Discussion of Experimental Electromagnetic Wire Rope Inspections Performed at the Health and Safety Laboratory in Sheffield England

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October 21, 2002

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1. INTRODUCTION

A recent study by the Health and Safety Laboratory (HSL), Sheffield, England examined and compared the performance of a number of rope inspection instruments (Smith and McCann, 2002).

Six rope inspection organizations participated in these trials:

1. Anglo Testing Division (RMS and ATD) from South Africa,
2. CASAR (CMRT) from Germany,
3. Lloyds Beal Ltd. (Ropescan) from the UK,
4. NDT Technologies, Inc. (LMA-175L, LMA-250) from the USA,
5. Rotesco Inc. (Rotescograph) from Canada, and
6. Heath and Sherwood Ltd. (Magnograph) from Canada.

A total of 9 instruments was used. Some of the operators provide commercial inspection services in their own areas and some are involved in the design and marketing of instruments. The instruments were all operated by their respective owners or staff.

Six ropes were used in the project, (Table 1). The individual ropes were color coded as indicated in the Table.

Table 1: Summary of basic information on the ropes under test

	Color Code	Dia.	Description
1	RED	38mm	S.M.R.E. Reference Locked Coil. Right hand lay. Known artificial internal faults.
2	BLACK	32mm	Colliery, Locked Coil. Left hand lay. Variable corrosion
3	YELLOW	38mm	Colliery, 6 strand rope. Fibre Core. Right Hand Lang's Lay Uniform wear
4	WHITE	32mm	Offshore, 6 strand rope IWRC. Left hand lay. Potential odd broken wires. No corrosion
5	GREEN	34mm	Eliminated.
6	BLACK/ YELLOW	28mm	CASAR (Germany) plastic filled multistrand crane rope. Wire strand core. Left hand Lang’s lay.Internal broken wires. No corrosion
7	TURQUOISE	25mm	Multistrand Dyform Rope. (rotation resistant) Wire strand core. Right hand Lang's Lay. Artificial surface defects (not well defined).

Apart from the SMRE locked coil test rope, which was specially constructed for earlier trials in 1972, little history was available for the selected ropes. In this context, it should be pointed out that rope examiners prefer to have access to a rope at regular intervals starting with the new condition. Especially, a thorough inspection of wire ropes requires a combination of visual as well as electromagnetic (EM) methods. The inspector must consider and weigh all obtainable and pertinent details on the state of the rope under test. Useful information includes

(1) the findings of a visual inspection,
(2) the results of an EM rope inspection,
(3) the rope’s construction (including a cross-sectional diagram),
(4) the rope’s operating conditions and damage mechanisms, and
(5) the history of the rope and that of its predecessors.

Unfortunately, very little of this information was available for the tests.

Of particular interest is Rope 1 (red). This locked-coil rope was manufactured with built-in well-documented internal defects and, over many years, has been extensively used for evaluating rope test instrumentation. This fact makes it particularly useful for evaluating and comparing the performance of different instruments.

After the tests, the black, yellow, white and black/yellow ropes were dismantled to quantitatively characterize all defects. This characterization allows a comparison and correlation of test results with the actual rope condition. Such a comparison is valuable because very few ropes are dismantled after evaluation, and an evaluation of NDT test results against the actual rope condition is usually not possible.

Another notable study of this type was performed in Anglo American Corporation of South Africa (Dohm, 1999).

The present memorandum compares the test results obtained by NDT Technologies, Inc. with the actual condition of the red, black, white and black/yellow ropes. (The yellow and turquoise ropes are not discussed because they have no internal deterioration and their condition is easily evaluated with a simple visual inspection.)

2. ROPE NO. 1 (RED), 38 MM LOCKED COIL SMRE REFERENCE ROPE. RIGHT HAND LAY.

Description of Test Sample

This reference rope was manufactured by the Safety in Mines Research Establishment (SMRE) in Sheffield, England. A typical rope construction for a locked coil winding rope is shown in Figure 1.

