Investigation of failure of crane rope from DSV DSND PELICAN

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Investigation of failure of crane rope from DSV DSND PELICAN

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Summary

This report describes the inspection of a 34LR whipline rope on the DSV PELICAN which failed in service on 17th March 2001 whilst deploying a subsea module. The whipline was rated at 10 tonnes. The weight of the module (weight in air 3.5 tonnes) was such that even allowing for dynamic loading and the effect of added mass, the integrity of the rope must have been severely impaired for failure to occur.

Review of the BP/DSND Dangerous Occurrence Final Investigation Report revealed that the rope had been pressure lubricated in September 1999, and that “light lubrication” was a Planned Maintenance System requirement, to be carried out every two months. It is not clear if the “light lubrications” were conducted. A break test on a section of rope removed from the line was conducted one year earlier in March 2000, obtaining a value of 49.9 tonnes (cf MBL 51.25 tonnes when new). Proof load tests (to 12.5 tonnes i.e. SWL + 25%) and visual inspection were conducted in September 2000 and December 2000, when no problems were reported.

Inspection of the lengths of rope from either side of the rope failure and subsequently the length of rope removed from the winch drum showed that the rope was severely corroded and completely lacking in lubrication in the area of the failure. It is considered that the primary cause of failure of the rope was due to corrosion exacerbated by poor dynamic load sharing between the layers of strands also caused by corrosion and lack of lubricant.

It is important to recognise that the 34LR rotation-resistant type construction of the rope will be especially vulnerable to corrosion degradation for two reasons: (i) over 50% of the load bearing cross section is hidden from visual inspection; and , (ii) this type of rope is difficult to relubricate.

It is recommended that a more rigorous lubrication policy be instituted to prevent the onset of corrosion. The removal of break load test samples should be used as an opportunity to assess the level of internal lubricant. Where the exposed rope does degrade, a cut and slip policy should be employed to remove the most damaged portion.

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1. Background

On 17th March 2001, whilst deploying a 3.5 tonne Subsea Control Module, the 10 tonne (rated) whipline on the main crane of the DSV PELICAN failed. The rope was a 26mm dia. 34LR type, (34 x 7 + core (the core is a 9/9/1 Seale construction)), RHO, 1960N/mm^2 galvanised, and had a certified strength of 51.25 tonnes when supplied in 1997. The rope parted at a location 1 – 1.5m below the jib tip sheave (at which point the module was 3 – 5m below the water surface), as a 3m swell passed under the vessel.

Allowing for the dynamic loading effects on the rope, the maximum load which the rope would have experienced would not have exceeded 9 tonnes, a value below the 10 tonne rating of the crane.

The Health and Safety Executive commissioned The University of Reading to investigate the incident to:

- determine the primary mechanism for the rope failure;
- identify whether circumstances in the maintenance and inspection of the rope played a significant role in the failure; and,
- make recommendations for an inspection and maintenance regime that would minimise the likelihood of a recurrence of such a failure.

The University of Reading were supplied with documentation including an incident report, crane inspection records, rope test certificates and records of rope maintenance. Lengths of the rope from either side of the failure were delivered to the University for examination. The remainder of the rope from the winch drum was also subsequently delivered, to enable comparisons to be made with the rope at the failed section.

2. Preliminary Inspection

On delivery at Reading (19th June 2001), a preliminary external examination was made of the lengths of rope either side of the failure point. The two pieces of rope were 18.9m and 3.4m long. No indication was available as to which side of the break each length of rope had been. It will be shown in section 3.3 that the length of rope between headache ball and point of rope failure was of the order of 27m, so either piece could be from either side of the failure.

It was noted that the rope was heavily corroded and there was no externally visible lubrication (Figure 1). The rope was inspected for wire breaks, local damage, wear etc. No significant defects were found; minor damage and wire breaks along the examined rope lengths are listed in Table 1. It is not clear where the rope had been stored during the period between failure and delivery to Reading, but it is likely that some additional corrosion will have taken place. However, photographs taken at time of rope failure on board the vessel show the rope to be corroded throughout the construction at that time.

