RECOMMENDED PRACTICE
DNV-RP-E304

DAMAGE ASSESSMENT OF FIBRE ROPES FOR OFFSHORE MOORING

APRIL 2005

DET NORSKE VERITAS

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Introduction

This recommended practice has been developed in a joint industry project which was carried out 2001 - 2003. The project was broadly supported by the oil industry and rope makers; and DNV values highly their contributions, and the contributions from others, which made it possible to develop the recommended practice.

The damage assessment method is based on detailed knowledge of the rope that has been damaged. This information shall be provided by the manufacturer of the rope, and the technical documentation shall be available when the damage assessment is performed. The rope manufacturer will provide data tables and tables to fill in step by step during the assessment. The work is carried out with hands-on access to the rope with tension removed.

The recommended practice does not cover repair of the load bearing subropes of the rope. Hence, if a rope is deemed not suitable for service, this concerns the rope in the damaged condition. If a damaged rope is deemed suitable for further use, then the filter and jacket must be repaired.

The recommended practice includes field experience gained up to the time of publication. Stricter requirements to the removal of rope jacket prior to assessment have, therefore, been incorporated.

CONTENTS

1. Application of the recommended practice

The purpose of this recommended practice is to provide assessment basis for the suitability of a polyester mooring rope to remain in service, after it has been mechanically damaged by external objects.

The recommended practice is applicable to any “parallel-subrope” type of rope. The inputs required to perform the necessary calculations are provided by the rope manufacturer. This information is given in the Manufacturer’s Report.

The damage assessment is based on the subrope-to-rope relationship, since the subrope is the primary building block of the rope. Subrope-to-rope assessment is required since the effect of damage is highly dependent on the damage distribution.

This implies that for a given loss of area, the resulting rope strength and fatigue performance will vary depending on the distribution of the damage.

The result of the damage assessment is a revised minimum breaking strength MBS, denoted $MBS_{DAMAGED}$.

This (revised) $MBS_{DAMAGED}$ is used to determine if a damaged rope is suitable for temporary or prolonged service, and use of this guideline shall provide documentation for that decision.

Prolonged service may be possible if the fatigue performance of the damaged rope is deemed satisfactory.

2. Definitions

2.1 Terms used in this recommended practice

Rope: The mooring rope being examined and assessed for damage. The mooring rope is constituted by an assembly of subropes, which is held in place as a bundle by a jacket and terminated at each end by spliced eyes.

Subrope: A rope-like assembly of strands.

Guidance note:

Per definition, in this recommended practice subropes are not referred to as “rope”, but they are indeed ropes in their own right.

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Strand: The principle component of the subrope. An assembly of rope yarns which are grouped to form the strand. The strands form a subrope by either a helical or braided arrangement.

Rope yarn: The largest yarn component of the strand, made by twisting or bundling smaller yarns together.

Minimum breaking strength: The minimum required breaking strength of a rope or a subrope in the undamaged condition. Often determined as the average break strength minus two standard deviations of five break test results.

Filter: A barrier towards ingression of foreign matter, which is applied to the rope between the jacket and the load bearing subropes.

Jacket: A non-load bearing external sleeve designed to maintain the bundle of subropes in an organized manner.

Damaged rope: A rope with mechanical damage to one or more subropes.

Damaged subrope: A subrope with damage to one or more of its strands.

Manufacturer’s Report: Data sheets containing all information about the particular rope, prepared for use as a resource and reference for performing damage assessment based on this guideline.

Rope Layout: A description of how the subropes are individually arranged in the bundle, and how they are spliced together.

Damaged-Subrope Strength Data: Test results provided in the Manufacturer’s Report for selected sizes and combinations of strand damage within a subrope.

Strength Ratio: The strength of a damaged subrope ($bs_{damaged}$) divided by the average subrope strength (avs).

Highest design load: The highest force occurring in the rope as derived by the mooring-design analysis.

Ultimate load: The failure load of a damaged rope.

Fatigue Amplification Factor: The ratio between the average subrope strength (avs) and the damaged strength of a subrope ($bs_{damaged}$). This ratio represents the increase of stresses locally in a subrope due to the damage in that subrope.

