Tension Technology International Ltd

REPORT

'MV NORTHERN FAITH'

VISUAL EXAMINATION AND TENSILE TESTING OF A FAILED MOORING LINE TO ESTABLISH THE CAUSE OF FAILURE

For

Federal Bureau of Investigation of Maritime Casualty Investigation

EXECUTIVE SUMMARY

The mooring line has failed at a region where external abrasion is very evident. From inspection and analysis of the failure, it is not possible to say if this abrasion had occurred at some time before the accident or if it happened during the accident. Photographic evidence supplied to Tension Technology suggests that the zone of damage was in the free length of the mooring line, between the pier bollard and deck winch/fairlead. If this is true, then the rope at its fail zone was not in contact with anything when it failed and thus the damage must have occurred before the accident.

Areas of blue and red staining to the rope of the fail zone appear to be paint residue, matching the colours of the vessel. If this is the case, then this is evidence of recoil of the rope against the vessel after it had failed.

It is estimated that the rope had a residual strength in the abraded region as low as 60% of the strength of the same rope in new condition at about 400 kN. Elsewhere within the failure zone, where abrasion damage was less severe, the rope had an estimated residual strength of 75% of new strength, about 500 kN.

These percent residual strengths are estimates based on 'dry' tensile testing. In wet conditions, the actual strength of the abraded zone could be reduced by about 10%, from about 400 kN to 360 kN.

Other samples submitted to TTI for examination had different constructions. Data from tensile testing of these ropes has been used for comparison purposes in this report, but need to be understood in the light of these constructional differences.

It has not been possible to say if the damage occurred during its deployment on this particular mooring or if it had occurred previously. However this accident highlights the necessity of regular monitoring of the condition of any rope by a responsible person on a vessel and that if there is any doubt as to the condition of the rope then it should be removed from service until a full inspection has been carried out. There are several published sets of guidance and recommendations on the subject of rope inspection [listed as references], but experience, common sense and an awareness of the consequences of not taking a cautious approach to rope condition will always reduce the chances of an accident.

Terms and Definitions

Filament	Fundamental textile component from which ropes are constructed
Textile yarn	Assembly of filaments, typically 100-200 filaments per textile yarn
Rope Yarn	Assembly of textile yarns
Monofilament	The rope samples had 4 mm diameter polyamide components, referred to as 'monofilament' for the purposes of this report.
Core	Inner structure of rope
Strand	Conventionally, a strand is an assembly of rope yarns. The 'failed' Atlas rope sample sent to TTI for investigation had outer strands consisting of rope yarns and large diameter monofilaments. Other samples, remote from and adjacent to the failure, had outer strands consisting of monofilaments, rope yarns and textile yarns.
Polyamide	Synthetic polymer material from which the present rope is made. Commonly known as 'Nylon'. Ropes made from polyamide yarn are characterised by having the highest extensions at break of all the synthetic materials commonly used in marine rope applications. Also, the breaking strength of polyamide material is reduced when it is wet, by at least 10% of its dry breaking strength.
MBL	Minimum breaking load, in kN, as specified by manufacturer.
Residual Strength	Estimated strength of a rope, expressed as a percentage of MBL
Linear density	The weight in grams of 1000 metres of material. The unit is called 'tex'
Melding	A term used to describe bonding between rope elements that is a combination of mechanical entanglement and fusing of the thermoplastic polyamide material.. This is evidence that heat and/or pressure had been generated during the failure.
Realisation Factor	A factor, when multiplied with the summed strengths of the rope elements, that is used to estimate the rope strength. It is always less than 1 and has different values for different rope types and diameters. In this investigation, the Realisation Factor was calculated by dividing the aggregated strengths of the rope elements by the breaking strength of a rope sample tested by others for FBMCI

1. INTRODUCTION

This report is submitted to Bundesstelle fur Seeunfalluntersuchung, [Federal Bureau of Maritime Casualty Investigation, FBMCI] in response to their request to investigate the failure of an Atlas rope mooring line. The accident resulted in injury to an officer on deck of the MV Northern Faith.

FBMCI requested the following:

a. Visual examination to establish the cause of failure

b. Determination of the rope residual strength by yarn realisation

c. Scanning Electron Microscopy of rope filaments

d. An analysis of the mooring system using TTI software, ‘Optimoor’ to establish probable line loads at the time of the accident

e. An analysis of the energy and lashback characteristics at the time of failure

f. Recommendations for the avoidance of future accidents

This report covers items ‘a’, ‘b’ and ‘f’. Items ‘c’ was considered not to be necessary at this stage. Item ‘d’ is the subject of a second report and item ‘e’ remains to be completed.

2. DETAILED REPORT

2.1 Visual examination and tensile testing of fail zone

Visual examination of the hawser in accordance with OCIMF, ACI and CMI guidelines.
Three samples were submitted for examination as follows:

1. One half of the fail zone of the rope
2. One short section of rope labeled ‘adjacent to failure’
3. One short section of rope sampled from about 20 metres from the failure

2.1.1 Initial visual examination of Fail Zone

Photograph 1 shows a general view of the rope just behind the fail zone. Figure 1 is a sketch of the main features of the failure and Table 1 gives the details of the construction. It consists of a central core of textile-based rope yarns, around which are 6 strands, helically wound, normally referred to as a ‘6 round 1’ construction.

Each strand consists of a core of rope yarns around which is wound a combination of thick monofilaments and textile-based rope yarns. These particular rope yarns will make some contribution to strength, but also have a function of making the rope easier to handle. Once the rope yarns begin to abrade, the rope is softer to the hand.