Table 1

Results of preliminary external examination

Location Dist. from failure (m)	**Damage**
Length 1 (18.9m):	
3.3	2 outer strand wire breaks; 1 outer strand wire break in next strand
3.45	Local damage to 1 outer strand
10.0	Kink in rope
12.25 – 13.6	Kink in rope
18.33	Very local damage to 1 outer strand; 1 possibly 2 broken outer wires
18.89	3 wire breaks in outer strand apparent where rope cut
Length 2 (3.4m):	No apparent wire breaks or damage

Figure 1

Typical external condition of the rope in the as received condition (length 1: 18.33m)

(Note the wire break in the middle of the figure)

3. Review of Documentation

3.1 DOCUMENTATION SUPPLIED

The documents supplied to The University of Reading were:

- Particulars and General Arrangement drawing of the DSV PELICAN.
- Crane drawings and load diagrams.
- The BP/DSND Dangerous Occurrence Final Investigation Report: Whip Line Failure DSV PELICAN. The contents of this report included:

    Introduction
    Management Summary
    Incident Details
    Wire Rope History
    Short Term Recommendations
    Long Term Recommendations
    Appendices:
    1. Terms of reference
    2. OIR 9B/DSND and BP reports / photographs
    3. Weather / Sea state and chart
    4. CIA reports
    5. Wire Rope History
    6. Planned Maintenance System History
    7. Bibliography

3.2 WIRE ROPE HISTORY

From the documentation supplied in the BP/DSND report the whipline test and maintenance history was as follows:

Apr 1997	Rope supplied by IOS Offshore (Break test 51.25 tonnes)
May 1998	Break test (48.6 tonnes) conducted by OTIC
Sept 1999	Pressure lubrication of approx. 200m by DSND PELICAN staff
Mar 2000	Break test (49.9 tonnes) conducted by Grampian Test & Certification Ltd.
Sept 2000	Proof load (to 12.5 tonnes) and visual check conducted by Chandlers International Aberdeen (CIA) Ltd.
Dec 2000	Proof load (to 12.5 tonnes) and visual check conducted by CIA Ltd.

A ‘light’ lubrication (presumably this means external lubrication of the rope, not a pressure lubrication) of the crane wires was a Planned Maintenance System requirement, to be carried out every two months. (Note: The effectiveness of such lubrication applications is questionable, as the lubricant will only be applied to the outer surfaces of the rope. This type of rope construction is such that it is very difficult to replace lubricant if it has been lost from the inner layers. Additionally it is inadvisable to lubricate a wet rope, since the lubricant will trap the moisture and promote corrosion. Any policy of external relubrication of rope as it is recovered from submersion should be avoided.)

Proof load and visual examinations were performed in September 2000 and December 2000; there is no evidence to show that the state of the rope or its lubrication were not satisfactory. However, loss of internal lubrication is impossible to detect by visual examination, particularly in non-rotating ropes where the inner strands are hard to inspect without dismantling the rope. The results for the breaking load tests would suggest that the rope was in reasonable condition one year prior to failure.

Regarding slip and cut of the crane rope there is no documentation of any specific policy in this regard. However, it is noted that two break load tests on the rope were carried out, in May 1998 and in March 2000. For each of these tests a section will have been cut from the end of the rope, thus moving the rope relative to the rope sheaves and winch.

3.3 LOCATION OF ROPE FAILURE

In the BP/DSND report and its appendices there are conflicting accounts of the location of the break:

- In the main report it is stated that the rope broke ‘just below the sheave approximately 20m back from the headache ball’.
- In Appendix 2, the OIR/9B form states that ‘the whip line parted mid-way along the crane boom’.
- In Appendix 2, the Serious Occurrence Report says that ‘the whip line parted approximately 4 metres from the headache ball’.
- In Appendix 4, the CIA report states that ‘The whip line of the main crane had broken approximately 7m from the crane ball’.