2.2 Notation

Table 2-1 presents the notation used in this recommended practice.
Notation pertaining to the rope is in uppercase letters.
Notation pertaining to the subrope is in lowercase letters.

Table 2-1 Notation in the damage assessment

MBS	Minimum breaking strength of the rope.
AVS	Average strength of the rope from testing.
$MBS_{DAMAGED}$	The recalculated minimum breaking strength of the rope in the damaged condition.
mbs	Minimum breaking strength of the subrope.
avs	Average strength of the subrope from testing.
$BS_{damaged, No.i}$	The rope force at which subrope No. i will fail.
$bs_{damaged, No.i}$	Break strength of damaged subrope No. i.
$BS_{damaged, next}$	Rope force greater than the highest design load at which the next subrope in the rope will fail.
$bs_{damaged, next}$	Break strength of the next subrope to fail, above highest design load.
$bs_{damaged, ULTIMATE}$	Break strength of the subrope that fails at the ultimate load in the damaged rope.
n_{total}	Number of subropes in the rope.
$n_{damaged, unbroken}$	Number of damaged subropes not yet broken.
$n_{undamaged}$	Number of undamaged subropes.
$n_{affected}$	Number of subropes either damaged or spliced in pair with a damaged subrope.
k	Fatigue amplification factor due to reduced cross section of a damaged subrope.
ML	The loading of the undamaged rope as derived in the mooring-design analysis.
$ml_{damaged}$	Corrected, amplified loading in the critical strand (in the critical subrope), due to loss of other subropes and reduced cross section of the strands in the critical subrope.

3. Manufacturer's Report

3.1 Contents of the Manufacturer's Report

The rope manufacturer shall prepare a report for the particular rope delivered. This report shall contain the necessary rope-specific information to perform the damage assessment. The main contents are:

1) Damaged-Subrope Strength Data.
2) Rope Layout.
3) Strength data from rope qualification testing.

Guidance note:

The Manufacturer's Report may also contain jacket removal and repair instructions.

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The Manufacturer's Report as defined herein should be an integral part of the rope documentation package. A detailed description of the rope construction and the assembly shall be given in the Manufacturer's Report. It shall contain key information as outlined in sections 3.3 and 3.4.

3.2 Description of types of rope

The Manufacturer's Report shall contain a detailed description of the subropes which may be of various constructions, depending on the choice of the manufacturer. Examples of possible subrope construction types are:

— 3-strand helical.
— 4-strand helical.
— 8-strand braided.
— 12-strand braided.
— Six-around-one helical.

The manufacturer may vary the strength of the rope in two ways:

— vary the strength of the subropes
— vary the number of subropes in the rope.

The method of damage assessment is the same for all parallel-subrope ropes, but a distinction is made for ropes where subropes are spliced to form a pair with another subrope. In each pair, two subropes are connected at each spliced termination. If subropes are not in pairs, each subrope forms a rope in its own right, with a spliced eye each end. If subropes are in pairs, each pair of subropes form a loop.

The required information is found in the Manufacturer's Report.

3.3 Manufacturing data to be used as basis for damage assessment

The Rope Layout is used to assess the effect of subrope damage with respect to the rope.

Key information is:

— number of subropes in the rope
— identifying marker system for the subropes in the rope, used to determine if any damaged subrope forms a pair with another damaged or intact subrope
— rope cross-section layout.

An example Manufacturer's Report is given in Appendix A.

Level 1 damage assessment is based on the Rope Layout. (See Sec.5). This information from the Manufacturer's Report is applied in connection with the Subrope Inspection. (See Sec.4.3)