Photograph 1 General view of the rope just behind the fail zone

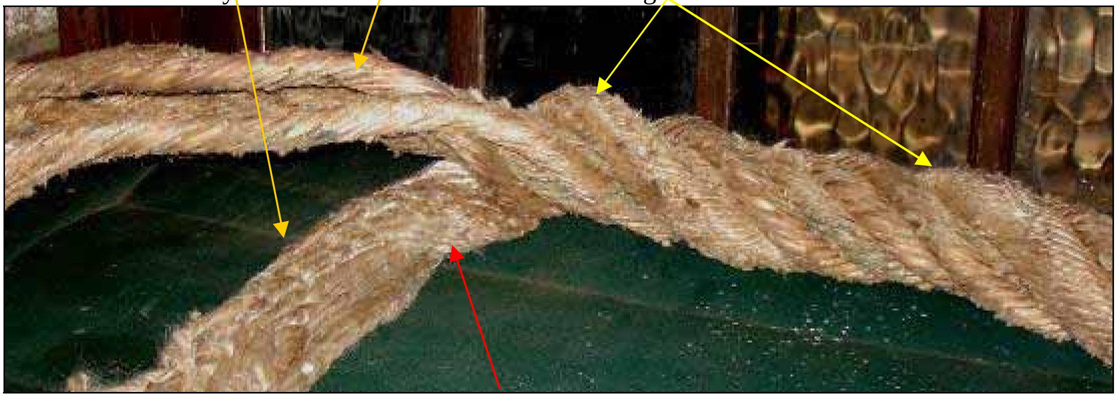


Figure 1 Sketch of main features of the failure

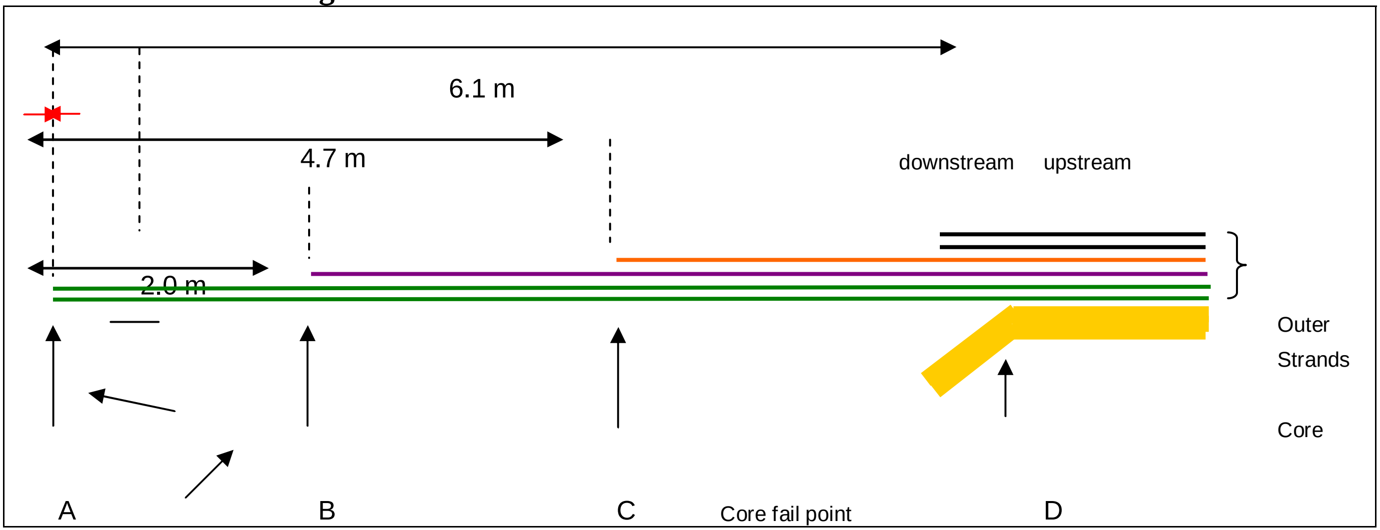


Table 1 Rope construction of rope in fail zone

Rope Component	Construction
Core, one assembly	**Outer layer: 21 rope yarns, approx lin density 11000 Tex** **Inner layer: 33 rope yarns, approx lin density 11000 Tex** **1 rope yarn, approx lin density 2300 Tex**
Outer strand, x 6	**Outer layer: 9 monofilaments, diameter 4.2 mm** **9 rope yarns, approx lin density 5033 Tex** **Inner layer: 20 rope yarns, approx lin density 2300 Tex** **5 rope yarns, approx lin density 4600 Tex** *NB A second strand was analysed and the inner layer had a different construction, having 16 thin rope yarns and 4 thicker rope yarns*

It was not possible to measure the linear densities [tex or g/1000metres] of the various elements of the rope accurately. This was due to their overall condition.

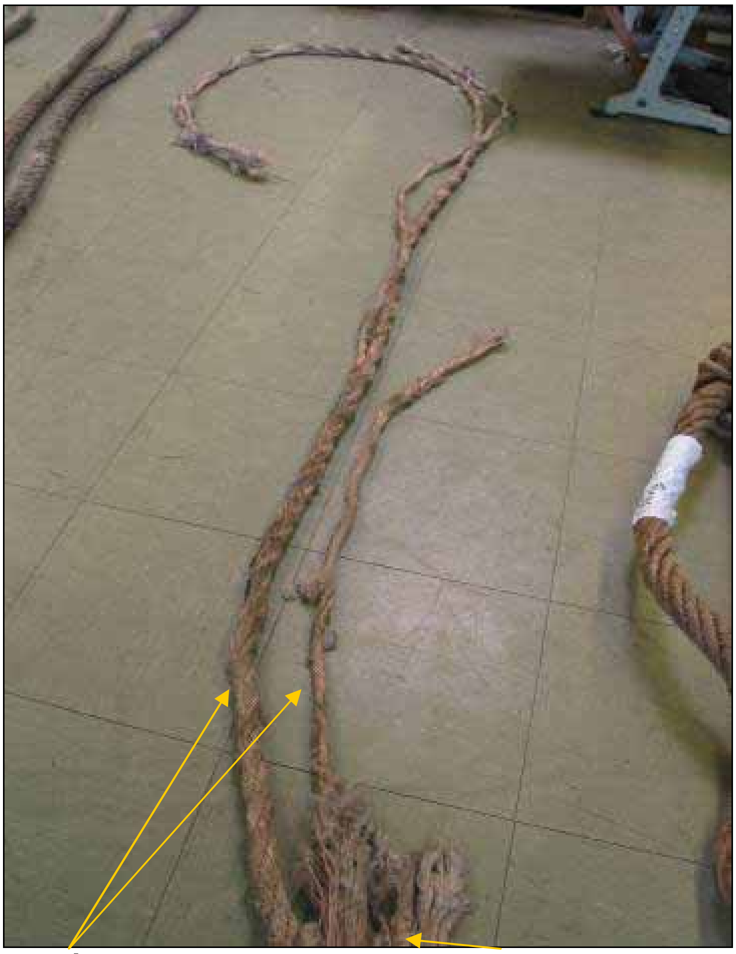
Any differences in strand construction should not affect rope performance as long as they have been properly specified and controlled within a Quality Assurance procedure.