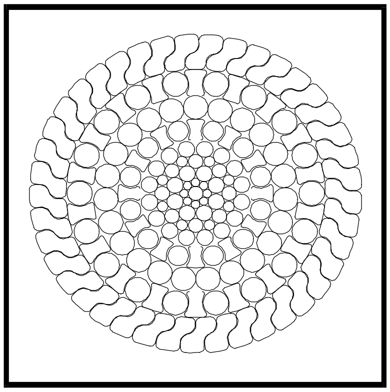

Figure 1 Rope 1
Typical locked coil construction similar to the SMRE 38 mm Reference Rope

The rope contains a series of 10 artificial internal defects over a nominal distance of 22 m, with a nominal spacing of 2 m. The arrangement of these defects is shown in Figure 2. Note however, that today the percentage reductions in strength indicated in Figure 2 would more accurately be described as percentage loss of metallic cross-sectional area (LMA).

Defects are distributed through the second, third and fourth layers and have two profiles; narrow defects (N) consist of a single 4 mm wide groove and wide defects (W) consist of 18 grooves, 4 mm wide at 8 mm separations. All grooves are machined to a depth of half of an individual wire diameter around the whole circumference.

Defects 7 and 8 and defects 9 and 10 were designed as matching pairs. However, there are some variations in the defect profiles and discrepancies in the indicated LMA values.

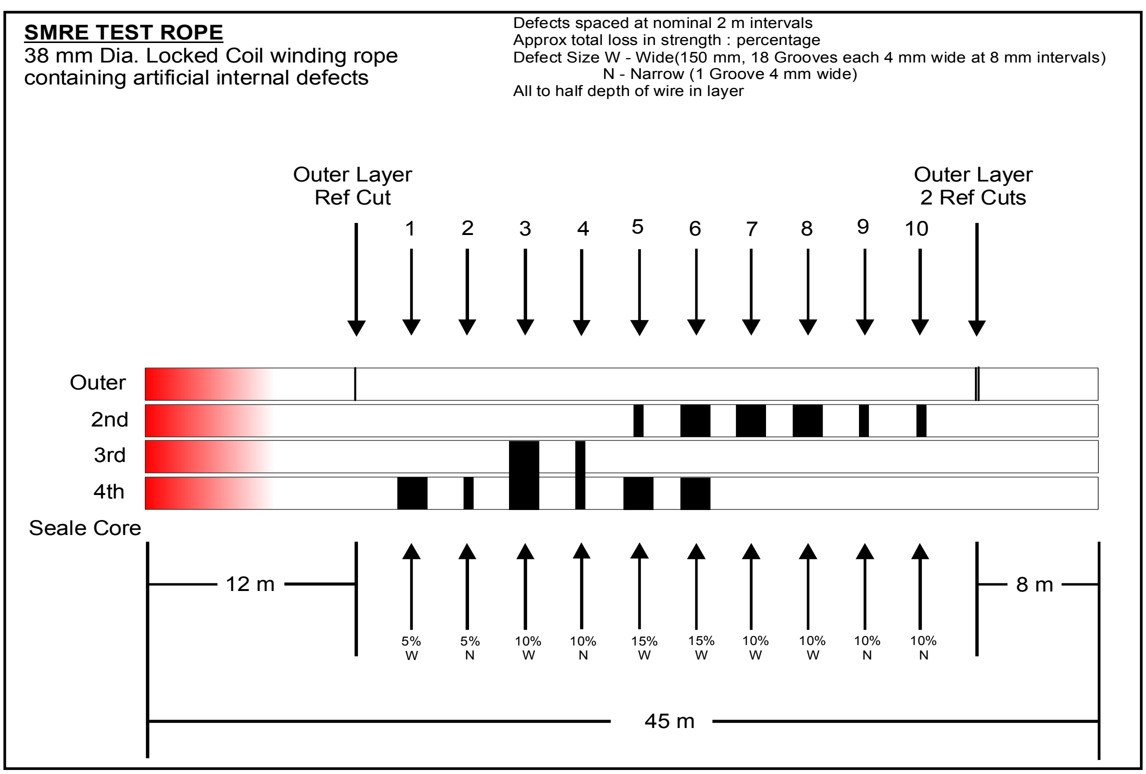

Figure 2 Details of the SMRE Reference Rope

Sample Test Results

The following are sample charts obtained with various wire rope test instruments as labelled. Sample traces for Defects 7 and 8 are shown as indicated. Note that no LMA trace is available for the CASAR CMRT 40 rope tester. Guidelines for evaluating and comparing the quality and accuracy of these charts are presented in (Weischedel, 1999).

