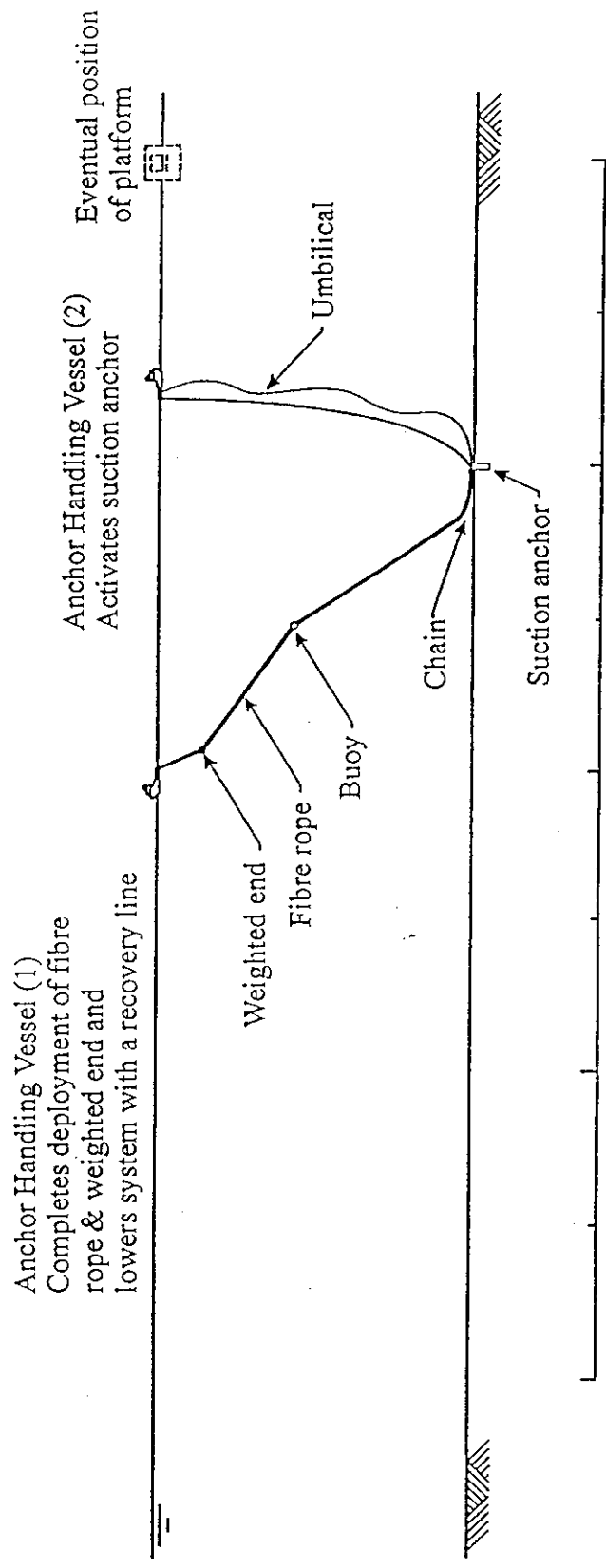


Figure EC 12.7.4 a  
Installation of a Fibre Rope Insert Catenary Mooring



**Figure EC 12.7.4 b**  
**Installation of a Fibre Rope Insert Catenary Mooring**

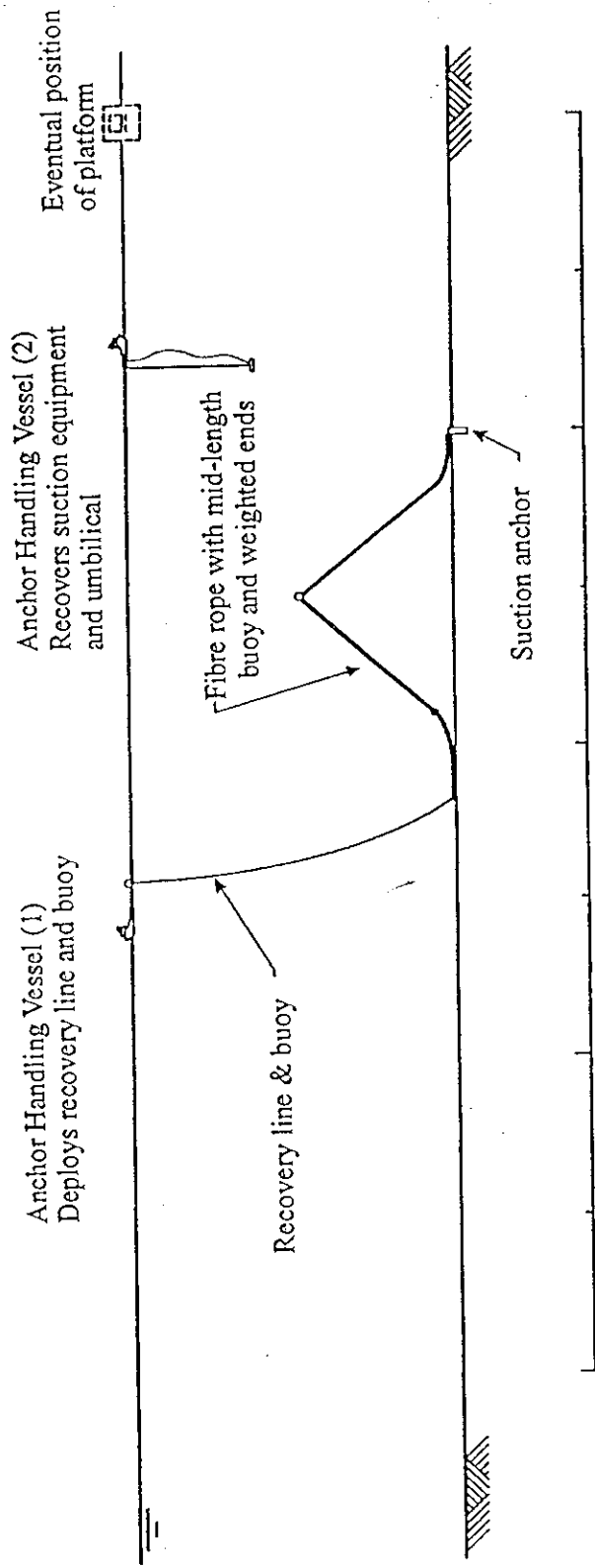


Figure EC 12.7.4 c  
 Installation of a Fibre Rope Insert Catenary Mooring

Document History:

r2va	new	rwps	Oct 97
	plus final mods	rwps	30.Nov.97
r3va	part updating	rwps	20 May 98

<b>EC - 13. OPERATION, LIFETIME INSPECTION AND RETIREMENT</b>	<b>1</b>
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**EC - 13. OPERATION, LIFETIME INSPECTION AND RETIREMENT**

EC - 13.1 INTRODUCTION

No additional comment.

EC - 13.2 OPERATION

As in the case of other operations where personnel are close to the rope and which involve equipment being handled adjacent to the fibre rope care must be exercised to avoid injury from snap-back energy released if the rope breaks (see DPD-12.2.11)

EC - 13.3 LIFETIME INSPECTION

*EC - 13.3.1 GENERAL*

No additional comment.

*EC - 13.3.2 EXTERNAL CONDITION INSPECTION*

No additional comment.

### EC - 13.3.3 INTERNAL CONDITION ASSESSMENT

When designing the representative insert lines they should be short enough to minimise handling problems and also to allow the complete insert (including terminations) to be break loaded in a shore based testing machine.

In cases where the inspection specification developed by the Operator does not envisage retrieval and testing of insert lines it may be prudent for the operator to supply such insert lines so that the option of testing a sample of rope without removing the entire mooring line is available.

### EC - 13.3.4 DESTRUCTIVE TESTING

No additional comment.

#### EC - 13.3.4.1 Break Tests

Testing facilities world-wide for large fibre ropes are limited. This is due partly to the large load capacity required to break the sizes of ropes under discussion. Also the axial extensibility of fibre ropes (in comparison with steel) means that a large loading stroke is required. Only a few large rope testing machines are available world-wide and the size of ropes they can accommodate depends on the extensibility, strength and length of the specimen. Typically specimen lengths of about 10 metres can be tested in the largest machines currently available (1997). The length chosen when designing Insert lines should take account of testing machine dimensions.