Photographs 2 and 3 give general views of the failure. The images were supplied by FBMCI

Photograph 2   General view of failure, looking towards pier bollard eye

The failure is located about 20 metres from the pier bollard eye and thus would probably have been located within the 'free length' of the line, between the pier bollard and deck winch/ fairlead at the time of the accident.

Photograph 3 General view of one half of the fail zone

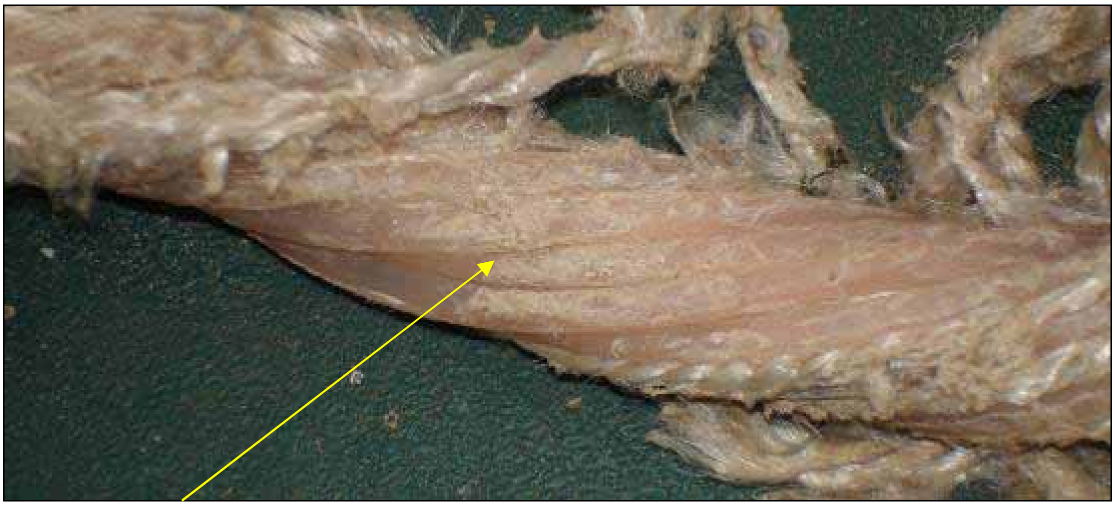


The following part of the report starts with the findings of the investigation of the rope condition downstream of position D of figure 1, where the majority of the rope component failures occurred. Further findings about the rope condition upstream of D are then discussed.

2.1.2 Detailed examination, downstream of position D

Photographs 4 and 5 shows a view of the condition of strands within the fail zone.

Photograph 4
Condition of a strand in fail zone, 1 metre behind position A of figure 1



External abrasion

Photograph 5
Condition of a strand 1 metre downstream of position D of figure 1

Fused rope yarn material

Both images reveal that the rope yarns of the strands had been subjected to severe external abrasion, resulting in either complete removal [photo 4] or fused material [photo 5]. Inspection of all the strands revealed that a general melding of the textile and monofilament components had occurred, indicating a failure under elevated temperature and/or pressure conditions.

In photograph 4, abrasion to the monofilament material is also clearly seen.

Photograph 6 shows about 1.2 metres of an outer strand core assembly of rope yarns, behind its fail point.

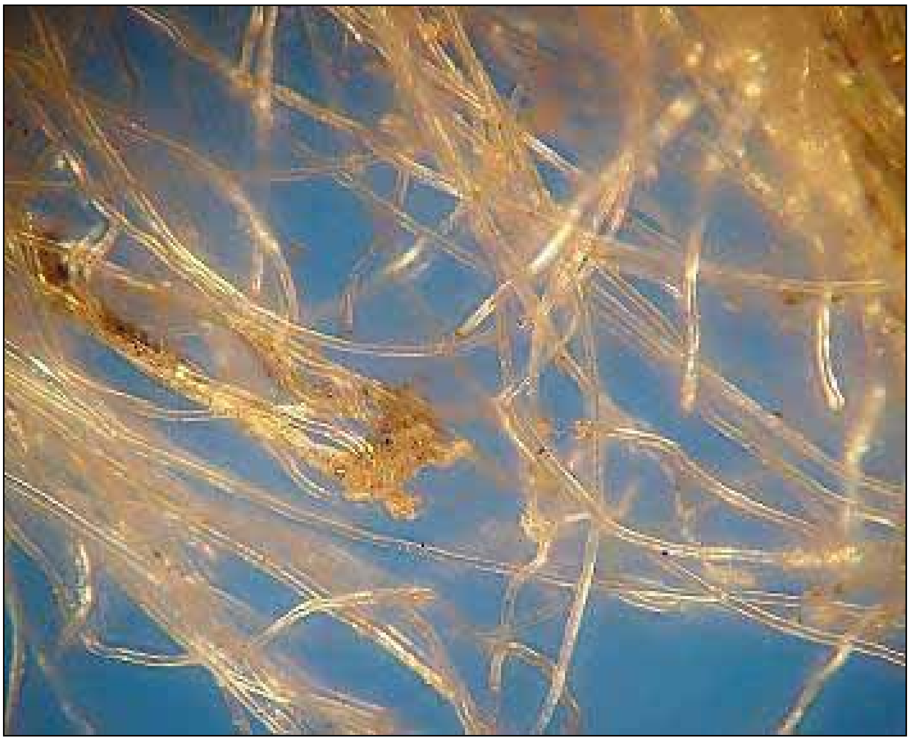
Photograph 6

Fail point

The rope yarns are relatively clean and in reasonable condition up to about 400 mm from the actual fail point. As the fail point is approached, contamination increases and the overall condition declines rapidly. These are indications of external abrasion having occurred.

Photograph 7 shows an optical microscopy image of filaments from the core fail point.

Photograph 7 Fused filaments from core fail point of figure 1



A cluster of fused filaments is seen in the centre of the image. Darker spots are also seen which could be charred material or contamination. The image is evidence of excessive heat being present at the time of failure.