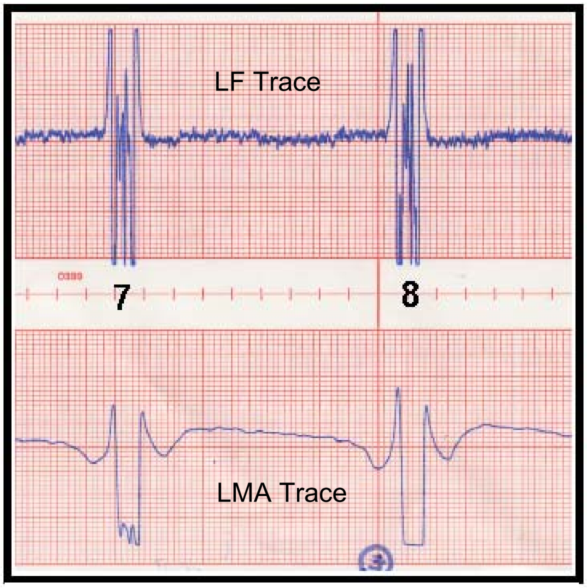

Figure 3a
Lloyds Beal Ropescan

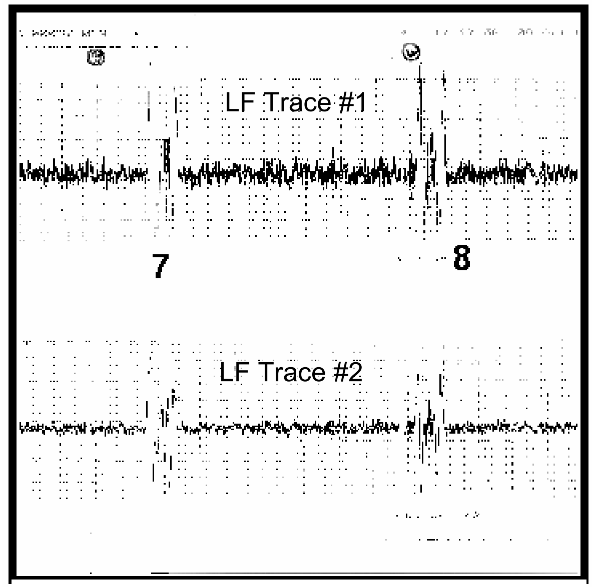

Figure 3b
CASAR CMRT 40

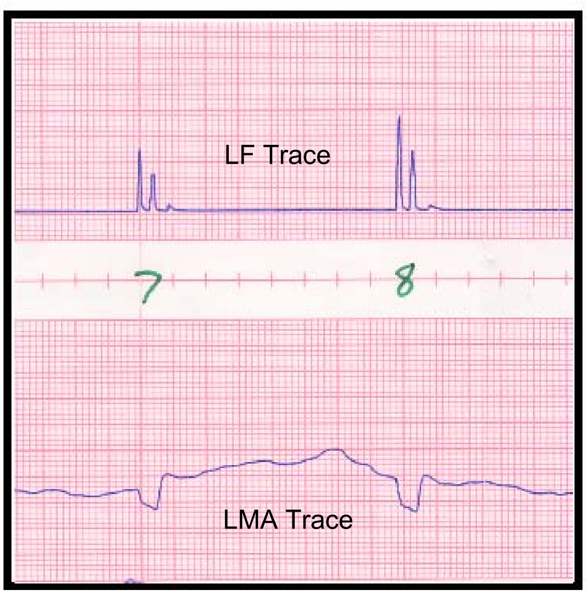

Figure 3c
ATD RMS RAU301

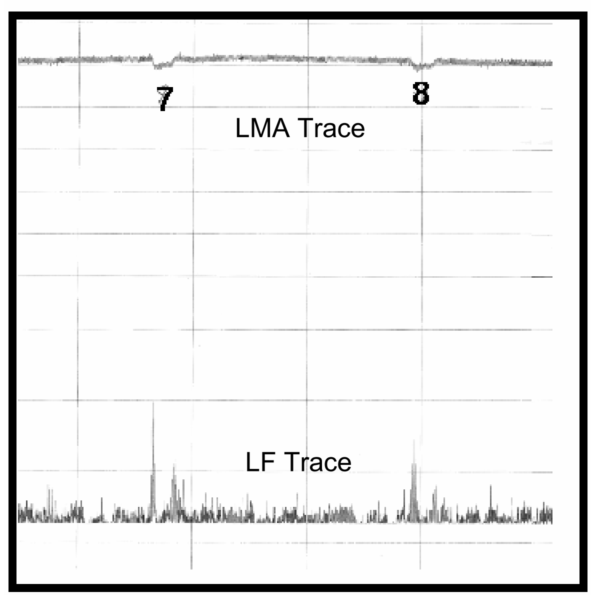

Figure 3d
ATD 817

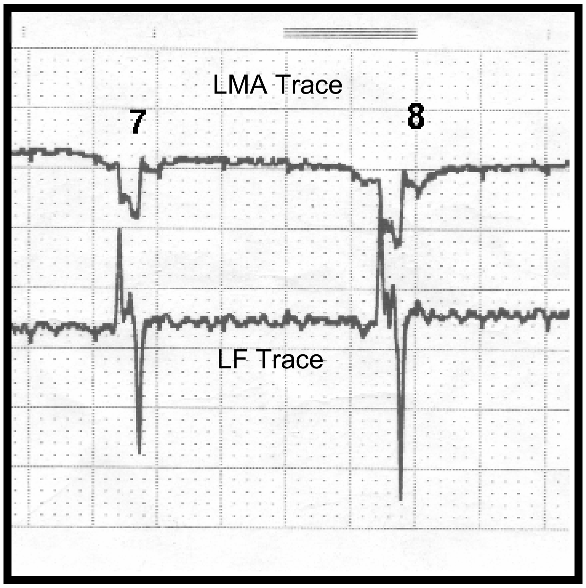

Figure 3e
NDT Technologies LMA-175L