If a complete fibre mooring line is recovered for testing it should be cut to a suitable length but the test length should include one of the original terminations.

Residual fatigue life tests could also be conducted to assess rope condition as discussed further in EC-13.

#### EC - 13.3.4.2 Detailed Rope Core Examination

An estimate of the residual strength of a rope can be obtained by a dismantling a section of rope into the strand and yarn components and observing damage and undertaking break tests on the constituent yarns. This method has the advantage of detecting any incipient fatigue mechanisms that rope strength testing may not detect. Such an inspection should be undertaken by a suitably qualified specialist. Following inspection a report should be prepared which estimates the residual strength of the rope based on the findings of the examination.

#### EC - 13.3.4.3 Yarn Finish, Lubricants and Filler Durability

Reduction of yarn finish, lubricants or fillers may occur as a result of leaching in seawater. The effect can be expected to be more severe in parts of the rope where the jacket has become damaged. Reduction in these lubricating agents may result in accelerated friction and wear of the fibres.

### EC - 13.4 RETIREMENT

The mooring line retirement plan should provide for the replacement of mooring lines which fall below an agreed retained strength limit. This limit should be consistent with the assumptions made in the calculation methods and tension limits used in the mooring analysis. Further work is required to determine the appropriate target residual strength at which line replacement should occur.

**References**

- API RP 2SK (1996) "Recommended Practice for Design and Analysis of Station keeping Systems for Floating Structures"; American Petroleum Institute Recommended Practice 2SK; 2nd Edn. December 1996 (effective date : 1st March 1997)
- Fibre Tethers 2000 (1995) Joint Industry Study Fibre Tethers 2000; High Technology Fibres for Deepwater Tethers; Phase 1; NDE/NEL/TTI; Noble Denton Report L17317/NDE/rwps dated 10th Feb 1995 with Rev 1 additions dated 20 June 1995.

**Appendices**

## Engineers Design Guide - Deepwater Fibre Moorings

### Appendices List

(for DPD Rev 4 Issue)

Appendix	Title	Supplied by
<b>1</b>	<b>Terminology etc</b>	
1.1	Fibre Rope Terminology	JWSH
1.2	Fibre Rope Units and Conversions	NDE
1.3	Fibre Rope Modulus Definitions	JWSH/RWPS ?
<b>2</b>	<b>Fibre Properties</b>	
2.1	List of Yarn Tests	SJB
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9.1	Proposed prototype testing	



DRAFT

jwsh - June 24, 1998

jwsh - June 29, 1998

**ENGINEERS DESIGN GUIDE FOR DEEPWATER FIBRE MOORINGS****APPENDIX 1.1****FIBRE ROPE TERMINOLOGY**

This Appendix contains a list of definitions of fibre rope terminology, which is relevant to deepwater moorings and directed towards design engineers. Alternative definitions may be appropriate in other contexts. Generally, the first definition given is the most academically precise; the second definition (*in italics*), where given, is an indicative expression selected for ease of understanding. Terms in **bold** in a definition are themselves included as definitions. Definitions taken directly from other published sources are marked with the abbreviations below; if the definition is slightly modified the source is put in (brackets).

- AS ASTM D 123-96: Standard Terminology Relating to Textiles 1996  
 BS British Standard BS 3724: Glossary of Terms - draft 1964  
 CE American Society of Civil Engineers: Glossary of Fiber Rope Terms 1993  
 ISO ISO 1968-1973 (E/F): ROPES AND CORDAGE - VOCABULARY 1973  
 TI Textile Institute: Textile Terms and Definitions 10th edition 1995

Other sources, which were consulted, include

- CMI [UK] Cordage Manufacturers' Institute: Glossary of Cordage Terms 1989  
 CI97 [USA] Cordage Institute Standards CI 1403-97: Terminology for Fiber Rope - provisional 1997  
 FT Fibre Tethers 2000 Main Report Preface: Table of Definitions 1995  
 IM Institute of Marine Engineers: Glossary of Marine Technology Terms 1980  
 SA Fibre Tethers 2000 State of the Art Report Section G: Terminology 1990  
 SPM Halyard Guide to Single Point Moorings of the World

**abrasion ( see also internal abrasion, external abrasion)**

- CE Surface wear on fibers, yarns and strands due to rubbing between these internal elements, or on the rope surface due to rubbing against an external surface.  
*Wearing away of fibres by friction.*

**Admiralty splice (see splice)****angle of lay (helix angle)**

- BS The angle at which the strands lie in relation to the axis of the rope.

**aramid** (*see also aramid fibre, aramid fibre (ISO generic name)*)

Linear polymers consisting of benzene rings linked by amide, -CO.NH-, groups.

*Note* This definition includes the meta-aramids (linked 1,3 on benzene ring), such as *Nomex*, which are thermally resistant but otherwise have typical textile fibre properties. The HM-HT fibres used in ropes are para-aramids (linked 1,4 on benzene ring), in which the benzene rings are in line with the linking groups.

**aramid fibre** (*see also aramid, aramid fibre (ISO generic name)*)

*High-modulus high-tenacity (HM-HT) fibres, such as Kevlar, Twaron and Technora.*

*Note* *Kevlar* and *Twaron* are **poly(phenylene terephthalamide)**; *Technora* is a **copolymer**.

**aramid fibre (ISO generic name)**

TI A term used to describe fibres composed of synthetic linear macromolecules having in the chain recurring amide groups, at least 85% of which are joined directly to two aromatic rings and in which imide groups may be substituted for up to 50% of the amide groups.

**area** (*see rope area*)**axial compression fatigue**

(*see fatigue, axial compression*)

**axial stiffness** (*see stiffness*)**back splice**

(CE) A method of finishing off the end of a rope by splicing strands back into the structure of the rope.

[CE adds "or by tucking the ends of the rope back into the center.  
Is this acceptable? I would not call it a splice.

**balanced twist** (*see torque-balanced*)**barrel and spike**

CE A rope termination in which the end of the rope is placed in a tapered barrel cavity (socket), the strands and yarns are flared and pushed out toward the barrel wall, and a tapered spike is inserted and pressed into the barrel cavity.

*A rope termination which grips the rope between a central conical spike and a surrounding conical sleeve.*

**base yarn** (*see textile yarn*)

**bedding-in**

A tightening of the rope structure, which causes an increase in length, under applications of tension for a number of cycles after manufacture.

**birdcage**

CE The appearance of a rope in which the outer strands have been flared outward due to torque or axial compression, usually caused by sudden release of load.

**bobbin**

(CE) A cylindrical or slightly tapered barrel, with or without flanges, for holding yarns.

**braided rope**

EU Rope formed by **braiding** or plaiting the strands together as opposed to twisting them.

*Note:* Plaiting is generally regarded as synonymous with braiding, but CE states that *some manufacturers make distinctions*. A plait is normally a solid structure with a limited number of strands.

**braiding (braid, braided)**

TI The process of interlacing three or more threads in such a way that they cross one another in diagonal formation. Flat, tubular or solid constructions may be formed in this way. *Note:* Tubular fabrics made by this process may be constructed with or without core, gut, filler, or stuffing threads, which when present are not interlaced in the fabric.

*Formation of a rope by interweaving strands under and over one another along the length of the rope, as distinct from twisting.*

**braid-on-braid (see double braid rope)****break load (see break tension)****break tension (break load, breaking load, breaking tension)**

The maximum tension (axial force) found in a tensile test of a rope.

**breaking elongation (break elongation)**

(CE) The **elongation** of a fibre, yarn, strand or rope at break.

**breaking extension (break extension)**

(CE) The **extension** of a fibre, yarn, strand or rope at break.

**breaking factor, ISO (see tenacity)**

**breaking length**

The length of a fibre, yarn, strand or rope which will break under its own weight.  
Equivalent to **tenacity**.

**breaking load (see break tension)****butt splice**

A splice used to join two pieces of rope.

**cable-laid rope**

ISO A product consisting of several ropes cabled together in the opposite direction to that of the constituent ropes.