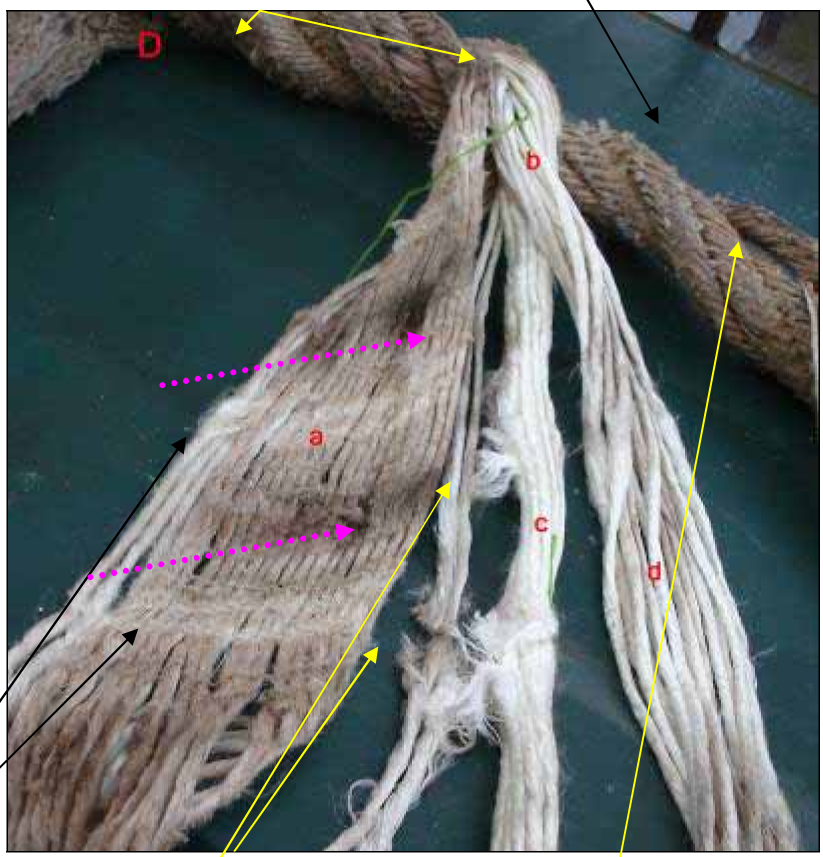
2.1.3 Detailed examination, upstream of position D

General melding of the rope components was found. Photograph 8 shows the rope core assembly, opened up to reveal the condition of the elements. At ‘a’, the outer rope yarns are seen. The view is of their inner faces. The yarns have been ‘melded’ together but could be separated by pulling them apart. The outer faces of these yarns show evidence of damage that is consistent with the effects of heat and pressure.

Above and below ‘a’, two zones of excessive damage are seen running in the line of the purple arrows across the image. These have been caused by pressure from the two strands, coloured black in figure 1, repeated below for convenience. During the investigation, these two strands were found to be severely melded to the outer rope yarns of the core and could only be separated by exerting considerable force

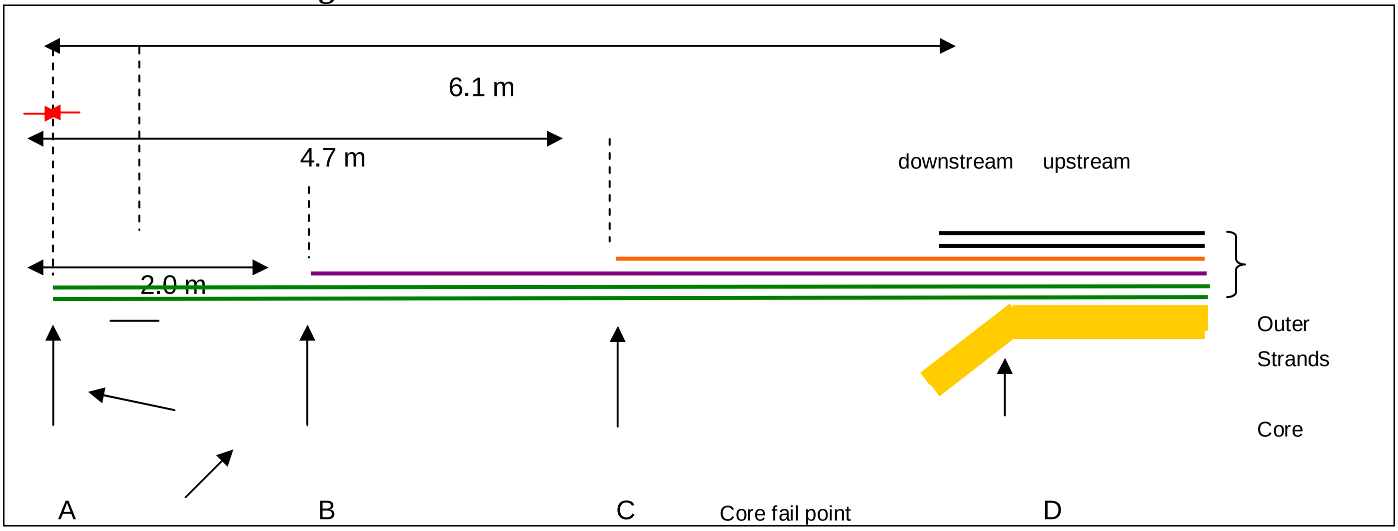
Photograph 8 Unraveled core, upstream of position D

Core assembly, helically arranged around rope axis   melded cluster of 4 strands



Localised compression   localised failure   one of two strands not melded with 4-strand c