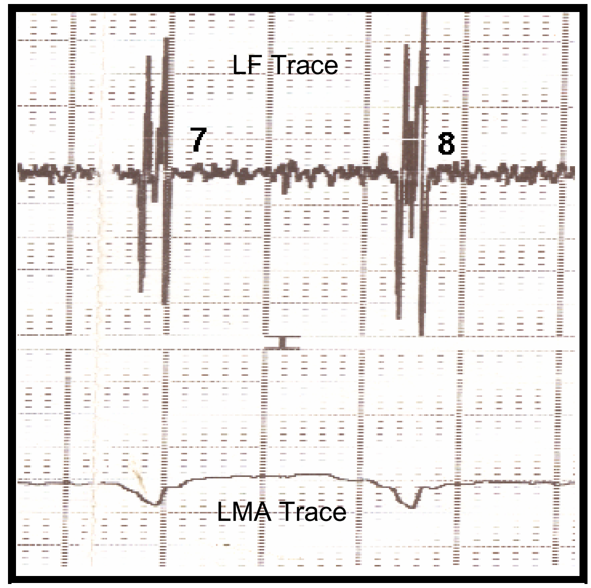

Figure 3f
Rotesco Rotescograph

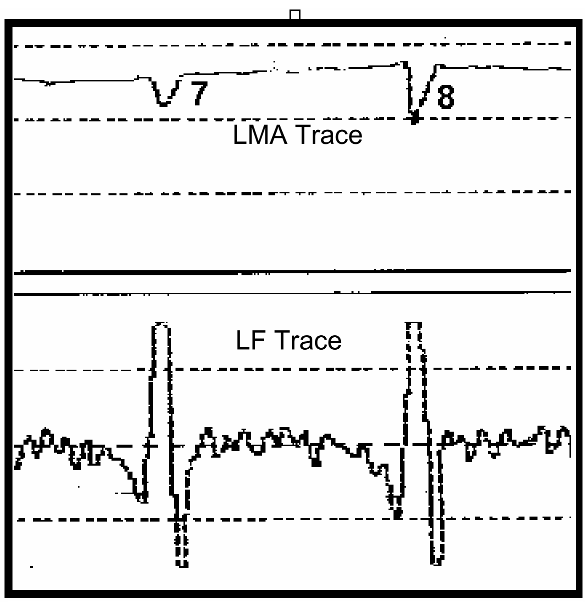

Figure 3f
CANMET/Noranda Magnograph II

Figures 4a-b show additional charts of Rope 1. This data was acquired with the LMA-175L Rope Tester. The charts are displayed by the NDT_CARE™ (**C**omputer-**A**ided **R**ope **E**valuation) software from NDT Technologies, Inc.