**cabled yarn**

ISO Two or more folded yarns (or alternatively folded and single yarns) twisted together in one or more folding operations.

CE A yarn formed by twisting together two or more plied yarns.

**carbon fibre**

TI A term used to describe fibres containing at least 90% of carbon obtained by controlled pyrolysis of appropriate fibres.

*Note* This definition include low-strength fibres, used for thermal resistance, as well as **HM-HT** fibres used in ropes in the form of **pultrusions**.

**CBS (see certified break strength)****certified break strength (CBS)**

Minimum **break tension** of rope as guaranteed by the manufacturer or proven by testing.

*Note:* (1) Minimum may mean the lowest from a given number of break tests or the lowest value quoted by the manufacturer on the basis of experience and calculation. (2) Alternative terms include guaranteed minimum (or manufacturer's) break load (GMBL), minimum break strength.

**chafing**

CE Abrasion and wear to the surface of a rope which results from scraping or rubbing against another object.

**chafing gear**

CE Any material or device that is used to prevent or reduce wear of ropes. May be material placed around rope, i.e. chafe sleeve, or a device placed in series with rope, i.e. chafe chain.

**circumference** (*see also rope circumference*)

**cockle** (*see hockle*)

**condition**

CE The quantity of moisture present in a textile material.

**conditioning**

CE The process of allowing a textile material to reach hygroscopic equilibrium with the surrounding atmosphere.

**construction** (*see rope construction*)

**constructional stretch**

The increase in length in **bedding-in** due to changes in rope structure.

**continuous-filament yarn**

TI A yarn composed of one or more **filaments** that run essentially the whole length of the yarn.

*Note:* Yarns of one filament are usually referred to as monofilament and of more than one filament as multifilament.

**conversion factor (conversion efficiency, realization factor)**

*Ratio of rope property (e.g strength, modulus) to component property.*

*Note:* Due to length contraction in manufacture, different values are obtained depending on whether the ratio is (a) taken relative to the sum of the component yarn properties, or (b) based on properties normalised by rope linear density or fibre area normal to rope axis.

**copolymer**

A polymer made from a mixture of different **monomers**.

**cordage**

(EU) Product independent of size, in which twisting, plaiting or braiding of any fibrous material produces a finished article, sensibly round in cross section [capable of sustaining load (BS,CE)]. The collective term for rope, line and cord.

CE *also has* 1) .....usually applied to smaller products. 2) Traditionally and by some US Government regulations, under 2/32 in. diameter = twine, 2/32 to 3/16 in. = cordage, 3/16 in. and above = rope.

**core** (*see rope core*)

**cover** (*see rope jacket*)

**creep**(*see also: primary creep (recoverable); secondary creep (non-recoverable)*)

TI The time-dependent increase in strain resulting from the continuous application of a force. *Note: Creep tests are usually carried out at constant load and constant temperature.*

*Continuing elongation with time in a rope under a constant or varying tension.*

**creep rupture**

Breakage after a time under tension.

**crotch**

(CE) In an eye splice the point at which the two legs come together

[CE has "or end-to-end" splice - but has that got a crotch?

**D/d Ratio**

Where a rope is bent around a curved surface, the ratio between the diameter D of that surface to the diameter d of that rope.

**decitex (dtex)**

*0.1 g/km, often used as a measure of yarn or fibre linear density.*

**denier**

*g/9000m, obsolescent measure of yarn or fibre linear density.*

**diameter** (*see rope diameter*)**dissipation factor (loss factor,  $\tan\delta$ )**

Ratio of energy lost to energy stored in a cyclic deformation.

*Note:* (1) The stored energy is the increment related to cyclic force and deformation and not the total down to zero stress. (2) In sinusoidal cycling of a linear viscoelastic material,  $\tan\delta$  equals the ratio of the in-phase stress to the out-of-phase stress.  $\delta$  is the phase difference between stress and strain.

**double braid rope (braid-on-braid, 2-in-1 braid)**

CE A rope constructed with an inner hollow single braid rope structure (core) enclosed by another hollow single braid rope structure (cover). The core and cover share load in a proportion determined by the rope design.

*Rope with an outer hollow braid surrounding an inner solid braid.*

**drawing**

CE The hot or cold stretching of continuous filament yarn to align and arrange the crystalline structure of the molecules in order to achieve improved tensile properties.

**eight-strand rope**

CE A rope consisting of two pairs of strands twisted to the right and two pairs of strands twisted to the left and braided together such that pairs of strands of opposite twist alternately overlay one-on-another.

*A solid braided rope with eight strands in pairs.*

**elastic recovery (recovery)**

CE The ability of a fiber or rope to immediately or eventually recover from the change in length after removal of the load which caused that change in length.

**elongation**

(TI) The elongation of a length of a specimen during a tensile test (or when tensioned in use), expressed in units of length.

*Actual increase in length.*

*Note:* ASTM interchange the definitions of elongation and extension.

**end fitting**

CE Hardware used to connect an end of a rope to a structure, a load, or another rope, i.e. thimble, socket, shackle.

**end to end splice (see butt splice)****endless sling (see also grommet, strop)**

CE A length of rope formed into a loop by having its ends joined together.

**extension (extension per cent)**

(TI) The increase in length of a specimen during a tensile test (or when tensioned in use), expressed as a percentage of the gauge length or nominal gauge length.

*Per cent increase in length.*

*Note:* ASTM interchange the definitions of elongation and extension.

**external abrasion**

**Abrasion** (q.v.) of a rope surface against external objects (e.g. guides, pulleys, terminations).

**eye splice**

A splice used to form an eye at the end of a rope.

**fatigue, axial compression**

Progressive weakening of the rope during cyclic loading in which some components are put into compression during each cycle.

**fatigue, bend-over sheave**

Progressive weakening of the rope caused by repeated cycling over sheave, reel, winch barrel or fairlead.

**fatigue, tension-bend**

Progressive weakening of the rope caused by bending of the rope accompanied by axial tension; as for instance induced by vortex vibration.

**fatigue, tension-tension**

Progressive weakening of the rope caused by repeated cycling of the rope in pure tension.

**fibre (fiber)**

ISO A unit of matter characterised by flexibility, fineness, and high ratio of length to thickness.

*The smallest component of a fibre rope.*

*Note:* Fibres are normally between 1 and 50 dtex (roughly 10 to 100 µm diameter). If smaller called microfibrres; if larger called monofilaments or wires.

**fibre producer**

A company producing manufactured **staple fibres** and **continuous filament yarns**.

**fibrillated-film yarn**

(BS) Yarn composed of fibres formed by allowing an oriented film to split or fibrillate.

**filament**

(TI) A fibre of indefinite (effectively infinite) length.

**filler**

A substance used to fill the spaces between the components of a rope.

**finish** (*see also marine finish*)

A substance applied to a fibre, yarn or rope to change surface properties, e.g. to reduce friction and improve abrasion resistance.

**Flemish eye** (*see splice*)**French splice** (*see splice*)**gauge length (gag length (USA))** (*see also nominal gauge length*)

TI The original length of that portion of the specimen over which strain or change of length is determined.

**grommet** (*see endless sling*)



**guaranteed minimum (manufacturer's) break load (GMBL) (see certified break strength)**

**hackle (see hockle)**

**hawser**

CE Any large rope used to tow or moor a vessel.

*Note:* The term does **not** include the long mooring lines that connect a vessel to a subsea anchorage point.

**heat setting (heat stabilizing, setting)**

CE Process of applying heat or steam to a synthetic fiber rope to set the yarns into the twist pattern, improve dimensional stability, or enhance other properties.

**heat shrinkage**

CE The tendency of some fibers and fiber ropes to decrease in length when exposed to high temperature.

**helix angle (see angle of lay)**

**high-modulus polyethylene fibre (HMPE)**

Highly oriented and highly crystalline **polyethylene** fibre with high modulus and strength produced by the gel-spinning process.

*High-strength polyethylene fibre used in high-performance ropes (e.g. Dyneema, Spectra).*

*Note:* Term sometimes includes polyethylene fibres, no longer commercially available, produced by melt-spinning and super-drawing with about half strength of gel-spun fibres. Polyethylene fibres produced by regular melt-spinning and drawing and used in commodity ropes are much weaker.