Figure 1 Sketch of main features of the failure

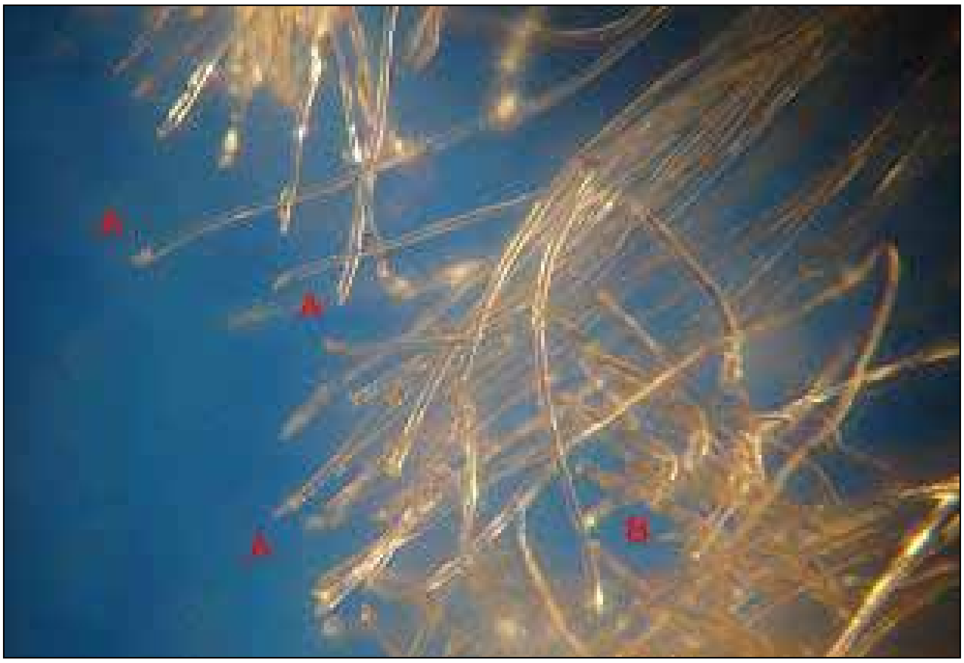


The rope yarns of the inner layer are seen at 'b'. They divide into two separate groups 'c' and 'd'. Group 'd' are loose and are in reasonable condition. Group 'c' show evidence of two clusters of localised failure and also melding. The melding is found between the upper and lower clusters of damage, suggesting a short zone where internal structure of the rope had been subjected to excess pressure. These clusters of localised failure are in line with the localised distortion seen at 'a'.

The rope yarn failures found at 'c' are unusual as they have occurred on inner rope yarns whilst their partner outer rope yarns [at 'a'] have only been severely compressed. The damage to both sets of rope yarns has probably been caused by the two strands, black in figure 1. This evidence suggests that at the time of failure, there was excess load and that the load distribution between the elements within the core was poor. The inner rope yarns were strained to a higher extent than the outer rope yarns. The pressure from the outer strands would have resulted in localised restraint of the material lying beneath them, further complicating the load distribution. Due to the excess strain on the inner rope yarns, some have failed whilst the outer rope yarns, under less strain, have been able to withstand the strand pressure more successfully.

Photograph 9 shows an optical microscopy image of failed filaments from the localised failure ‘c’

Photo 9   Failed filaments from inner rope yarns of core assembly



At ‘A’, the failed ends have a shape that is typical of ductile tensile failure. At B, folding and flattening of filaments is seen [the image is slightly out of focus]. This indicates that pressure has been a factor in these failures of the internal rope yarns

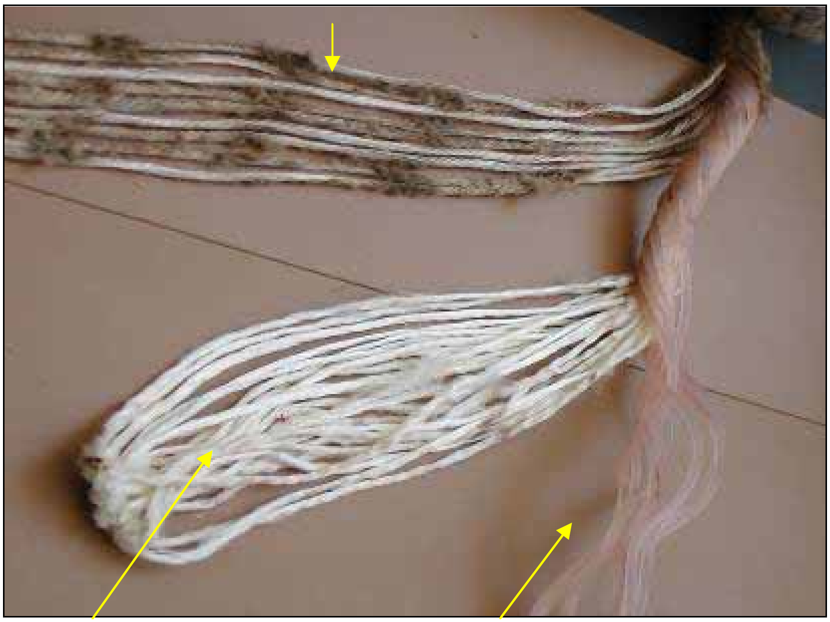
Investigation of the remaining four strands revealed that they were melded firmly together as a cluster of four, coloured orange, purple and green in figure 1.

The core assembly was found to be arranged in a helical fashion around the rope axis and this must have happened as a result of the failure when the rope recoiled following the release of strain energy. This is shown in photograph 1

Photograph 10 shows one of the strands upstream of D, unraveled. The outer rope yarns are abraded, but retain some structure. Also, the yarns had a soft ‘feel’ to the hand, in contrast to the harder ‘feel’ found on surviving rope yarn material downstream of D. In addition, examination of the monofilaments failed to reveal the same degree of external abrasion as that found on monofilaments downstream of D.