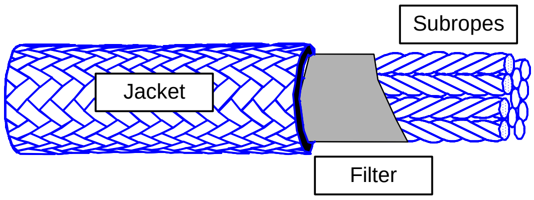

Figure 3-1
Principle sketch of a parallel-subrope rope

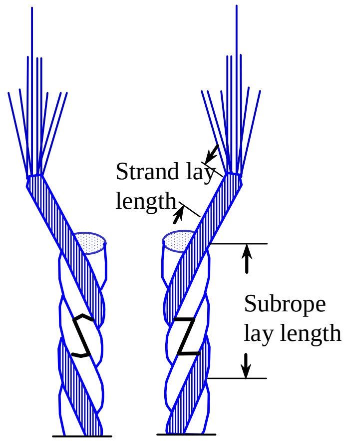

Figure 3-2
Details of 3-strand helical subropes. "S" and "Z" helix orientations are indicated

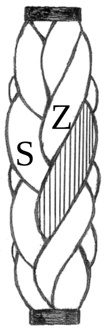

Figure 3-3
Details of 8-strand braided subrope. "S" and "Z" strand orientations are found in the same subrope

3.4 Damaged-Subrope Strength Data

The Damaged-Subrope Strength Data describes the strength of subropes with various "standard sizes" of damage.

Typical examples are:

— 25% damage to 1 strand of 3.
— 50% damage to 1 strand of 3.
— 50% damage to 2 strands of 3.
— 50% damage to 1 strand of 8.
— 50% damage to 1 of 4 S-strands, and 1 of 4 Z-strands.

The rope manufacturer provides the Damaged-Subrope Strength Data in a table in the Manufacturer's Report.

Level 2 damage inspection is based on the level 1 assessment and the Damaged-Subrope Strength Data. This information is applied in connection with the Damage Inspection (of the subropes). (See Sec.5.)

4. Inspection

There are four categories of rope inspection defined:

Carried out before damage assessment, or during service/operation as part of regular inspection:

— General Inspection.
— Close Inspection.

Carried out under level 1 damage assessment (see Sec.5):

— Subrope Inspection.

Carried out under level 2 damage assessment (see Sec.5):

— Damage Inspection.

4.1 General Inspection

The General Inspection is performed to survey the exterior of the rope for potential areas of damage.

Two means exist to check for mechanical damage to the rope jacket:

— ROV survey of an installed line
— visual survey during reeling and/or installation.

Guidance note:

Mechanical damage to the jacket is a condition to mechanical damage to the subropes which is not related to the loading of the rope.

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4.2 Close Inspection

If a point of potential damage to the jacket has been located, this area of the rope requires closer inspection. Close Inspection is carried out by inspectors with access to the rope length in question, with tension removed from the rope.

Guidance note:

Hands-on approaches are the basis of this guideline. This should however not be construed as a limitation to the use of reliable ROV or future non-destructive techniques to assess the extent of damage to the jacket.

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Perform a close examination of the jacket. Look for any severed jacket yarns, and record the extent of damage to the jacket.

Take photographs.

If the damage does not penetrate the jacket, then the rope is ok. Jacket repair is not required.

If the damage penetrates the jacket, but not the filter, then the rope is ok. Jacket repair may be required, depending on the extent of damage to the jacket.

Guidance note:

For the examination of the filter, a blunt fid or similar tool such as the handle of a spoon may be used to force the over braiding aside to get the necessary access view. Observe any instructions provided by the manufacturer.

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If the filter is damaged, but not penetrated, consider whether a filter patch is needed. If not, the rope may be returned to prolonged service immediately.

If the damage penetrates the filter, then a Subrope Inspection must be performed.

4.3 Subrope Inspection

Open the jacket for a distance of approximately 0.6 metres (2 feet) to each side of the damage area. Follow the rope manufacturer’s instructions, to prepare for the jacket repair.

Guidance note:

This procedure may well be carried out by a representative of the manufacturer.

If sufficient subrope identification is provided, together with documentation of their exact arrangement, it may be possible to determine that subropes adjacent to a damaged subrope are intact and present without opening the jacket around the entire circumference. Otherwise observe below important notice.

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Count the number of subropes in the damage area.

Important notice: Assessment of extent of damage without sufficient jacket removal to physically count all subropes is highly unreliable.

Verify the number of subropes towards the Manufacturer’s Report; and make sure that all subropes have been found.