Figure 4a and 4b illustrate the appearance of chart recordings before and after signal enhancement, respectively.

Note that the indicated LMA values of discrete Flaws 1 – 10 are essentially unaffected by signal enhancement. However, in Figure 4a, the indicated LMA values in the immediate vicinity of the flaws are distorted. Because enhancement eliminates these disturbances, Figure 4b gives a more accurate indication of the true rope condition.

In this particular case, for widely spaced discrete defects, enhancement does not improve inspection accuracy. The benefits of this procedure become more evident for continuous defects. This is illustrated by the example of Rope 2, which will be discussed in the next chapter.

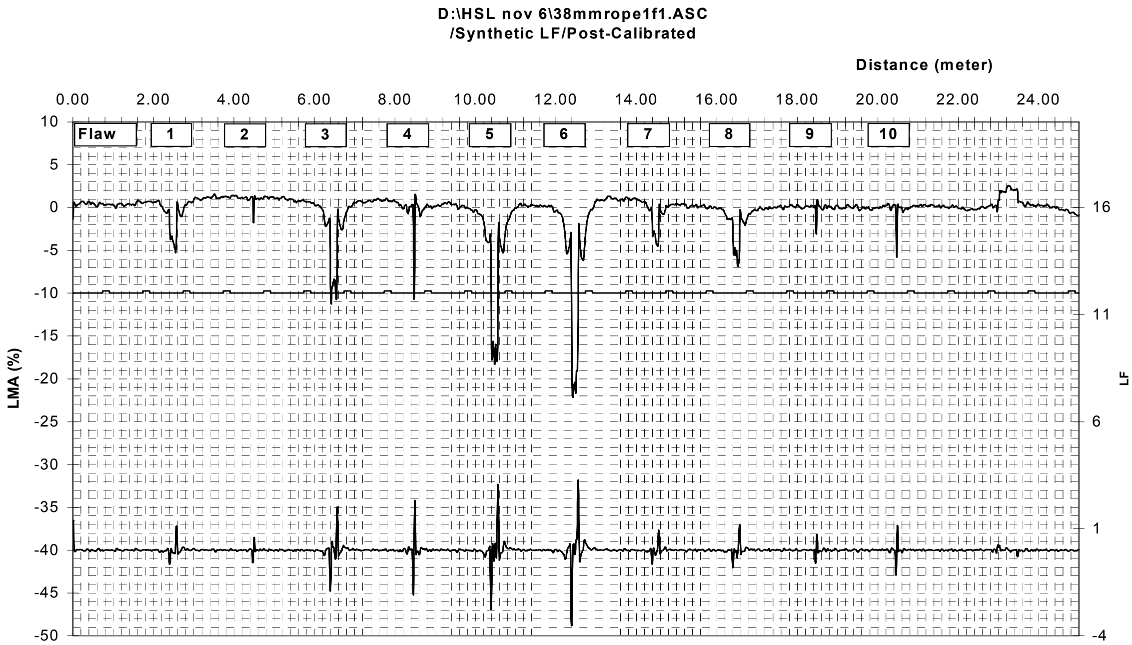

Figure 4a Rope 1 (Red, SMRE 38 mm Locked Coil)
Chart Displayed by the NDT_CARE
(**C**omputer-**A**ided **R**ope **E**valuation) Software
Not Enhanced