**HMPE (see high modulus polyethylene fibre)**

**hockle (cockle, hackle)**

CE A form of rope damage which occurs when load is suddenly released from a rope, or when a rope is twisted under little or no tension to form a loop and then tensioned to pull the loop tight. This action causing individual strands to kink or twisted contrary to the direction of their normal lay over a very short distance. The general appearance is that of a small knot in the rope. Such damage results in substantial strength loss and can not be repaired.

*A twisted kink in a rope.*

**homopolymer**

(TI) A polymer in which all the repeating units (**monomers**) are the same.

**hydrolysis**

CE The attack by water ions on polymer fibers, which results in the degradation of fiber physical properties.

*Chemical degradation of fibre in the presence of water.*

**hysteresis loop (see also dissipation factor)**

CE The loop formed by the non-coinciding loading and unloading curves in a plot of load vs. extension. The area between these curves is proportional to the energy absorbed by the fiber or rope during the cycle.

**initial modulus**

The slope of the initial linear portion of a stress-strain curve.

**intermediate stiffness**

Stiffness in the range between **minimum (post-installation) stiffness** and **maximum (storm) stiffness**. Depends on prior history and applied cyclic loading.

**jacket (see rope jacket)****kink**

A sharp bend in a rope or in a fibre or yarn within a rope.

**kink band**

A sharp buckling of the internal structure of a fibre in overall axial compression or on the inside of a bend in the fibre.

**laid rope**

BS A rope in which three or more strands are twisted to form helices around the central axis.

**lay angle (see helix angle)****lay length**

CE The length along the axis of a rope in which a strand makes one complete spiral around the rope axis. Also, the length along the axis of a strand in which a yarn makes one complete spiral around the strand axis.

*Length of one complete turn in the rope or strand.*

**LCAP, LCP (see liquid crystal aromatic polyester fibre)****left lay, left hand lay (see direction of twist)**

**leg**

CE One of several load bearing ropes in an assembly where the total load is sustained by a number of such parts.

**line**

Used as a synonym of rope, either for a special purpose, e.g. mooring line, or denoting a small rope.

**linear density (see also rope weight)**

(TI) Mass per unit length of a linear material.

*Mass (weight)/length, the usual way of expressing the "size" of a yarn.*

*Note:* Preferred unit for fibres and yarns is **tex** (g/km) and for ropes (kg/m).

**liquid crystal aromatic polyester fibre (LCAP, LCP)**

Melt-spun fibres produced from thermotropic liquid crystal copolymers consisting mainly of benzene rings joined by ester linkages, which form thermotropic liquid crystalline polymers

*High-modulus, high-tenacity aromatic polyester fibre, Vectran.*

**Liverpool splice (see splice)****load P:**

A term used for **reference load** by the Cordage Institute and U.S. Military Specifications test methods.

**long splice (see splice)****loss factor (see dissipation factor)****lubricant (see finish)****macromolecule**

*Alternative term for polymer.*

**man-made fibre (see manufactured fibre)****manufactured fibre**

TI A fibre that does not occur in nature, although the material of which it is composed may occur naturally.

**marine finish**

A **finish** designed to remain on the yarn in a marine environment.

**melt spinning**

CE The process in which the polymer is melted, extruded, cooled and solidified to form a fiber.

**merge**

CE A group to which fiber production is assigned based on properties. All fibers within a merge can be expected to behave uniformly and can be used interchangeably.

**merge number**

CE A designation assigned to a specific merge by the fiber producer.

**minimum break strength** (*see certified break strength, CBS*)**modulus (of elasticity)** (*see also specific modulus*)

Stress divided by strain.

*Note:* See comments on **stress** and **strain**.

**monofilament**

(BS) A continuous filament of approximately circular section having a diameter greater than 40  $\mu\text{m}$ .

**monomer**

Strictly the simple chemical compound which is polymerised to make the polymer; often used to specify the repeating chemical unit in the polymer.

**multifilament yarn**

(CE) A yarn composed of small, usually circular, filaments, generally less than 15 denier (40  $\mu\text{m}$ ).

*A yarn composed of many filaments.*

**nominal gauge length**

TI The length of a specimen under specified pre-tension, measured from nip to nip of the jaws of the holding clamps in their starting position.

**nylon**

Aliphatic polyamides used: (1) as thermoplastics; (2) as fibres, most commonly **nylon 6** and **nylon 66**.

**nylon 6**

Linear polymer with the chemical formula:  $[-\text{NH}(\text{CH}_2)_5\text{CO}-]_n$ .

**nylon 66**

Linear polymer with the chemical formula:  $[-\text{NH}(\text{CH}_2)_6\text{NH}\text{CO}(\text{CH}_2)_4\text{CO}-]_n$ .

**nylon fibre (ISO generic name)**

TI A manufactured fibre composed of synthetic linear macromolecules having in the chain recurring amide groups, at least 80% of which are attached to aliphatic or cyclo-aliphatic groups.

**packing factor**

CE Ratio of the area occupied by the fibre to the total circumscribed area..  
*Fraction of rope volume occupied by fibre.*

**para-aramid fibre (see Note on aramid)****parallel lay ropes (see parallel yarn rope, parallel strand rope)**

(CE) Rope in which the fibers, yarns, strands or sub-ropes are laid parallel to each other.

**parallel strand rope**

Rope in which components are laid parallel to each other within a jacket.

*Note* The "strands" are normally sub-ropes in a three-strand or braided construction.

**parallel yarn rope (parallel fibre rope)**

Rope in which yarns, usually low-twist rope yarns, are laid parallel to each other within a jacket.

**per cent extension (see extension)****PET (see polyester, polyethylene terephthalate)****plait, plaiting (see braiding)****plied yarn (folded yarn)**

(CE) A yarn in which two or more single yarns are twisted together in one operation, eg. two-fold yarn, three-fold yarn.

**polyamide**

Most generally, polymers containing the amide link  $-\text{CO}\text{NH}-$ . This includes the aliphatic nylons and the aromatic aramids.

**polyester (see also polyester fibre, polyester fibre (ISO generic name), polyethylene terephthalate (PET))**

Most generally, a polymer containing the ester, -CO.O-, linkage. This includes: (a) cross-linking resins, which may be used as potting materials in socket terminations; (b) linear polymers used in fibres, most commonly **polyethylene terephthalate (PET)**, but including others such as polyethylene naphthalate (PEN) and polybutylene terephthalate (PBT).

**polyester fibre (see also polyester, polyester fibre (ISO generic name))**

*PET fibres, e.g. Trevira, Diolen, Seaguard, used in ropes.*

**polyester fibre (ISO generic name) (see also polyester, polyester fibre)**

TI A term used to describe fibres composed of synthetic linear macromolecules having in the chain at least 85% (by mass) of an ester of a diol and benzene - 1,4 - dicarboxylic acid (terephthalic acid).

*Note* The FTC (USA) definition is broader.

**polyethylene**

The linear polymer with the chemical formula [-CH<sub>2</sub>-]<sub>n</sub>.

*Note:* Various forms include low-density polyethylene, in which there is appreciable chain branching, high-density polyethylene, which is used in commodity ropes, and **high-modulus polyethylene**, which is used in high performance ropes.

**polyethylene (fibre) (ISO generic name)**

TI A manufactured fibre composed of synthetic linear macromolecules of unsubstituted aliphatic saturated hydrocarbon.

**polyethylene terephthalate (PET)**

The linear polymer with the chemical formula [-CO.O.CH<sub>2</sub>.CH<sub>2</sub>.O.CO.C<sub>6</sub>H<sub>4</sub>-]<sub>n</sub>.

[replace C<sub>6</sub>H<sub>4</sub> by a benzene ring if symbol available]

**polymer**

CE A macromolecular material formed by the chemical combination of monomers having either the same or different chemical composition.

**polymer tape**

TI A tape of synthetic polymer in unfibrillated form, that may be used as produced, or converted into a fibrillated-film yarn.