From a review of the documentation provided, the following has been assumed:

- The base of the module was 4m below the water surface (in the DSND Near Miss report in Appendix 2, the Deck Foreman states that the wire parted when the load was 3 to 5m below the surface).
- The vessel deck was 2m above the water surface (based on general arrangement drawing and vessel principal dimensions).
- The point where the rope entered the jib tip sheave on the crane was 27.5m above the deck. (This assumes that the crane boom was at 45^o to the horizontal when the

rope failed, and that the length of boom from pivot to tip is 30m. The pivot is 6.3 m above the deck.)

- The rope failed 1 to 1.5m below the sheave (as stated in Appendix 4 to the main report, and from photographs given in Appendix 2).
- The crane ball was 5m above the base of the module (the actual figure would depend on the module dimensions and sling configuration (which are not known); it is assumed that the rigging included a 3m single strop between the module and the hook, as it is understood is common practice).

All of the above taken together, indicate that the break was likely to have been at a distance of some 27m from the headache ball (Figure 2). However, it should be noted that with so many uncertainties and approximations in the data, this distance is far from accurate and has a tolerance of several metres either way. Figure 3 shows the PELICAN at sea. It is interesting to note how the crane hook is tied back to the stern bollards to prevent unnecessary thrashing about. Figure 4 shows where the calculated point of failure on the rope (i.e. 27 m from the headache ball) would have been during storage of the crane.