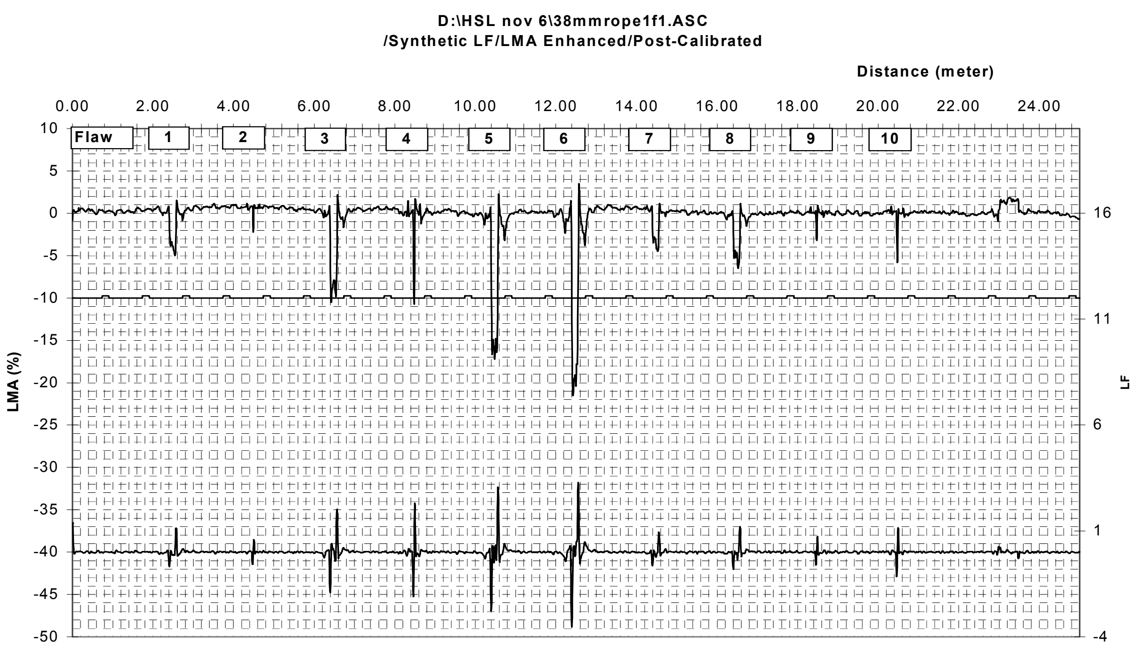

Figure 4b Rope 1 (Red, SMRE 38 mm Locked Coil),
Chart Displayed by the NDT_CARE
(**C**omputer-**A**ided **R**ope **E**valuation) Software,
Enhanced

The following table summarizes actual and measured percentage LMA for each defect as measured by different rope inspection instruments.

Note the differences in the indicated LMA values for the narrow (N) flaws, which reflect the resolution (or inspection accuracy) of each instrument (Weischedel, 1999).

Table 2
Comparison of measured and actual percentage LMA for defects in the Red Rope (Rope 1) (normalized with respect to Defect 1)

Defect Number	1	2	3	4	5	6	7	8	9	10
Actual LMA (%)	5 W	5 N	10 W	10 N	15 W	15 W	5 W*	5 W*	5 N*	5 N*
	Measured LMA (%)									
Lloyds Beal	No LMA values quoted									
CASAR	No LMA signal available									
RMS	5	1	7	5	13	16	4	5	1	2
ATD	5	5	11	9	11	14	7	7	3	5
NDT Technologies	5	3	10	11	17	20	5	6	3	6
Rotescograph	5	1	9	3	15	16	4	4	1	1
Magnograph	5	1	14	3	19	23	4	2	0	1

* Corrected values. (The LMA defect sizes of Flaws 7-10 have been adjusted to reflect the graphically indicated values in Figure 2.)

3. ROPE NO 2. (BLACK), 32 MM LOCKED COIL ROPE LEFT HAND LAY

Description of Test Sample

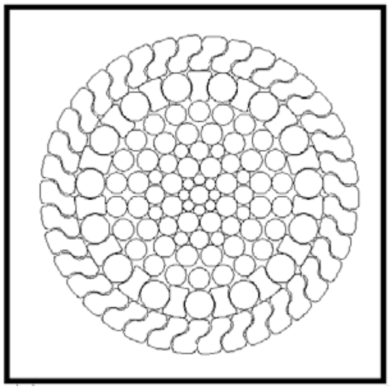

Figure 5 Rope 2 (black), Typical 32 mm locked coil construction

This rope was mounted on an external mobile winch for approximately 10 years after 3 months earlier use on a friction winder installation. The rope showed clear evidence of external corrosion, variable along the test length. Using retirement criteria that are appropriate for visual inspections, this rope would have been rejected for further use. Due to its service history the rope was not believed to contain any internal local defects.

Examination after Dismantling

After dismantling, the rope showed severe corrosion on the outer layer and also significant corrosion on the second layer. The third layer showed less corrosion, and from the fourth layer onward the rope appeared undamaged, because lubricants were still present. No local defects were found. Figures 6 and 7 show the extent of corrosion.