**polyolefin (fibre); olefin (fibre) (USA generic name)**

TI A manufactured fibre in which the fibre-forming substance is any long-chain synthetic polymer composed of at least 85% by mass of ethene (ethylene), propene (propylene), or other olefin units. The term includes the ISO generic names: **polypropylene** and **polyethylene**.

**polyphenylene terephthalamide**

The linear polymer with the chemical formula  $(-\text{NH.C}_6\text{H}_4.\text{NH.CO.C}_6\text{H}_4.\text{CO}-)$   
[substitute benzene rings for  $\text{C}_6\text{H}_4$  if available]

**polypropylene**

The linear polymer with the chemical formula  $[\text{CH}_2.\text{CH}(\text{CH}_3)-]_n$ .

**post-installation stiffness**

Stiffness immediately after installation.

**potting**

CE The process of terminating a rope by inserting it into a conical cavity socket, unlaying the strands and yarns, and encapsulating the fibers within the cavity with a hardening resin.

**pretension (see also reference tension)**

CE 1) Force applied to a rope when measuring properties, such as circumference and linear density, and when establishing marks upon which to base subsequent elongation and extension.  
2) Force applied to a rope during installation between two fixed points to achieve desirable system characteristics.

**prototype rope**

(CE) A rope manufactured to a rope design specification and then tested to demonstrate certain properties.

**pultrusion**

CE A continuous length, fiber reinforced, composite material tension member formed by pulling a bundle of fibers, impregnated with resin, through a die.  
*A fibre-reinforced rod, which can be used like a wire in ropes, providing a way of using brittle fibres, such as glass and carbon, in ropes.*

**realization factor (see conversion factor)**

**recommended working load**

**CE** A recommended maximum load which should not be exceeded in a rope or rope assembly when performing its normal working function. Also called safe working load, but that term is not preferred because the load may not be safe due to other factors.

[Query: Maximum Design Load: Definition please]

**recovery** (*see elastic recovery*)

**reference tension** (*see also tension for measurement, ISO*)

A nominal **pretension** applied to remove slack and hold a rope straight when measuring rope size and length. The value is variously defined: 1% of break tension is common, but 2% of break tension is recommended in this EDG for large ropes.

*Low tension applied when measuring rope length.*

**residual strength**

Strength remaining after a period of cyclic load testing or after a period of use.

**resin socket**

A type of termination in which the rope is secured in a conical end piece with a resin matrix, which is cured after being poured in place.

**right hand lay** (*see twist direction*)

**rope**

**CE** A long, flexible assembly of fibers, laid, braided, or bundled together, to serve as a tensile strength member.

*Note:* In some standards, cordage with a diameter greater than 4 mm (ISO) OR 3/16 inch (USA).

**rope area**

The area perpendicular to the axis of a rope.

*Note:* The area may be related to the external dimensions of the rope, with or without jacket, or to the the fibre area perpendicular to the rope axis, excluding spaces between fibres and usually limited to the main load-bearing **rope core**.

**rope circumference** (*see also rope size number*)

The length of a rope perimeter.

*Note:* See comment on **rope area**.



**rope construction (construction)**

**CE** The geometric description of a rope's structure, such as the number and arrangement of strands and sometimes the number and arrangement of the yarns which make up these strands

**rope core**

Depending on context, used alternatively to mean:

- (1) The main load-bearing fibre assembly within the rope jacket.
- (2) A central yarn or strand, which may or may not be load-bearing, around which other rope components are assembled.

[Comment please - see other definitions]

**rope diameter**

The diameter corresponding to the rope perimeter.

*Note:* See comments on **rope area** and **rope size number**.

**rope jacket (cover, jacket, sheath)**

Outer protective cover of rope, usually substantially non-load-bearing, made of braided yarns or solid plastic and applied as part of rope manufacture.

*The outer cover of a rope.*

*Note:* (1) The outer strength-carrying braided component of a double braid rope may also function as a jacket. (2) An additional protective coating may be applied after rope manufacture.

**rope length (see also reference tension)**

The total length of a piece of rope as supplied, or in a given use, e.g. a mooring line, or as used in testing.

*Note:* The length will depend on the tension on the rope and its previous history.

**rope size number**

**CE** A traditional nominal designation of the rope size. By marine industry practice, rope size number is expressed as a dimensionless number, which corresponds to the measurement in inches taken by wrapping a tape around a three-strand rope having the same weight per unit length as the subject rope.

*Note:* Because of differences in rope cross section geometries and rope densities, this measurement is not the actual circumference of the rope. General practice is to multiply Rope Size Number by 8 to convert to the nominal diameter in millimeters and to divide size number by 3 to convert to the nominal diameter in inches. *Caution:* Other systems of numbers are sometimes used to designate rope size in other industries.

*An arbitrary number related to the size of a traditional three-strand rope having the same weight as the actual rope.*

**rope weight**

Commonly used term for the **linear density** (mass per unit length) of a rope.  
Preferably given in kg/m.

**rope yarn**

CE The largest yarn component of the strand, formed by twisting intermediate yarns together; normally with an opposite twist direction in twisted rope and eight-strand rope and the same direction in braided rope. Sometimes called cable, multi-ply, or rope-makers yarn.

*A number of textile yarns twisted together by rope makers and used as the input to strand production.*

**S lay, S twist** (*see twist direction*)

**safe working load** (*see recommended working load*)

**safety factor**

CE The factor by which the rated or minimum breaking strength of the rope is divided in determining its recommended (safe) working load.

**secant modulus**

CE The ratio of change in stress to change in strain between two points on a stress-strain curve, usually the points of zero stress and breaking stress.

*The slope of the line joining two points on a stress-strain curve.*

**setting** (*see heat setting*)

**short splice** (*see splice*)

**shrinkage**

Reduction in length, caused by heat or moisture.

**single yarn (singles yarn)**

TI A thread produced by one unit of a spinning machine or of a silk reel

*A simple unitary yarn, as distinct from a plied yarn.*

**specific modulus** (*see also dynamic modulus, secant modulus, tangent modulus*)

Specific stress divided by strain.

*Modulus expressed on a weight basis instead of an area basis.*

*Note:* (1) When the context is clear, e.g. by use of units, may be abbreviated to modulus. (2) See comments on **stress** and **strain**.

**specific stress**

Force divided by linear density.

*Stress expressed on a weight basis instead of an area basis.*

*Note:* (1) When the context is clear, e.g. by use of units, may be abbreviated to stress. (2)  
See comment on **stress**.

**spin finish**

A **finish** applied during fibre production.

**spinning**

Producing a **continuous filament yarn** by extrusion or a **staple fibre yarn** by twisting.

**splice** (*see also back splice, butt splice, eye splice*)

(CE) Method of joining a rope to itself, to another rope, or of producing an eye in its end or ends, or of finishing the end of a rope, by interweaving the strands together to give a positive and secure joint which retains a high proportion of the original strength of the rope.

*A means of forming an eye, ending a rope or joining ropes by interweaving strands.*

*Note:* Names of particular splice constructions include Admiralty splice, Flemish eye, French splice, Liverpool splice, short splice, long splice.

**spring constant**

Tension divided by increase of length of a system, e.g. the whole length of fibre rope in a mooring.

**spun yarn** (*see staple fibre yarn*)**staple fibre**

TI A fibre of limited and relatively short length.

**staple fibre yarn** (**spun yarn**)

A yarn made from short fibres, e.g. cotton, hemp.

**stiffness**

Generally a measure of resistance to deformation. In this EDG, it refers to axial stiffness, defined as rope tension divided by rope **strain**. Equals **modulus times area EA** and **spring constant times length KL**.

**storm stiffness**

Stiffness in storm conditions.

**strain**

Displacement between ends of a specimen divided by length of specimen.  
*Ratio of increase in length to original length.*

*Note:* In this context refers to engineering tensile strain, and not to strains in other modes, e.g. shear, and not to other strain definitions, e.g. logarithmic strain.

**strand**

CE The largest component of the rope, which is twisted or braided together to form the finished rope, and which is formed by twisting rope yarns together, generally with an opposite twist direction to that of the yarns  
*The intermediate component between rope yarns and the whole rope or sub-rope.*

**stranded construction (see wire-rope construction)****strength**

General term indicating resistance to break. In context, e.g. by use of units, may refer to absolute break tension or to normalised values, i.e. stress at break.