Photograph 10 Unraveled strand, upstream of D

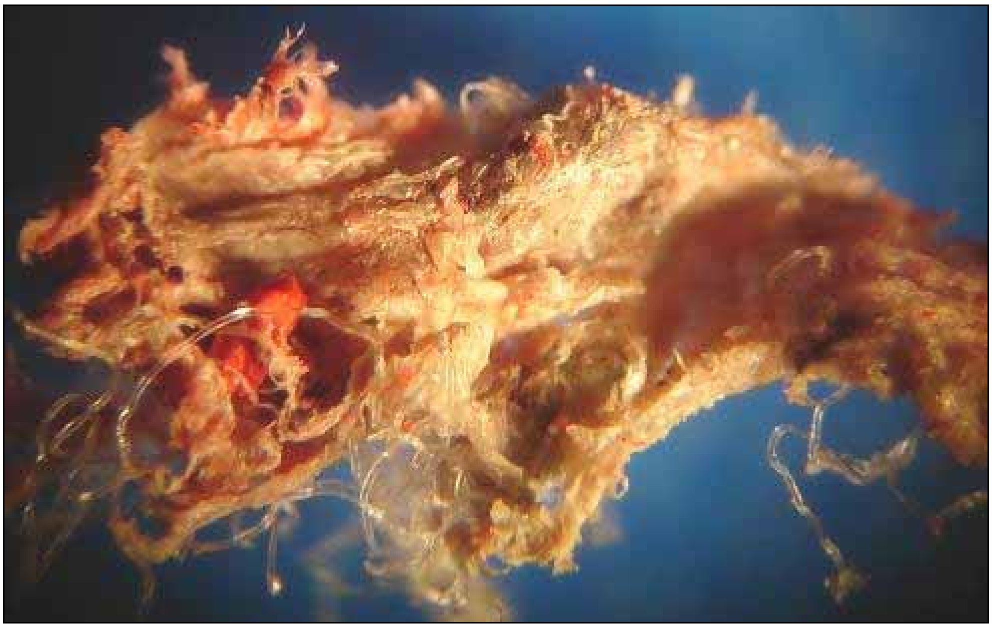
Strand outer rope yarns



Strand core rope yarns strand outer monofilaments

Small areas of rope both upstream and downstream of D were seen to have coloured contamination, dark blue and red. These were examined under optical microscopy and photograph 11 is an example of part of a red stained area. A particle of red material can be seen embedded in an area of fused rope filaments

Photograph 11 Red particle embedded in fused matrix of rope filaments



It was concluded that these areas of contamination were most likely to be paint that had contaminated the rope when the rope had made high energy contact with the vessel during the recoil after the failure.

2.1.4 Comparison of tensile strengths of the rope components upstream and downstream of position D

Table 2 shows the results of tensile tests on the elements that it was possible to test upstream of D. Table 3 shows the results for elements downstream of D

Table 2

Fail zone, upstream of position D					
		number	BL kN	sum kN	
Core, x 1					
Outer layer					
Rope yarn	11000 tex	21	3.162	66.402	
Core					
ropeyarn	11000 tex	33	3.162	104.346	
Rope yarn	2300 tex	1	1.562	1.562	
			Sum	172.31	kN
Strand, x 6					
Outer layer					
Monofilament		9	4.713	254.502	
Rope yarn	5033 tex	9	1.386	74.844	
Core					
Rope yarn	2300 tex	20	1.562	187.44	
	4600 tex	5	3.162	94.86	
			Sum	611.65	kN
			Grand sum	**783.96**	**kN**

Manufacturer's data for the minimum breaking load of a new rope, 60 mm diameter, is 686.70 kN.

From information received from FBMCI, whole-rope tensile testing from another rope sample resulted in a fail load of 514.54 kN. This suggests a Realisation Factor of 0.66 [514.54/783.96] for used rope of this particular specification.

Thus, the estimated Residual Strength of the rope, upstream of Position D, is 517 kN, 75% of new Minimum Breaking Load.

Table 3

Fail zone, downstream of position D					
Strand, x 6		number	BL kN	sum kN	
Outer layer					
Monofilament		9	4.411	238.194	
Rope yarn	5033 tex	9	0.563	30.402	
Core					
Rope yarn	2300 tex	20	1.241	148.92	
	4600 tex	5	2.729	81.87	
			Sum	499.39	kN

It was not possible to perform tensile tests on the surviving downstream core rope yarns and only data from the testing of the elements of an outer strand is shown in table 3. Comparing this strand data, it can be seen that upstream of position D, the summed strength of all the elements of the outer strand is 611.65 kN, whilst downstream of D it is only 499.39 kN. This represents a 19% reduction of the strength of a strand and agrees with the visual assessment of the failure sample, i.e. there was a greater degree of damage to the strands downstream of position D. It is therefore reasonable to assume that the residual rope strength downstream of D would be lower than that estimated for upstream of D because of the additional abrasion damage and a percent residual strength of 60% is used.

After considering all of these separate observations, the following is a reasonable explanation of the progression of the failure:

1. The rope had been weakened by localised external abrasion damage. It is estimated that the rope had a residual strength of about 60% of its new Minimum Breaking Load in the damaged zone. It is not possible to determine if this damage happened at the time of the incident or had occurred as a result of a previous incident. However, the location of the damage is very likely to be between the pier bollard and the deck winch and fairlead and could not have been in contact with anything at the time of failure. It is therefore likely that the damage had occurred before the actual failure.

2. The rope was subjected to severe load, possibly of a very localised nature and this load caused the failure at the abrasion damaged zone.

3. Position D of figure 1 is a transition point in terms of visible damage. Damage is greater downstream of D than upstream of D.

4. The two black coloured strands of figure 1 failed initially. During the course of their failure, the strands exerted extreme pressure on the core structure of the rope. This resulted in the damage seen to the rope yarns of the core, photograph 8.

5. The failure of these two strands created an instantaneous increase in load on the surviving 4 outer strands and the core.

6. The remainder of the rope failed and the rapid contraction of the rope resulted in the migration of the core assembly to the surface of the rope, filling the gap left by the failure of the first two strands.

7. This also resulted in the four strands remaining after the initial failure becoming melded together due to the higher energy involved in the final phase of the failure.

8. Red and blue contamination on the failure sample is likely to be paint from the vessel, transferred when the rope recoiled into it under high energy, following failure.

2.2 Visual examination and tensile testing of sample adjacent to fail zone

Table 4 shows the analysis of the rope construction.

Table 4 Rope construction of rope sample 'adjacent to fail zone'

Rope Component	Construction
Core, one assembly	**91 rope yarns, approx lin density 6300 Tex** **8 rope yarn, approx lin density 5067 Tex**
Outer strand, x 6 assemblies	**Outer layer: 9 monofilaments, diameter 4.2 mm** **9 rope yarns, approx lin density 5033 Tex** **Core : 378 textile yarns, approx lin density 217 Tex**

Table 1 Rope construction of rope in fail zone

Rope Component	Construction
Core, one assembly	**Outer layer: 21 rope yarns, approx lin density 11000 Tex** **Inner layer: 33 rope yarns, approx lin density 11000 Tex** **1 rope yarn, approx lin density 2300 Tex**
Outer strand, x 6	**Outer layer: 9 monofilaments, diameter 4.2 mm** **9 rope yarns, approx lin density 5033 Tex** **Inner layer: 20 rope yarns, approx lin density 2300 Tex** **5 rope yarns, approx lin density 4600 Tex** *NB A second strand was analysed and the inner layer had a different construction, having 16 thin rope yarns and 4 thicker rope yarns*

When compared to table 1, reproduced above, it can be seen that there are differences in the way the rope has been constructed. Firstly, the core of the strands of the 'adjacent' sample is made up of textile yarns whilst for the fail zone rope, the inner layer of a strand is made up of rope yarns, these in turn being made of a cluster of textile yarns. Thus, for the 'adjacent' sample, the intermediate manufacturing process of producing rope yarns has not been conducted.