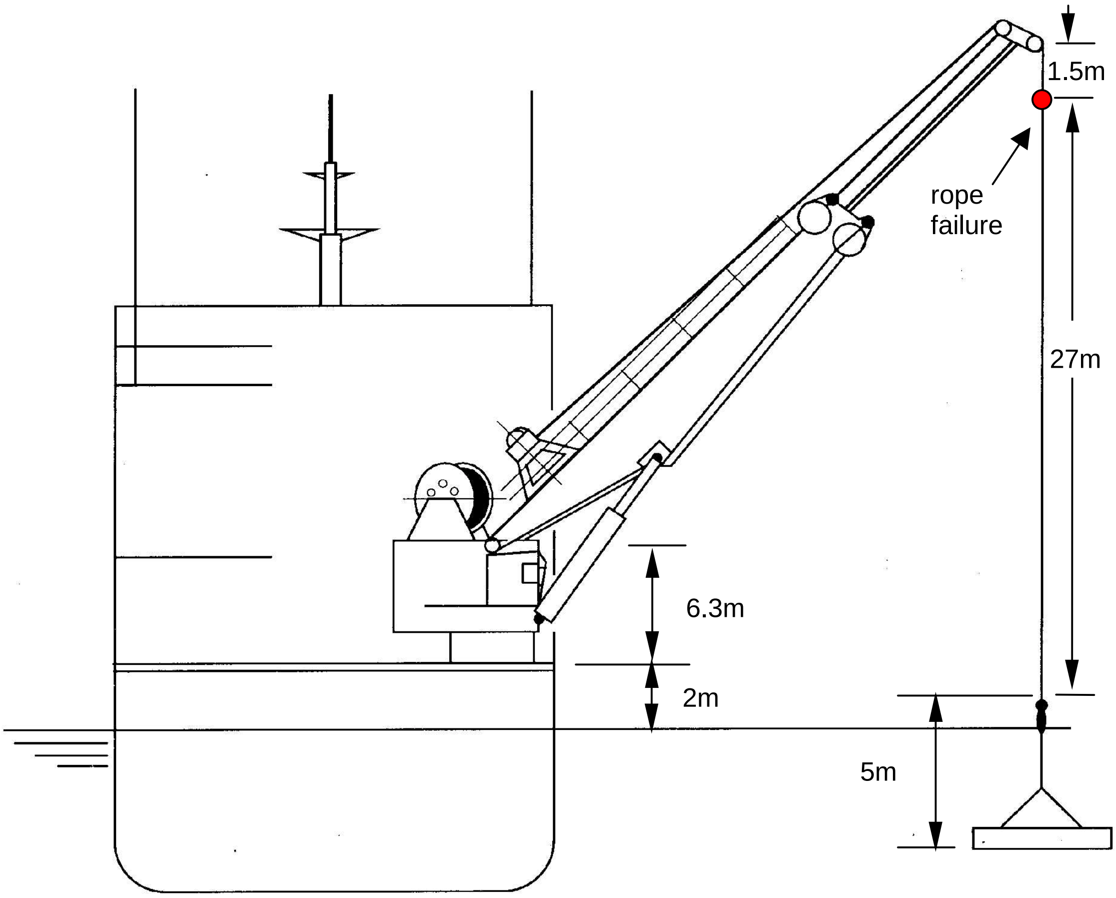


Figure 2

Schematic drawing of the location of the rope failure during deployment (stern view)

Figure 3

DSND DSV PELICAN at sea (starboard view)

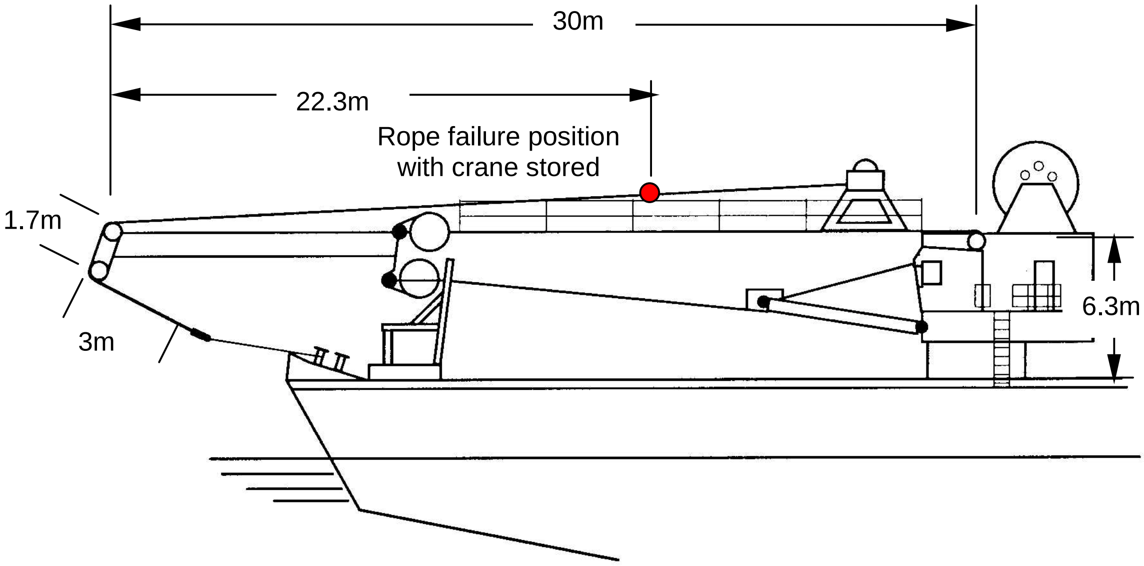


Figure 4

Schematic drawing of the position of the rope failure when crane stored (starboard view)

4. Internal Examination of the Rope

4.1 ROPE CONSTRUCTION

The rope is of a non-rotating type, 26mm dia., 34 x 7 + core (the core is a 9/9/1 Seale construction), RHO, 1960N/mm^2 galvanised (determined from an inspection of a rope sample removed from the winch drum). The catalogue MBL is 50 tonnes.

4.2 CONDITION OF THE ROPE EITHER SIDE OF THE FAILURE

The first length (the longer of the two) of rope was dismantled over a length of 2.65m. The second length was dismantled over a length of 2.10m from the failure location. The condition of the rope was similar along both these lengths. There was no evidence of multiple broken wires or signs of disintegration of the inner strands or core which would be associated with fatigue degradation of the rope. However, the rope was heavily corroded and dry at every layer in the construction. No lubrication was present between the strands in the first and second layers. Some evidence of lubrication was present between the strands in the third layer and the central core, but it was completely denatured, being dry and powdery in appearance. There was also considerable corrosion debris trapped within the construction.