**stress**

Force divided by area of cross-section.  
*Tension divided by specimen area.*

*Note:* (1) In this context refers to tensile stress, and not to stresses in other modes, e.g. shear, and not to other stress definitions, e.g. true stress. (2) Yarn and rope areas must be defined so as to make clear whether this refers to the solid fibre area in the cross-section or whether it relates to the total area including space between fibres and whether it is just the **rope core** or the whole rope with **rope jacket**.

**structured rope**

(CE) A rope in which the major components are twisted, laid, braided, or plaited together at an angle to the rope axis, as distinct from a **parallel yarn rope**.

**sub-rope**

CE One of the parallel ropes comprising the rope core in a parallel strand rope.

**synthetic fibre**

TI Man-made fibre produced from polymer built up by man from chemical elements or compounds, in contrast to fibre made by man from naturally occurring fibre-forming polymers.

**tan  $\delta$  (see dissipation factor)**

**tangent modulus** (*see also initial modulus*)

Increment of stress divided by increment of strain.  
*Local slope of stress-strain curve.*

**tenacity (breaking factor, ISO)**

**Specific stress at break.**  
*Strength normalised on a weight basis.*

**tension for measurement, ISO** (*see also reference tension*)

ISO The force applied to the rope at the moment of measurement of its main characteristics (**linear density** or net mass per metre, **diameter**). This tension is defined for each type and dimension of rope.

**tex**

Unit of **linear density** (mass/length) for fibres and yarns, g/km.

**textile yarn (base yarn, producer's yarn)**

(CE) Yarn as obtained from the manufacturer, consisting of a wound package of twisted, intertwined, or parallel filaments on which subsequent twisting operations are performed.  
*Yarn as supplied to the rope maker by the fibre producer.*

**torque-balanced**

CE Rope construction which has little or no tendency to rotate during a change in tension.

**torque-free (non-torque)**

CE Rope construction which has little or no tendency to rotate when permitted to hang freely.

**turn, quantitative**

*Complete 360° rotation.*

**twist, quantitative**

Number of complete rotations or turns in a yarn, strand or rope per unit length.

**twist angle** (*see helix angle*)

**twist direction**

(TI) Twist is described as S or Z according to which of these letters has its centre inclined in the same direction as the surface elements of a given twisted yarn [strand or rope], when the yarn is viewed vertically.

*Note:* S-twist (**left lay, left hand lay**) corresponds to a left-handed screw and Z-twist (**right lay, right hand lay**) to a right-handed screw.

**wire rope**

CE Rope made from steel wire, which may be galvanized, uncoated or stainless, and which may be twisted around a fiber core for flexibility

**wire rope construction (stranded construction, WRC)**

CE Rope made from manufactured fibers with a geometry, strand number and strand layering similar to those used in making wire ropes.

*A fibre rope with a construction similar to that of a steel-wire rope, consisting of a number of strands twisted in layers around a common axis. E.g. 6-round-1, 12/6/1, 18/12/6/1. The central strand may or may not be load-bearing.*

*Note:* Common constructions include: 7-strand, 6 round 1, all load-bearing; 18-strand (12/6/1) and 36-strand (18/12/6/1) with a filler core.

**WRC** (*see wire rope construction*)

**yarn**

(TI) A product of substantial length and relatively small cross-section consisting of **staple fibres** and/or **filaments** with or without twist.

*A linear assembly of fibres used for manufacturing fabrics and other products, such as ropes.*

**Z twist, Z lay** (*see twist direction*)

**APPENDIX 1.2**

**FIBRE ROPE AND YARN**

**UNITS AND CONVERSIONS**

**1. Units and Conversions**

The range of units used in this report come from both the Textile and Engineering world. Most of the Engineering units used are metric. A brief list of the most common Textile units and their engineering equivalents is provided in Table (a) in this appendix.

**Table A-1.2 – (a) : Basic Textile Units**

UNIT	DEFINITION
<b>DECITEX</b>  (dtex)	0.1 gram/Kilometre = gram/10,000 meters
<b>DENIER</b>  (den, d)	gram/9000 meter
<b>GIGAPASCAL</b>  (GPa)	1000 MN/m <sup>2</sup> =102 Kg/mm <sup>2</sup> =145,000 psi
<b>NEWTON/TEX</b>  (N/tex)	= 10.2 gf/dtex = 11.3 gf/den (g/den, GPD) = 102 Rkm = 3.94 x 10 <sup>6</sup> inches (psi/(lb/cu in)) = 145 ksi/(g/cm <sup>3</sup> ) = kJ/g = GPa/(g/cm <sup>3</sup> )=(km/s) <sup>2</sup>
<b>TEX</b>	gram/Kilometre = 10 <sup>-6</sup> Kilogram/meter

**APPENDIX 1.3**

**DEFINITIONS OF MODULUS**

(4 sheets)



## APPENDIX 1-3

## DEFINITIONS OF MODULUS

For a linear elastic material (Hooke's "Law"), there is no problem:

modulus = stress/strain is the same constant in all circumstances

compliance = reciprocal of modulus = strain/stress

*Note on area or mass (weight) basis and on units:*

Conventional usage in physics and engineering defines stress as force/area, so that modulus has the units  $\text{N/m}^2$ , which is also given the name Pascal (Pa). Soft materials will have moduli in MegaPascals (MPa) and stiff materials in GigaPascals (Gpa).

For materials where area is not well defined or easily measured (polymer molecules, fibres, yarns, fabrics, ropes), it is better to use the definitive measure, linear density or mass per unit length. The quantities, force/linear density, are strictly called specific stress and specific modulus, but, where the context is clear may be referred to as stress and modulus. The two forms are related by: specific modulus = modulus/density. Three other relations are of interest. (1) If a length of material is hung up, specific stress at top equals the gravitational weight of the material. This is most commonly found in the use of the term breaking length, but could be used for modulus. (2) The velocity of sound in the material equals the square root of the specific modulus. (3) The area under a (specific) stress/strain curve, or within a hysteresis loop, equals the energy per unit mass. This is most commonly found as specific work of rupture.

The following strict SI units are equal:

$$\text{N}/(\text{kg}/\text{m}) = \text{Pa}/(\text{kg}/\text{m}^3) = (\text{m}/\text{s})^2 = \text{J}/\text{kg}$$

The following more practically sized units are equal:

$$\text{N}/\text{tex} = \text{Gpa}/(\text{g}/\text{cm}^3) = (\text{km}/\text{s})^2 = \text{kJ}/\text{g}, \text{ where tex} = \text{g}/\text{km}$$

Many other units are found for stress and specific stress in various publications, due to:

- (1) the use of gravitational measures of force (e.g. gf, g-wt, kmf, often abbreviated to g or km, which are really mass units) instead of the proper inertial measures (N);
- (2) the use of old cgs units (dyne, erg);
- (3) the use of Imperial units (pound, inch etc);
- (4) the use of denier ( $\text{g}/9000 \text{ m}$ ) for linear density, giving g/den, and, in some contexts, old yarn count measures (reciprocals of linear density);
- (5) odd combinations such as  $\text{psi}/(\text{g}/\text{cm}^3)$ , which confuses density with the dimensionless specific gravity, and inches (used by AlliedSignal for Spectra properties).
- (6) multiples and submultiples, including such undesirable and unnecessary forms as

cN/dtex.

The attached Table gives a collection of conversions.

Any of the moduli listed below may be expressed in conventional form based on area or in specific form based on weight (strictly on mass).

For nonlinear and viscoelastic materials, modulus is defined in many ways.

*Initial modulus* is the slope of the stress/strain curve at the origin (zero stress and strain). Often this is the start of a linear region up to 1 or 2% extension. If not, the value depends on how a tangent is drawn. With crimped fibres or similar specimens, the slope increases as crimp is pulled out: the initial modulus is then, where possible, defined by extrapolation of a linear part of the plot at low strains.

*Tangent modulus*, which must be expressed as a function of stress or strain, is the local slope of the stress/strain curve at any point.

*Secant modulus*, also expressed as a function of stress or strain, is the local value of stress/strain, i.e. the slope of a line joining the origin to any point on the curve.