Guidance note:

If the number of subropes is less than what is stated in the Manufacturer’s Report, then one or more subropes have been completely severed, and pulled back into the rope to become invisible.

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Count and record the number of damaged subropes.

Record the identifying markers of the damaged subropes.

If subropes are missing from the damage area (i.e. completely severed and pulled back) then the identifying markers need to be identified for all subropes in order to distinguish which subrope(s) have severed.

Verify this information towards the Manufacturer’s Report.

If no subrope damage is found, the rope may be returned to prolonged service after repair of the filter and jacket.

4.4 Damage Inspection

The objective of the Damage Inspection is to quantify the strength contribution from the damaged subropes in the rope.

For each damaged strand in each damaged subrope, the number of intact rope yarns is counted and recorded, or alternative methods are applied as appropriate depending on type of rope. (See Sec.5.6).

5. Damage Assessment

5.1 Levels of damage assessment

There are three levels of damage assessment defined in this recommended practice:

— Level 1 is the simplest assessment, considering all damaged subropes as broken.
— Level 2 considers strength contribution from damaged subropes, without considering the effect of damage on fatigue life.
— Level 3 includes fatigue-life assessments in the level 2 approach.

5.2 Level 1 Simplified damaged-strength assessment

The level 1 damage assessment is used if it is assumed that the undamaged subropes alone have sufficient strength for the service of the rope; and that the damaged subropes do not contribute to the strength.

Guidance note:

Typical applications are oversized rope in MODU mooring, or rope with very limited damage. The level 1 assessment is also suitable for a quick assessment of the status of the rope, to determine if more detailed analysis is required.

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5.3 Method, level 1

- Carry out the General Inspection.
- Carry out the Close Inspection.
- Carry out the Subrope Inspection.
- Refer to the Manufacturer's Report to find out if any damaged subrope is spliced to any other subrope.
- If so, both subropes must be considered as affected.
- Consider all affected subropes as broken.

Guidance note:

This applies only to the level 1 approach.

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Calculate the damaged MBS of the rope by multiplying the original MBS with the ratio of number of unaffected subropes to the total number of subropes.

$$MBS_{DAMAGED} = MBS \times \frac{n_{unaffected}}{n_{total}}$$

Guidance note:

This formula applies only to the level 1 approach.

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If the damaged minimum breaking strength is deemed insufficient, discard the rope or proceed to the level 2 assessment.

If the damaged minimum breaking strength is deemed sufficient for the application, then the rope may be returned to temporary service.

Repair the filter and jacket according to the manufacturer's instructions, or have the filter and jacket repaired by the manufacturer.

If the rope is considered for prolonged service, the fatigue life should be reassessed according to level 3 based on the undamaged subropes.

Guidance note:

For the level 3 assessment based on level 1, the fatigue amplification factor k = 1.00, since only undamaged subropes are considered to carry load.

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5.4 Level 2 Detailed damaged-strength assessment

The level 2 damage assessment includes the strength of damaged subropes in the assessment of the strength of the damaged rope. It is assumed that the damage does not affect fatigue life. If this assumption is doubtful, then a level 3 assessment should be performed after the level 2 assessment.

5.5 Method, level 2:

- Carry out the Subrope Inspection.
- Refer to the Manufacturer's Report to find out if any damaged subrope is spliced to any other subrope.
- Carry out Damage Inspection as described in the following.

5.6 Damage Inspection

Inspect each strand of each damaged subrope, and identify the damaged strands with a marker pen for tracking. Use different colours to distinguish the damaged subropes, and use the colours for reference when performing the damage assessment.

The combination of damage to strands for each subrope is the basis for this assessment, and not loss of area.

Guidance note:

For example, if a subrope has 40% damage to one strand and there is break strength data for 50% damage to one strand, then that data should be selected.

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Examine each damaged subrope to assess the extent of damage. For each subrope, the actual combination of damage to strands is quantified to the nearest higher subrope damage size, as found in the Damaged-Subrope Strength Data.

Important notice: If necessary, special-purpose damaged subrope break tests can be conducted for the exact damage found in the critical subrope.