A sample of the rope away from the failure was also examined. This sample was taken from the longer sample, at a distance of 18.8m from the break. The condition of the rope was the same as the lengths either side of the failure, i.e. heavily corroded and dry at every layer in the construction, see Figure 5. No internal wire breaks were found which are characteristic of fatigue damage for this type of rope construction. It should be noted that although the storage conditions of the rope between failure and delivery at Reading could have allowed some additional corrosion, the state of internal lubrication would not have changed. Once internal lubrication and galvanising protection has been lost, internal corrosion of such ropes can proceed rapidly.

Figure 5

Internal condition of the rope 18.8m from the failure

4.3 ESTIMATE OF STEEL LOST AS A RESULT OF CORROSION

A 100mm length was cut from the rope and dismantled into its component wires. These wires were then soaked in penetrating oil before being put in degreasing agent in an ultrasonic bath to remove loose surface corroded material. The cleaned wires were then weighed. For comparison, a sample was also taken from the end of the rope which had been stored on the winch drum, which was well lubricated and showed no signs of corrosion. The wires were separated, cleaned and weighed in the same manner as before. The weights of the two samples were:

corroded sample, weight = 218g/100mm
“as new” sample weight = 281g/100mm

(Note: the catalogue weight for a similar rope (a 26mm low rotation Endurance® 35LS, 35 x 7 (6/1), 1960N/mm^2 Gal, MBL = 52.4 tonnes), is 309kg/m (309g/100mm). Adjusted to the same catalogue MBL as the PELICAN rope, new rope catalogue weight is 295kg/100m.)

Thus the PELICAN rope has lost approximately 22% of its metallic area due to corrosion. As a first approximation, the rope strength will be reduced proportionately, i.e. the corroded rope strength would be 39 tonnes. This calculation assumes that the corrosion is evenly distributed through the rope and along each wire; if proportionately more metal was lost from the outer strands then the strength of the rope could be degraded further. There is also considerable variation in the level of corrosion along the wires. Thus although the mean loss of area is 22%, the actual loss will inevitably be proportionally much higher than this.

Figure 6 shows a comparison of the cross section of the rope removed from near to the failure (left) and from the end of the rope stored on the winch drum, which may considered to be representative of the rope in the “as new” condition. Attention is drawn to the extraordinary loss of metallic cross section on the core strand, especially considering that this is at the heart of the rope where galvanising and residual lubricant are most likely to remain.