*Relaxation modulus*, which must be expressed as a function of time is (stress at time  $t$ )/(constant strain). For ideal linear viscoelastic materials, relaxation modulus is independent of strain. Consequently, plots of relaxation modulus against time are a normalised way to represent stress relaxation measured at any level of strain - and actual stress values can then be obtained by multiplying the relaxation modulus values by the strain.

*Creep modulus*, also expressed as a function of time, is (constant) stress divided by strain at time  $t$ . It is more common to use *creep compliance* equal to (strain at time  $t$ )/(constant stress). For ideal linear viscoelastic materials, creep compliance is independent of stress. Creep compliance is the normalised way to represent creep properties - and actual creep values can be obtained by multiplying the creep compliance values by the stress.

With nonlinear materials, a series of plots of relaxation modulus and creep compliance will be needed at different stress or strain levels, or, better, a three-dimensional plot can be used.

In cyclic loading, stress and strain follow a loop, which in the ideal case is an ellipse but which, particularly for large amplitudes, may be distorted in shape. If there is continuing creep or stress relaxation, the loop will not be closed. Various pragmatic definitions of modulus may be adopted: stress amplitude/strain amplitude; slope of major axis of ellipse or "average" slope of a distorted loop.

For ideal linear viscoelastic materials (see Note below), the following definitions of *dynamic modulus* are equal:

$$\begin{aligned} \text{dynamic modulus} &= \text{in-phase stress/in-phase strain (E)} \\ &= \text{real part of modulus in complex notation (E')} \\ &= \text{modulus of spring in parallel with dashpot (E}_p\text{)} \end{aligned}$$

= acoustic or pulse propagation modulus ( $c^2$ )

For non-ideal materials, particularly at large strains, the values of dynamic modulus will depend on the precise means of calculation.

For ideal viscoelastic materials, which can be represented by a spectrum of spring and dashpot units, there are mathematical formulae for inter-converting dynamic modulus, as a function of frequency, relaxation modulus and creep compliance. The classical text is Ferry's *Viscoelastic Properties of Polymers*. Attempts have been made to develop mathematical relations for nonlinear viscoelasticity, but, in my view, these have the dual defects of being mathematically complicated and limited to specific deviations from the ideal response. It is better to use empirical numerical fitting of data from experiments related to the conditions needed.

#### NOTE ON DYNAMIC PROPERTIES

The definitions of dynamic properties of materials, which are not perfectly elastic, are based on a linear visco-elastic response, which will usually be valid at low strain amplitudes. A number of inter-related quantities are used in different representations. These may be taken over into nonlinear responses at large strains, but will not necessarily be inter-related in the same way. The equations relate only to the dynamic effects. Any static stress and strain (mean load or elongation) will be superimposed. A strain  $e$  varying sinusoidally with time will give a stress also varying sinusoidally with time, but out-of-phase:

$$e = e_m \sin(\omega t)$$

$$f = f_m \sin(\omega t + \delta) = \underbrace{f_m \cos\delta \sin(\omega t)}_{\text{in-phase}} + \underbrace{f_m \sin\delta \cos(\omega t)}_{\text{out-of-phase}}$$

The dynamic modulus  $E$  is the in-phase stress/strain,  $f_m \cos\delta / e_m$ . The relative out-of-phase component is commonly expressed by a *loss factor* or *dissipation factor*  $\tan\delta$ . Note that the power factor  $\cos\phi$ , commonly used in electrical engineering, equals  $\sin\delta$ . In another (complex number) notation, the dynamic modulus is termed the real modulus  $E'$ , and the out-of-phase stress/strain  $f_m \sin\delta / e_m$  is called the *imaginary modulus* or *loss modulus*. There are also the following relations:

$$\tan\delta = E''/E'$$

$$\text{energy loss/cycle per unit mass} = \pi E'' [e_m^2] = \pi E' [e_m^2] \tan\delta = \pi f_m e_m \sin\delta$$

It is also of interest that a linear visco-elastic response can always be represented by an ideal elastic (Hookean) spring in parallel with an ideal (Newtonian) viscous dashpot.  $E'$  then equals  $E_p$  and  $E''$  equals  $\eta_p \omega$ . These parameters will change with frequency, when they may be represented by spectra of values, and with temperature, which may be given by a time-temperature superposition equation.

For large cyclic nonlinear deformations, it is probably better to define the energy loss directly as the ratio of dissipated energy  $\Delta W$  to stored energy  $S$ . This ratio is called the specific loss  $\psi$

by Raoof (1995). In the simple linear case,  $\tan \delta$  equals  $\Delta W / 2\pi S$  or  $\psi / 2\pi$ .

The damping parameter is the logarithmic decrement,  $\lambda$ , which gives the decay of amplitude in free vibration. Confusingly, Raoof denotes this quantity by  $\delta$ . The relations are:

$$\lambda = \log_e(x_1/x_2) = \psi / 2 = \pi \tan \delta$$

where  $x_1$  and  $x_2$  are the amplitudes in successive cycles.

It must be noted that NEL, for both steel wire and fibre ropes, use a hysteresis loss factor given by the energy loss  $\Delta W$  divided by the **total** area  $A$  under the loading line, as shown in Figure A 1.2.1. This quantity is not directly related to  $\tan \delta$  or  $E'$  in the simple linear case.

If  $\delta$  is small, so that the energy loss is not too great and the ellipse is narrow, as in Figures EC-2.2.4 and EC-5.3.1, the dynamic modulus can be approximated in various ways as  $f_m / e_m$ , or as the slope of the major axis of the ellipse in Figure A 1.2.1, in addition to the correct definition  $f_m \cos \delta / e_m$ .

**APPENDIX 2.1****LISTING OF YARN TEST METHODS**

1. Linear Density : ISO 2060 (BSS 2010)
2. Tensile Properties : ISO 2060 (BS 1932)
3. Long Term Creep: ACI STM (rope) 7
4. Short Term Creep: Instantaneous Creep Test Method developed by TTI for FT2000
5. Yarn External Abrasion: Test method developed by TTI for FT2000
6. Yarn on Yarn Friction: ASTM D 3412 1986, as modified by TTI for FT2000 (ASTM method had wrong number of wraps)
7. Yarn on Yarn Abrasion: Test method developed by AKZO UMIST and TTI
8. Yarn Buckling (Z-Kinking): Test method developed by TTI for FT2000

**APPENDIX 2.2****INFORMATION FROM FIBRE PRODUCERS OF FIBRE PROPERTIES****1. Introduction**

Data Sheets from Fibre Producers giving basic data on some of the main industrial fibres proposed for offshore mooring line use have been collected together and are reproduced below.

Users are recommended to contact fibre producers directly for current information on available fibre products.

**References**

**Product data sheet DYNEEMA SK60**

**Main textile properties of DYNEEMA SK60**

	DYNEEMA SK60	DYNEEMA SK60	DYNEEMA SK60	DYNEEMA SK60
	not treated	twisted yarn	corona treated	rope sizing
<b>Tenacity</b>				
N/tex	2.8	2.6	2.5	2.8
g/den	32	29.5	28	32
GPa	2.7	2.6	2.4	2.7
<b>Modulus</b>				
N/tex	91	75	71	91
g/den	1025	850	800	1025
GPa	89	74	70	89
<b>Elongation</b>				
%	3.5	3.5	3.5	3.5
<b>Twist in t/m</b>				
440 dTex	0	60	0	0
880 dTex	0	40	0	0
1320 dTex	0	30	0	0
1760 dTex	0	25	0	0
<b>Bobbin weight</b>				
kg yarn/bobbin	2	1	2	2

**Physical properties of DYNEEMA SK60**

<u>Specific gravity</u>	0.97	<u>Temperature</u>	
<u>Water and chemicals</u>		<b>Melting point</b>	144 - 152° C
Moisture regain	none	<b>Thermal conductivity</b>	
Boiling water shrinkage	< 1%	(along fiber axis)	20 W/mK
Affect by water	none	<b>Thermal expansion coeff.</b>	-12.10 <sup>-6</sup> per K
Resistance to acids	excellent	<u>Electric</u>	
Resistance to alkali	excellent	<b>Resistance</b>	> 10 <sup>14</sup> Ohm
Resistance to most chemicals	excellent	<b>Dielectric strength</b>	900 kV/cm
Resistance to UV light	very good	<b>Dielectric constant</b>	
		(22° C, 10 GHz)	2.25
		<b>Loss tangent</b>	2.10 <sup>-4</sup>