This inspection is best performed by counting the number of rope yarns that are undamaged within each damaged strand of the subrope. The total number of rope yarns per strand is found in the Manufacturer's Report. The extent of damage may also be determined by visual judgment of the strand area or other techniques found to be practical.

Refer to the Damaged-Subrope Strength Data, and list the subrope loads which will cause each of the damaged subropes to fail.

Rank the damaged subropes, with the most severely damaged subrope as No. 1.

The Manufacturer's Report provides empty tables to be used for damage recording, determination of nearest higher subrope damage size and severity ranking. See Appendix A for example tables.

Guidance note:

The most severely damaged subrope is that of the lowest strength. This might not be the subrope with most total damage.

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Estimate the force in the rope at which subrope No. 1 will fail:

$$BS_{damaged,No.1} = \frac{bs_{damaged,No.1}}{avs} \times AVS$$

Guidance note:

The force in the rope for the first subrope failure is the Strength Ratio for that subrope times the average strength of the rope from prototype testing also given in the Manufacturer's Report.

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Refer to the Rope Layout given in the Manufacturer's Report, and find out if damaged subrope No. 1 is spliced to any other subrope.

If the subropes are individually spliced, failure of subrope No. 1 will result in one less load-carrying subrope. (See Figure A-2.)

If subrope No. 1 forms a pair with another subrope, failure of subrope No. 1 will result in two less load-carrying subropes. Both affected subropes must be considered as broken when subrope No. 1 has failed. (See Figure A-3.)

Guidance note:

An intact (or less damaged) subrope that is spliced to form a pair with a damaged subrope is not considered load carrying after failure of the (most) damaged subrope. Until the (most) damaged subrope fails, both are considered fully load bearing.

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Estimate the force in the rope at which subrope No. 2 will fail.

$$BS_{damaged,No.2} = \frac{bs_{damaged,No.2}}{avs} \times AVS \times \frac{n_{damaged,unbroken} + n_{undamaged}}{n_{total}}$$

Guidance note:

The second subrope failure load is the Strength Ratio of that damaged subrope as found in the Manufacturer's Report times the average strength of the rope, multiplied by the ratio of number of unbroken subropes after the previous failure to the total number of subropes.

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Refer to the Rope Layout given in the Manufacturer's Report, and find out if damaged subrope No. 2 is spliced to any other subrope.

If the subropes are individually spliced, failure of subrope No. 2 will cause the rope to contain one (additionally) less load-carrying subrope.

If subrope No. 2 formed a pair with another subrope, both affected subropes must be considered as broken when subrope No. 2 has failed.

Continue the calculation for the total number of damaged subropes.

List the calculated subrope-failure loads of the rope.

Check if a subrope failure force is lower than the previous. If it is lower, the subrope is expected to break momentarily upon the previous subrope break.

Guidance note:

If this is the case, the ultimate capacity of the damaged rope is most likely, but not necessarily, exceeded.

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Determine the ultimate load, i.e. the highest force to be attained as already listed. (See example tables in Appendix A.)

Calculate the damaged MBS of the rope. This will be the original MBS, times the Strength Ratio for the subrope that fails at ultimate load, times the ratio of number of load-carrying subropes upon ultimate load, to the total number of subropes.

$$MBS_{DAMAGED} = \frac{bs_{damaged,ULTIMATE}}{avs} \times \frac{n_{damaged,unbroken} + n_{undamaged}}{n_{total}} \times MBS$$

Guidance note:

The number of load carrying subropes at ultimate load is the number of undamaged subropes + damaged subropes still carrying load at the attainment of ultimate load.

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Evaluate if the damaged MBS is sufficient. If not, the rope should be taken out of service.

If the strength is sufficient, the rope may be put back for temporary service, pending completion of the level 3 assessment of fatigue.

Repair the filter and jacket according to the manufacturer's instructions, or have this carried out by the manufacturer.

5.7 Level 3 Damaged fatigue-life assessment

The level 3 damaged fatigue-life assessment is carried out if there is a risk that the damaged subropes that survive the highest design load might fail by fatigue.

Important notice: The level 3 assessment is not meant to be carried out in the field unless personnel authorized for fatigue-life assessment and judgment of prolonged use of a damaged rope is present or available.