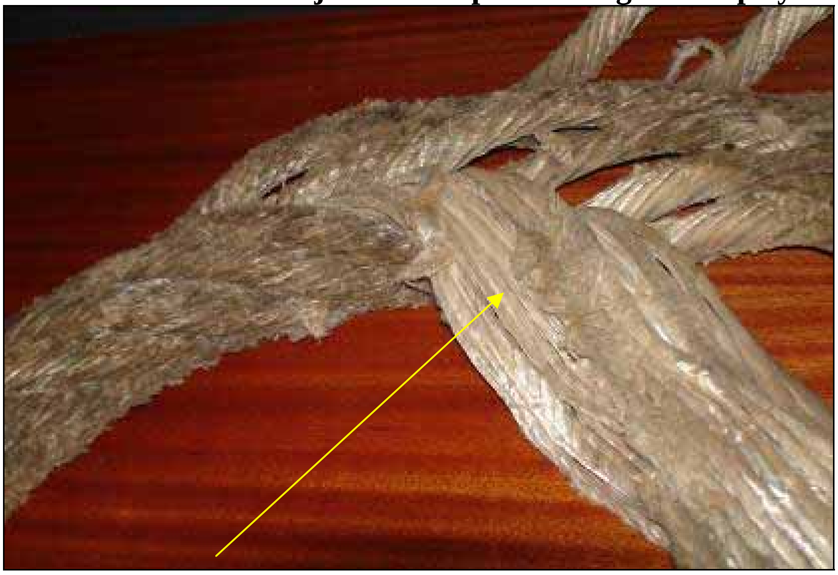
A second difference is in the core construction. Both rope samples have cores made from assemblies of rope yarns, but the number of rope yarns and their linear densities are different.

Summing up the total tex involved in each rope sample revealed that there was a small difference between them but this is probably due to inaccuracy in measurement of linear density. Thus there is no reason to believe that rope performance has been compromised by these differences in construction, but TTI can offer no explanation as to how they can appear in what should be the same rope.

A further difference is seen in the monofilament material. In the failed sample. It has a pink colour whilst in the 'adjacent' sample it is milky white.

Photograph 12 shows the adjacent zone, unraveled to reveal core rope yarns and photograph is an unraveled strand, showing the textile yarn assembly of the core.

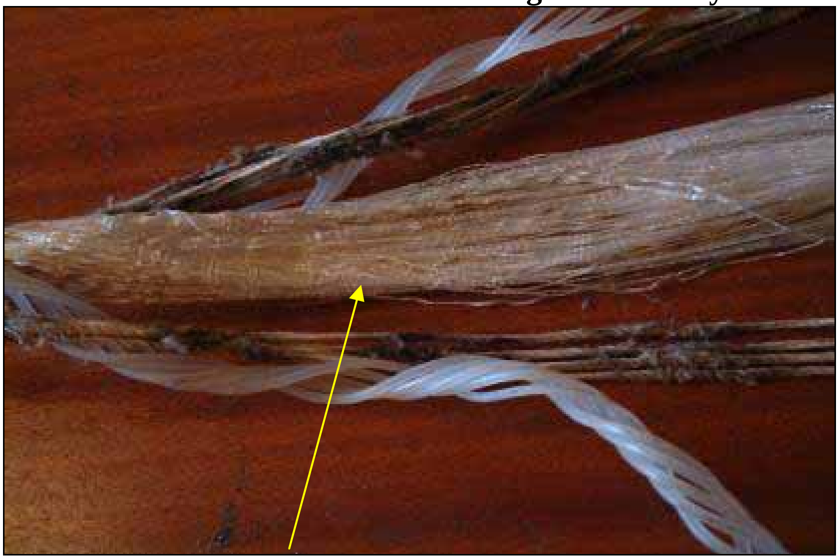
Photo 12 Unraveled 'adjacent' sample showing core rope yarns



Severe damage to cluster of core rope yarns

Photograph 13 shows an unraveled strand, to reveal the textile yarns of the core assembly

Photo 13 Unraveled strand showing core textile yarns



Textile yarns of core assembly

Severe damage was found to some of the rope yarns in the core assembly, photograph 12, but with little evidence of similar damage to the outer strands in the that region. This is similar to damage found in the 'failure' sample, upstream of D, where damage to the core was not matched by comparable damage to the outer strands. However, in this case, the cause may have been a previous compression incident, not related to the rope failure. The outer strands, with the tough monofilaments, were able to withstand the compression, whilst the softer core rope yarns could not.

As the 'failure' rope and the 'adjacent' rope are of different constructions a comparison of their tensile performances is not going to be very useful. However, table 5 shows the results of the testing.

Table 5 Breaking strengths of rope elements 'adjacent to fail'

Rope segment adjacent to fail			number	BL kN	Sum kN	
Core x 1						
Rope yarn	6300 tex	good	26	3.872	100.672	
		mild	13	3.263	42.419	
		modest	24	2.125	51	
		severe	25	0.912	22.8	
		broken	3	0	0	
Rope yarn	5067 tex		8	1.637	13.096	
					229.987	kN
Strand						
Outer layer						
Monofilament			9	4.632	250.128	
Rope yarn	5033 tex		9	0.296	15.984	
Core						
Textile yarn	217 tex	good	125	0.134	100.5	
		poor	253	0.078	118.404	
					485.016	kN
			Grand sum		**715.003**	**kN**

Because of the damage found to the rope elements, the elements were visually categorized by their degree of damage. A representative group of yarns from each category was tensile tested to calculate the average breaking load for the damage category. This value was then used to estimate the summed strengths for each category. The core rope yarns, 6300 tex, were separated into 5 categories; good, mild damage, modest damage, severe damage and broken. The strand core textile yarns were divided into just two categories, good and poor.

The summed breaking load for the 'failure' sample, upstream of D, is 784 kN. For the 'adjacent' sample it is 715 kN, a reduction of 9%. Thus, if the two samples are from the same mooring line, then the 'adjacent' sample is in a worse condition that the 'failure' sample.