Product data sheet **DYNEEMA SK75**

Main textile properties of		Dyneema SK75 Untreated yarn Typical	Dyneema SK75 Twisted yarn Typical
Nominal Titer	dtex	1760	1760
	denier	1600	1600
Tenacity	N/tex	3.5	3.2
	g/den	39.0	35.2
	GPa	3.4	3.1
Modulus	N/tex	110	100
	g/den	1190	1100
	GPa	105	97
Elongation	%	3.8	3.8
Number of filaments		780	780
Twist in t/m	1760 dtex	-	25
Bobbin weight	kg yarn/bobbin	2	2

**Physical properties of Dyneema SK75**

Specific gravity	0.97
<b>Water and Chemicals:</b>	
Moisture regain	none
Boiling water shrinkage	< 1%
Affect by water	none
Resistance to acids	excellent
Resistance to most chemicals	excellent
Resistance to UV light	good
<b>Temperature:</b>	
Melting point	144 - 152°C
Thermal conductivity (along fiber axis)	20W/mK
Thermal expansion coefficient	-12.10 <sup>6</sup> per K
<b>Electric:</b>	
Resistance	> 10 <sup>14</sup> Ohm
Dielectric strength	900 kV/cm
Dielectric constant (22°C, 10 GHz)	2.25
Loss tangent	2.10 <sup>4</sup>



**APPENDIX 2.3**

**NOTE ON REVERSIBLE AND IRREVERSIBLE ELONGATION**

**(FROM A DSM PUBLICATION)**

(1 sheet)

**Reversible and irreversible elongation in Dyneema ropes**

**1. Introduction**

Elongation on loading, reversible and irreversible, is normal in ropes. In Dyneema ropes these phenomena are also observed. In general the following parameters influence the elongation of ropes induced by loading:

**2. Constructional elongation**

This elongation is instantaneous and predominantly not reversible (does not come back when the load is removed). It is due to adaption of the structure of the rope to the load. This elongation amounts to some 2-6% and depends on the type of rope construction (e.g. laid, braided, number of strands, yarn type etc.). This elongation will only occur during the first few loadings of the rope.

**Yarn elongation**

The elongation of the yarn in the rope under load can be separated in three parts:

- *Elastic deformation.* This elongation is instantaneously and reversible and will occur on each loading. For Dyneema this elongation is proportional to the load and is maximally 3.5%. In typical practical conditions of loadings of 5-30% of the Minimum Breaking Load, the elongation amounts to 0.2-1%.

- *Delayed elastic deformation.* This elongation is also reversible and will occur on each loading, but there is a time delay between loading and elongation and the same holds after removal of the load. This elongation depends on loading time; its magnitude in Dyneema is about the same as that of the elastic deformation. Delayed elastic deformation is slower than elastic deformation but much faster than plastic creep.

- *Plastic creep.* This is a permanent elongation and it increases proportionally with time. Further we focus on this plastic creep.

**3. Plastic creep and load**

Plastic creep is in practice only relevant with long-term loading. Very high loads or a high temperature will accelerate plastic creep. Plastic creep is a complex function of load, characterised by a threshold load below which there is little or no plastic creep. Figure 1 shows creep of a Dyneema rope in relation to a percentage of the minimum breaking load (MBL).

**4. Plastic creep and rope efficiency**

In a rope the yarns are not parallel to the direction of the rope. This has two effects:

- The tenacity of a rope will be lower than the sum of yarn tenacities (the efficiency).
- The loading of the individual yarns (as a percentage of the breaking strength) is lower than the loading of the rope as a percentage of the MBL.

Plastic creep is only determined by the load as a percentage of the breaking strength of the yarns. So the plastic creep in a rope is always lower than the loading as a percentage of the MBL suggests. With an increasing rope diameter the efficiency generally decreases and so the creep at a given loading percentage will also decrease. Figure 2 shows the effect on the creep rate of different rope diameters

**5. Modelling and creep prediction**

The factors described above were studied in detail at Eindhoven University of Technology. A computer model has been developed that can be used to predict elongation and creep of Dyneema ropes.

fig. 1

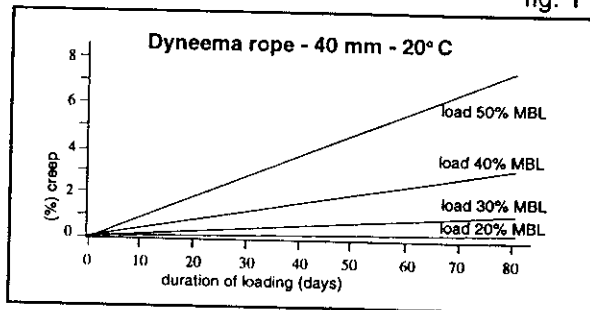
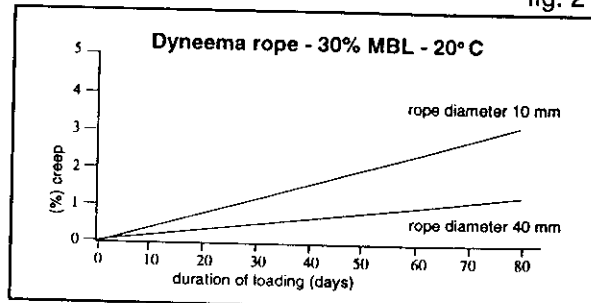


fig. 2



**APPENDIX 5.1****REFERENCES FOR TENSION-TENSION FATIGUE LOADING**

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## APPENDIX 9.1

### PROPOSED PROTOTYPE ROPE TESTING PROCEDURE:

#### **ROPE IN SERVICE LENGTH, ELONGATION AND STIFFNESS PROPERTIES**

##### **1. Introduction**

Pending issue of agreed testing guidelines for length, elongation and stiffness properties of deepwater fibre mooring assemblies, the following test method routine may be used for **polyester** ropes. Suitable adaptations may be required for ropes with higher stiffness or creep.

Prototype rope assemblies of the chosen rope should be made up in suitable lengths and tested to indicate likely properties in use. Tests on ropes should be conducted in the wet, immersed condition.

##### **2. Proposed Test Procedure**

At least 24 hrs after manufacture of test assemblies they should be put through the following experimental routine, with continuous recording of extension and elongation both between bearing points and on a pre-marked 1m length of rope clear of the termination region. All cycles are to be sinusoidal. Cycles a) to g) and j), k) are to be conducted at a cyclic period between 1 and 10 minutes. Cycles h) are to be conducted at a period of between 5 and 15 seconds

- a) First loading to 30% CBS, recording lengths at reference tension and at 30% load (Note : the reference length is the length over the markers when first loaded to the reference tension)
- b) Relax to 10% CBS and maintain 10% CBS load for one hour
- c) Reload to 30% CBS (Define minimum post-installation stiffness as secant stiffness between 10% and 30% CBS on this cycle)
- d) Relax to 10% CBS
- e) Without pause, cycle up to 30% CBS and down to 10% CBS for 99 further cycles
- f) Hold at 10% CBS for one hour
- g) Reload to 50% CBS

- 
- h) Cycle over a strain range of +/- 0.25% around a mean load of 50% CBS for 10,000 cycles (Define maximum storm stiffness as the secant stiffness on the 10,000th cycle)
  - i) Increase load to 60% CBS. Hold for 1 hour. Drop to 30% CBS. Immediately record lengths between bearing points and over pre-marked length (Define total elongation at 30% CBS as length i ) - length a )
  - j) Hold at 30% CBS for 3 hrs and re-measure (Define permanent elongation at 30% CBS as length j ) - length a)

### **3. Alternative Test Procedures**

In addition to the test procedure provided above, other testing proposals have been suggested including those by Bureau Veritas (1997) and by NEL/TTI (1997).

Alternatively, the loads, load-rates, load-histories and relaxation times may be defined by the purchaser for the location in question.

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