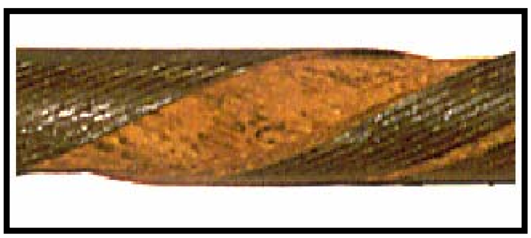

Figure 6 Corrosion in the first and second layer of the rope

Figure 7 Corrosion in the second and third layer of the rope

Findings of Electromagnetic NDT Inspection

Figure 8a shows a chart of this rope without signal enhancement. Figure 8b shows this chart with the LMA signal enhanced. Here, enhancement improves inspection accuracy. For example, maximum measured LMA in Figure 8b (before enhancement) is 4.5% . In Figure 8a, after enhancement, the maximum measured LMA is 5.1%. The latter value is more accurate. Note that, compared to Figure 8a, all measured LMA values have increased after enhancement as shown in Figure 8b.

The charts shows variable corrosion, corrosion pitting and, possibly, broken wires with the worst sections indicated in Figure 8b. The deterioration to the left of the charts is probably caused by winding the rope on the drum with the worst deterioration occurring where the rope changes layers while winding on the drum.