By taking the best individual results of the tensile tests of table 5, it is possible to estimate the strength of a rope without the degrees of damage found. Table 6 shows the calculation.

Table 6 Estimate of summed strengths of rope elements for rope in good condition

Estimate of good condition rope		number	BL kN	Sum kN	
Core x1					
Rope yarn	6300 tex	91	3.872	352.352	
Rope yarn	5067 tex	8	2.000	16.000	
				368.352	kN
Strand x6					
Outer layer					
monofilament		9	5.15	278.1	
Rope yarn	5033 tex	9	2.000	108	
Core					
Textile yarn	217 tex	378	0.134	303.912	
				690.012	kN
		Grand sum		**1058.364**	**kN**

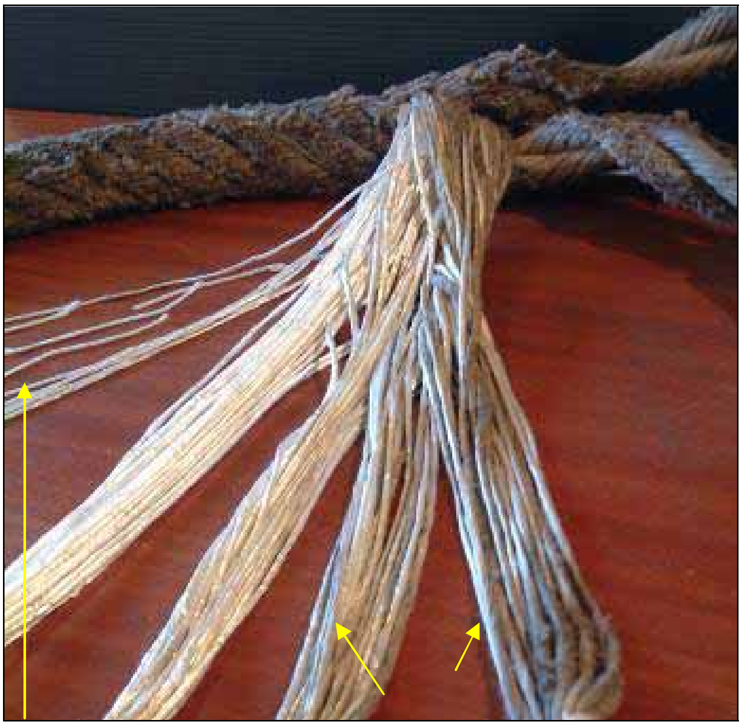
If the realization Factor of 0.66 is applied to this summed strength, then the estimate of a 'good condition' rope strength is 698 kN. This compares well with the manufacturer's MBL of 687 kN and suggests that the rope as delivered to the customer was up to specification.

2.3 Visual examination of sample clear of fail zone

The structure of this sample appears to be the same as for the 'adjacent' sample, but both are different from the 'failure' sample.

Photograph 14 shows the sample 'clear of fail zone'. This was sampled about 20 metres from the fail zone.

Photograph 14 'Clear of fail zone' sample unraveled to expose core rope yarns



Broken small diameter rope yarns contaminated and damaged large diameter rope yarns

Photograph 15
Strand from 'clear' sample, unraveled to core reveal textile yarns

Damage to the rope yarns and textile yarns were seen, but it was thought not to be of much use for the present investigation to perform further tensile testing.

Note:
A further sample was sent to TTI for investigation, taken from the whole-rope tensile test mentioned in 2.1.1.3. An initial examination revealed a difference in the diameter of the monofilament used in strands of this rope as opposed to the samples already delivered to TTI. No further investigation was conducted.

3. CONCLUSIONS

Samples were examined visually and tested for their tensile properties. They were identified as follows:

One half of the failure
Adjacent to fail zone [parted end]
Clear of fail zone [parted end]

1. The rope sample from the failure zone of the line had been severely abraded, though the monofilaments of the outer strands had given some protection to the textile elements of the rope.

2. It is not possible to say from inspection of the failure, if this abrasion had occurred before the failure or was created during the failure. However, photographic evidence supplied by FBMCI show the fail zone to be about 20 metres from the pier bollard eye and it is thus likely that the damage was located between the vessel and the pier at the time of the accident. Thus, if this is correct, the abrasion damage could not have occurred at the time of the accident as the rope could not have been in contact with anything. Therefore the damage must have occurred at some time before the failure.

3. Either way it would have represented a weakened zone within the mooring line.

4. In the fail zone of the rope, it is estimated that the rope had a strength of about 75% of its new strength before the failure. However, tensile tests made on surviving elements of the rope where abrasion damage was very evident showed that they had a combined strength 19% less than the same elements within the fail zone where abrasion damage was less evident.

5. Therefore, from the observations of item 4 it is entirely possible that the abraded rope just before failure would have had a strength of less than 60% of its new MBL at about 400 kN.

6. From the visual inspection of the failure sample, it is possible to construct a sequence of events that occurred during the failure.

7. The two samples ‘adjacent to’ and ‘clear of’ the fail zone were of a different construction though appear to be of the same general specification.

8. Tensile testing of the ‘adjacent’ sample suggests an estimated residual strength of 69% when compared to the new MBL of the rope. It must be remembered that this was a rope of a different construction from the fail rope, however.

9. It has not been possible to say if the damage occurred during its deployment on this particular mooring or if it had occurred previously. However this accident highlights the necessity of regular monitoring of the condition of any rope by a responsible person on a vessel and that if there is any doubt as to the condition of the rope then it should be removed from service until a full inspection has been carried out. There are

several published sets of guidance and recommendations on the subject of rope inspection [references 1-5], but experience, common sense and an awareness of the consequences of not taking a cautious approach to rope condition will always reduce the chances of an accident.

References

1. "The selection, use, care, inspection and maintenance of non-metallic ropes and cords" United Kingdom Defence Standard DEF STAN 40-7/1.

2. "Mooring Equipment Guidelines", 2nd Edition, Oil Companies International Marine Forum 1997.

3. "Admiralty Manual of Seamanship' III 1983

4. "The selection, use and care of man-made-fibre ropes in Marine applications". British Standard BS 4128 1967 : Now lapsed, not replaced.

5. Cordage Manufacturers Institute, Recommendations for Rope Safety, 1984.