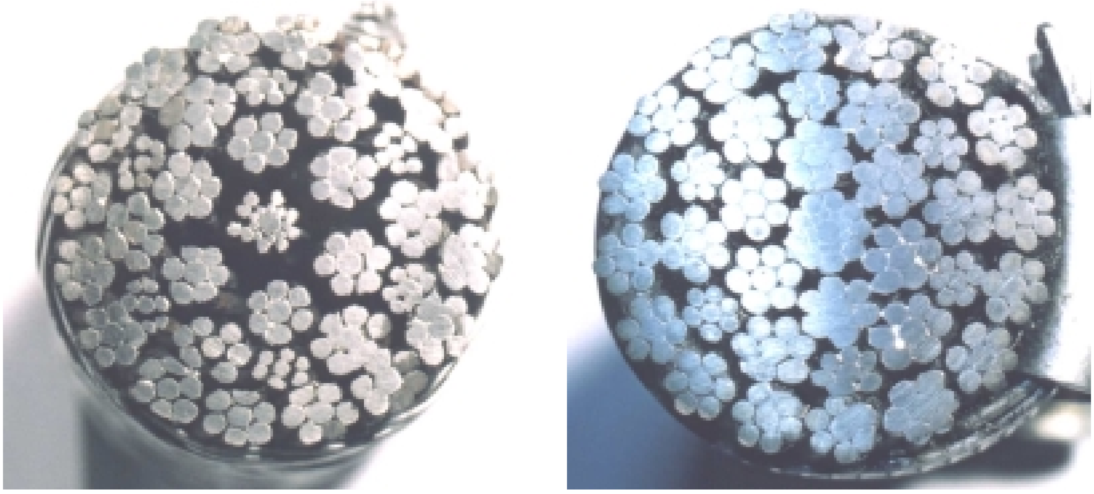


Figure 6

Cross sections of corroded (left) and "as new" (right) rope

5. Categorisation of Wire Fractures

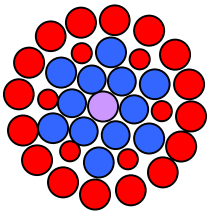
Sections of the rope on both the winch side and the hook side of the fracture were dismantled and the component strands examined to determine the type of failure of each wire in the strands.

Each wire of each strand was examined under a microscope and the cause of failure determined. A summary of the results are given in Table 2, refer also to Figure 7.

Table 2

Categorisation of wire fractures

Wire location	Type of failure
Outer strands	Corrosion induced wear; core wires tensile.
2nd layer, large diam. strands	Predominantly tensile, with 17% wear and 4% fatigue; core wires tensile.
2nd layer, small diam. strands	Predominantly corrosion induced wear, with 22% tensile and 4% wear; core wires tensile.
3rd layer	Tensile failures.
Core	Mixture of tensile and corrosion induced wear failures.



Key: 🟥 Predominantly corrosion induced wear failures
🟦 Predominantly tensile failures
🟪 Mixture of tensile and corrosion induced wear failures

Figure 7

Schematic drawing showing the location of the wire failure types across the rope section

Examples of typical corrosion induced wear and tensile failures are shown in Figures 8 and 9. Figure 10 shows the very local wear induced at the strand cross over points (for a selection of wires). This degradation, taken in connection with the comments in section 4.3 on the distribution of the loss of metallic area, confirms that the loss of breaking strength would have been much greater than 22%.

Figure 8

Typical appearance of corrosion induced wear strand failure

Figure 9

Typical appearance of tensile load induced strand failure

Figure 10

Local loss of metallic area in wires caused by corrosion induced wear

6. Comparison of Rope at Failure Location and Rope Stored on Winch Drum

A length of rope was cut from the rope a distance 2m from the hawse hole on the winch drum and its condition compared with that of the rope in the failure region. The rope on the drum has had comparatively little exposure to sea water and air, and the surface lubricant was still present and in good condition. Inspection of this sample confirmed that the rope had originally been galvanised. Internal examination of the rope revealed the internal lubricant to be present and in good condition throughout the construction. Figure 11 shows the rope sample with three of the outer strands removed. The lubricant is clearly visible.

Figure 11

Internal condition of the rope from the winch drum

7. Site Visit to DSV PELICAN

On 6th February 2002 a visit was made to the DSV PELICAN at the port of Leith, Scotland. The main reason for the visit was to see whether there were any possible causes of excessive rope corrosion or local damage, not obvious from drawings or documentation, that might have been contributory factors in the deterioration of the whipline crane rope. In addition it was possible to discuss the background to the incident and details of normal operating procedures with DSND personnel.

Inspection of the crane and vessel led to the conclusion that there was no source of increased local corrosion (e.g. vent pipes in the vicinity of the rope; points where sea water could collect and immerse part of the rope). There was a possible source of local rope abrasion: a sheave fitted in the upper surface of the crane, against which the whipline rope could rub or catch, see Figure 12 (although this sheave is some 12m from the estimated location of the wire break when the crane is in its stowed position, the estimates of wire break location are somewhat vague, as described in section 3.3 above). However, inspection of the broken rope did not indicate that the failure was due to local external wear or damage, so it is unlikely that this potential clash was significant in the incident under investigation. It is worth noting, though, that this structural detail is a potential source of abrasion to the whipline rope, and the rope should be checked with particular care for local damage during the annual crane inspection.