In addition to the Damaged-Subrope Strength Data and the Rope Layout provided by the manufacturer, the level 3 assessment requires the data on highest load that is likely to occur as given by the mooring-design calculations.

Guidance note:

The level 3 damage assessment is most likely relevant in case of a highly utilized rope, or a rope with severe damage. The severity of damage is based on the number of subropes affected, rather than the extent of damage to each subrope. Severe damage is typically that more than 15% of the subropes are affected by damage. An affected subrope is either damaged, or spliced to, a damaged subrope. Minor damage is typically that less than 10% of the subropes are affected by damage. These values are given as examples; whether an actual damage is severe or minor will depend on the actual damaged rope.

(Example: A twenty-four-subrope rope has comprehensive damage to two of the subropes. If the subropes are spliced individually, this damage would typically be minor. If the rope is spliced with the subropes in pairs, rope damage will typically be severe if the two damaged subropes are not in the same pair, and minor if they are in the same pair. If they are not in the same pair, then four subropes of twenty-four are affected.)

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5.8 Method, level 3

- Determine the highest design load for the mooring leg containing the damaged rope, by referring to the mooring-design calculations.
- Carry out the level 2 assessment.
- From the level 2 assessment ranking table, determine how many affected subropes will fail when the rope is tensioned to the highest design load.
- Consider those affected subropes to have broken.
- Consider all other subropes, including damaged subropes, to be unbroken.
- Estimate the force in the rope that will cause the next subrope to fail (above the highest design load):

$$BS_{damaged,next} = \frac{bs_{damaged,next}}{avs} \times AVS \times \frac{n_{damaged,unbroken} + n_{undamaged}}{n_{total}}$$

Guidance note:

For a certain damaged rope, it is possible to have for example one damaged-subrope failure due to design loads, and two damaged subropes remaining in service since they will break at loads above the highest design load.

The fatigue assessment shall be concentrated to the most severely damaged remaining subrope, or an intact subrope if all damaged subropes fail due to design loads.

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The fatigue-life assessment is focused to the next subrope to fail, where the fatigue life is assessed for the strand that is most damaged.

Guidance note:

Due to the removed material in the damage zone of a subrope, the yarn stress will be higher in damaged subropes, and highest in the most severely damaged strand. In for example a 3-strand subrope with 50% damage to one strand, the yarn stress will be the highest in the damaged strand, compared to the two other strands. Hence, the most damaged strand is the focus of the fatigue assessment.

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Correct the forces in the mooring analysis by multiplying with the ratio of total number of subropes to the number of subropes not yet broken.

Refer to the Manufacturer's Report and obtain the fatigue amplification factor for the most severely damaged subrope not yet considered as broken by the highest design load.

The Fatigue Amplification Factor describes the increase of stresses in the most severely damaged strand in a damaged subrope. It is equal to the ratio of average subrope strength to damaged subrope strength.

$$k = \frac{avs}{bs_{damaged}}$$

Multiply the corrected mooring loads by the fatigue amplification factor, to obtain the equivalent undamaged fatigue forces of the most damaged strand of the most severely damaged subrope, which will not fail by design loads.

These calculations are performed as follows:

$$ml_{damaged} = \frac{n_{total}}{n_{damaged,unbroken} + n_{undamaged}} \times ML \times k$$

where ML is the forces in the mooring design analysis for the rope, and $ml_{damaged}$ is the corrected and amplified forces as experienced by the critical strand.

Verify that the amplified, corrected mooring loads are acceptable towards the appropriate fatigue-life design curve.

Guidance note:

For a rope that has seen prolonged service already, the fatigue-life condition at present must also be taken into account.

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

If unacceptable, the damaged subrope in question should be considered as broken. In this case, repeat the level 3 assessment for the next damaged subrope.

If eventually all damaged subropes are expected to fail by fatigue, check the fatigue situation of the unaffected subropes alone.

When this iterative process is completed, update the conclusion of the level 2 assessment if the subrope to fail at ultimate load is expected to fail by fatigue.

If the resulting damaged strength or fatigue capacity is deemed insufficient, the rope should be taken out of service.

If the resulting damaged strength or fatigue capacity is deemed sufficient, the filter and jacket should be repaired, and the rope may be put back for prolonged service.

Important notice: The corrected, amplified fatigue loads are calculated for the next subrope to fail. In the other (damaged or undamaged) subropes, the fatigue exposure is less severe. Due to the complex changes in internal compliances within a damaged subrope, derivation of fatigue amplification factors based on lost area of either strand, subrope or rope is not recommended, and will be ambiguous. The ratio of average subrope strength to damaged subrope strength should be used.

APPENDIX A
INPUT REQUIRED TO PERFORM DAMAGE ASSESSMENT

A.1 Example Manufacturer's Report

This appendix shows typical contents of the Manufacturer's Report, which shall provide the necessary rope-specific input to perform the damage assessments. Since the guideline shall be applicable to any parallel-subrope type of rope; it is the responsibility of the rope manufacturer to produce these data that shall be specific to every rope delivered.

Hence, the guideline is not generic to general types of rope, however when experience and data have been accumulated it will be likely that generic information can be derived from the Manufacturer's Reports previously produced.

Rope-specific information:

Table A-1 Rope-layout data	
Number of subropes in rope:	
Number of strands in subrope:	
Number of rope yarns in strand:	
Splicing method:	
Subrope identification:	

Table A-2 Undamaged-state data		
Average breaking strength of rope:	AVS	
Minimum breaking strength of rope:	MBS	
Average breaking strength of subrope:	avs	

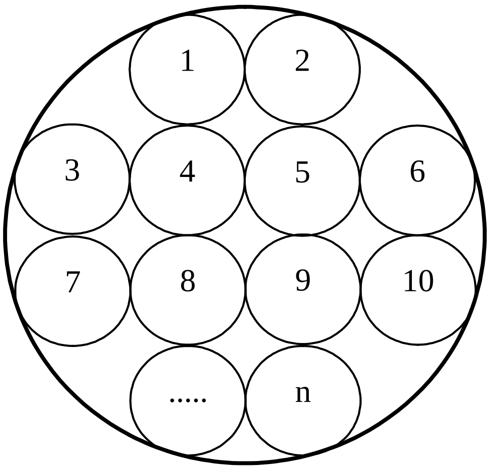

Figure A-1
Cross section of assembled rope, indicating subrope arrangement and id numbers

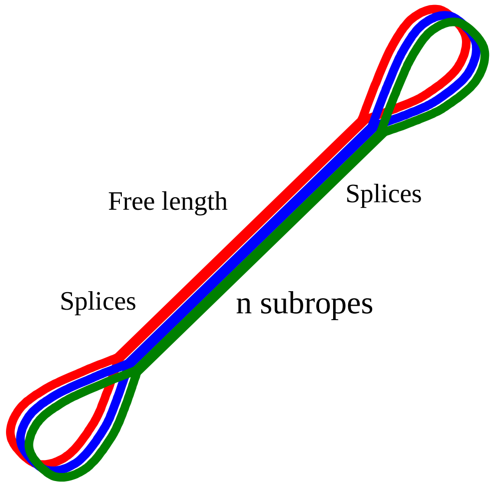

Figure A-2
Principle of rope assembly for individually spliced subropes

In the rope-layout data table it will be indicated that splicing method is either "in pairs" or "individual". If some subropes are spliced in pairs and some subropes are spliced individually in the same rope, more detailed indication of this will be given.

It must be noted that if subropes are spliced in pairs, failure of one subrope renders two subropes to be counted as broken. This is reflected when the figures for $n_{damaged,unbroken} + n_{undamaged}$ are entered in Table A-7 and Table A-8, and the associated calculations are carried out. If a combination of individual and paired subrope splicing is used, this also must be reflected in the damage assessment when filling in Tables A-7 and A-8.

A sketch of a rope that uses paired splicing is shown in Figure A-3.