Figure 12

Whipline lying alongside redundant sheave fitting

8. Conclusions and Recommendations

8.1 CAUSE OF ROPE FAILURE

The investigation clearly indicates that the chief cause of rope failure was corrosion, which caused the strength of the rope to be reduced far below its catalogue value. It is speculated that once the protective galvanising and lubricant had been lost, the wires in the outer strands suffered corrosion induced wear type failures, leading to tensile failures of the remaining inner strands.

An approximation to the loss of strength based on a measured average loss of metallic area gives a reduction in rope strength of approximately 22%. However, this assumes that the corrosion is evenly spread both through the rope cross section and along its length. It has been shown that in fact there are considerable local variations in corrosion. This will mean that the *effective* loss of strength is much greater, possibly even two or three times the average *nominal* value. A loss of strength proportional to two to three times the average loss of metallic area due to corrosion would imply an *effective* rope strength of between 28 and 17 tonnes. It is estimated that the hook load at the time of failure would have been below this reduced strength capacity. Even allowing for dynamic effects of vessel motion and shock loading, the load on the rope could only have been 9 tonnes maximum.

Three other factors are likely to have contributed to the strength loss

(i) There will be additional strength loss due to fatigue, given that the rope was four years old at the time of the incident, and would have been subject to bending-tension loading. (However, as the load history of the rope is not known the potential loss of endurance cannot be quantified.)

(ii) There will be a reduction in breaking strength of the rope as it passes over the jib tip sheave. (The rope parted very close to or on the jib tip sheave.)

(iii) In addition to allowing the onset of corrosion, loss of lubricant throughout the rope construction will impair the load sharing performance of the rope. The heavily corroded strands will not able to slide freely relative to one another and hence the load distribution between the layers in the rope will be poor. The effect of the load imbalance in the rope will be further exacerbated by a disproportional loss of metallic area from the outer vs. the inner strands. It is not clear what the level of this effect will be. Once torsional imbalance occurs at any point along a rope, damage will concentrate there leading to rapid degradation.

8.2 SIGNIFICANCE OF WIRE BREAK LOCATION

From the review of supplied documentation, supplemented by our own calculations, and an on-site inspection of the DSV PELICAN, we conclude that there is no special significance to the rope failure location. It was not at a position where the crane rope was normally stored over a sheave or winch, nor were there any reasons why the corrosion of the wire would be greater at this point than any other. This fits with the conclusions drawn from the inspection of the broken rope, which showed consistently severe corrosion over a distance of 2m either side of the break, with no evidence of excessive local wear.

8.3 RECOMMENDATIONS

The DSV PELICAN crane rope failed due to very heavy corrosion, despite the fact that the crane had been visually inspected 6 months and 3 months prior to its failure. A sample from the whipline had also been break-load tested one year prior to the failure, with a rope strength only 2.6% less than its value when new. It thus appears that although the rope had been regularly inspected and tested, the deteriorating condition of the rope had not been noticed. With a view to the age of the rope (which was fabricated in April 1997), and the fact that it was operating in an offshore environment, a more careful inspection should have been carried out to check for any signs of internal corrosion (e.g. unusual increase or decrease in rope diameter, lack of gap between strands, dryness and deterioration of the lubricant, increased resistance to bending).

It is therefore recommended that:

- A more rigorous and effective lubrication policy be instituted to prevent corrosion. In this type of rope, once lubrication has been lost in the inside layers of the construction it is almost impossible to successfully re-lubricate the inner strands. Therefore it is very important that a new rope is kept very well lubricated to avoid penetration of water into the inner layers.
- The removal of samples for break-load tests be used as an opportunity to examine the rope internally to see whether there is still adequate lubrication in the inner layers, and to assess the level of galvanising remaining on the wires. This can be done either when the rope is opened up at its ends to fit terminations to the break load sample; or, after the break-load testing.
- Consideration is given to a ‘slip and cut’ policy, whereby the most severely corroded section of the rope (i.e. that on the crane boom when the crane is stowed) is periodically removed. It is not known how much rope was removed for each break load test, but it is unlikely to have been as much as this (about 35m).
- NDT testing is currently the only effective means of assessing the internal condition of this type of rope construction.

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