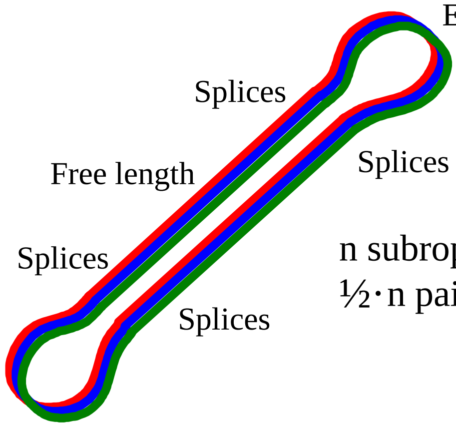

Figure A-3
Paired splicing layout

Table A-3 Example table for Damaged-Subrope Strength Data			
No. of strands damaged	*Extent of damage to strand(s) [%]*	$\frac{bs_{damaged}}{avs}$	*Fatigue amplification factor k*
1	25		
	50		
	75		
2	25		
	50		
	75		
3	25		
	50		
	75		

This is an example table for 3-strand helical subropes. If the subrope has four strands, the left-hand column will reflect that.

If the rope is of a type that uses braided subropes, the orientation (S or Z) of the damaged strands will also be listed together with the number of damaged strands, damage sizes and the effect on strength and fatigue amplification factor.

Assessment tables:

Table A-4 is used to complete the subrope inspection required for the level 1 damage assessment, only counting the number of damaged subropes.

Table A-4 Subrope Inspection recording table						
Total number of subropes found:						
Number of intact subropes:						
Number of damaged subropes:						
Damaged-subrope identities:						

In order to proceed with level 2 assessment, perform the damage inspection and fill in Table A-5.

Table A-5 Damaged-subrope recording table						
Subrope identity	*Damage recording*					
	Strand No. 1		*Strand No. 2*		*Strand No. 3*	
	Intact rope yarns	*Damage [%]*	*Intact rope yarns*	*Damage [%]*	*Intact rope yarns*	*Damage [%]*

Use Table A-5 to record the intact rope yarns that can be identified in each strand of the damaged subropes. Calculate the % damage to each strand, based on the number of rope yarns in intact strands as given in Table A-1, the rope-layout data table.

When the actual damage has been quantified for each subrope, refer to Table A-3 and determine for each damaged subrope the nearest higher damage size that has been tested. Enter this data in Table A-6 for each damaged subrope.

Table A-6 Recording table for nearest higher damage sizes				
Subrope identity	*Nearest higher damage size [%]*			$\frac{bs_{damaged}}{avs}$
	Strand No. 1	*Strand No. 2*	*Strand No. 3*	

Then proceed to the ranking table, denoting the most severely damaged subrope (i.e. that of lowest strength) as damaged subrope No. 1. The damaged strength ratio and fatigue amplification factor is found in Table A-3, the damaged-subrope strength table.

Table A-7 Damaged-subrope ranking table

Damaged subrope No.	*Subrope identity*	$\frac{bs_{damaged}}{avs}$	k	$n_{damaged,unbroken} + n_{undamaged}$
1				
2				
3				
etc.				

The completed Table A-7 shows the sequence of subrope failures that is utilized in the estimation of damaged strength. Table A-7 also shows the number of subropes that carry load upon the next subrope failure.

For level 2 assessment, complete the prediction table, Table A-8, and estimate the damaged-state ultimate load.

Table A-8 Rope strength prediction table

Subrope No.	$\frac{bs_{damaged}}{avs}$	$n_{damaged,unbroken} + n_{undamaged}$	$\frac{bs_{damaged,No.i}}{avs} \times AVS \times \frac{n_{damaged,unbroken} + n_{undamaged}}{n_{total}} =$	$BS_{damaged,\ No.\ i}$ [kN]
1				
2				
3				
etc.				

The highest value for $BS_{damaged,\ No.\ i}$ will be the predicted ultimate load, denoted $BS_{damaged,\ ultimate}$.

Calculate the damaged-state minimum breaking strength according to the following formula:

$$MBS_{DAMAGED} = \frac{bs_{damaged,ULTIMATE}}{avs} \times \frac{n_{damaged,unbroken} + n_{undamaged}}{n_{total}} \times MBS$$

Proceed to the level 3 assessment as required.