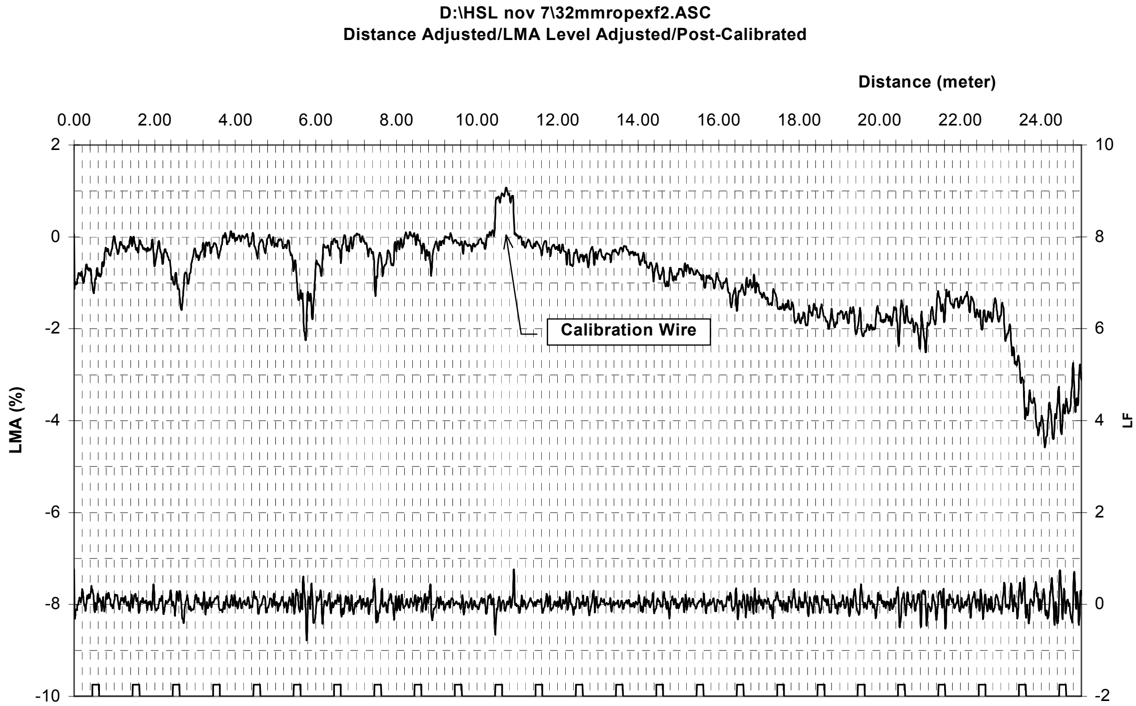

Figure 8a Chart of Rope 2 before Enhancement

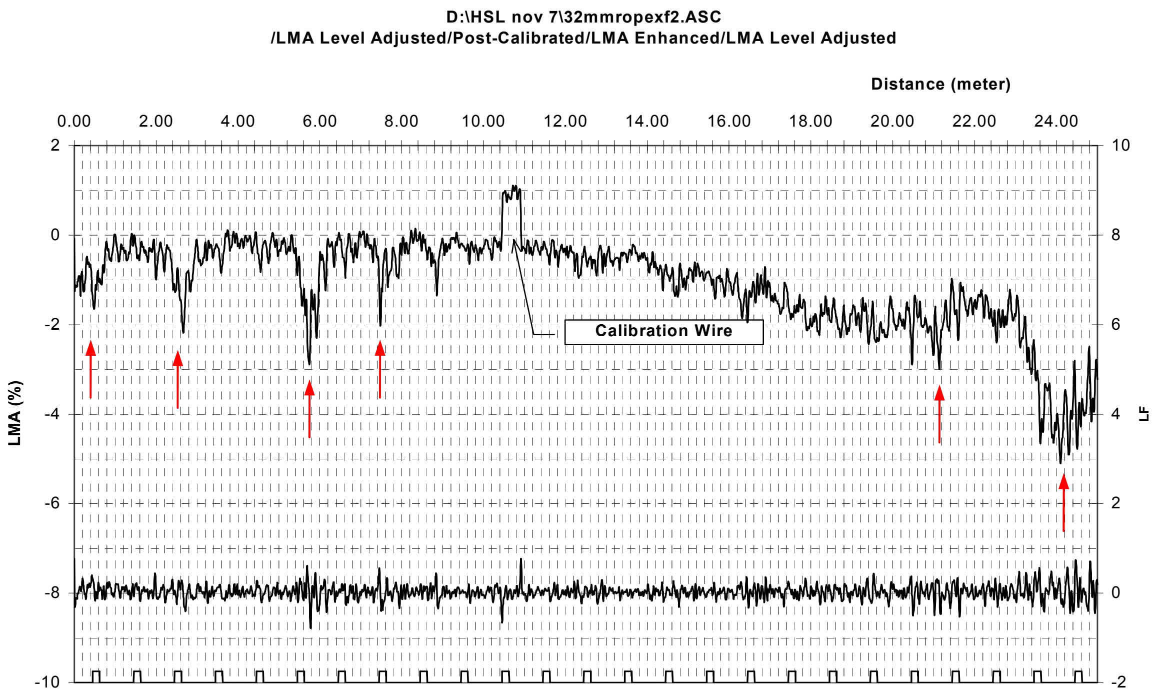

Figure 8b Chart of Rope 2 after Enhancement

4. ROPE NO 4 (WHITE), 32 MM 6-STRAND ROPE LEFT HAND LAY, INDEPENDENT WIRE ROPE CORE

Description of Test Sample

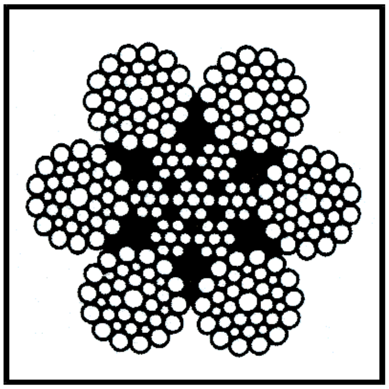

Figure 9 Rope 4 (white), typical 6 strand 32 mm haulage rope with IWRC

The service history of this rope is unknown. The construction is six strand, left hand lay with an independent wire rope core (IWRC). A typical rope construction for this type of rope is shown in Figure 9.

Examination after Dismantling

After dismantling, this rope appeared in generally good condition. There was some drying out of rope lubrication with associated staining and slight corrosion products on the second layer, which was mostly the result of oxidation of the galvanised coating. There was evidence of slight deformation of the core and some limited inter-strand nicking. No cracked or broken wires were found.

Findings of Electromagnetic NDT Inspection

Chart 10 shows the results of the EM inspection. Note that, in this case, the scale of the LMA axis is greatly enlarged with a maximum indicated LMA of only 0.4%.

The Chart shows subtle global and localized cross-sectional area changes along the inspected length of the rope. For IWRC ropes, this indicates deterioration of the IWRC with - possibly numerous - nicked and/or broken wires. In the initial stage of this core deterioration, the wires of the outer strands are not yet affected by this damage, and the breaking strength has not significantly decreased. In the final stages of core deterioration, without support by the core, the outer strands collapse and are squeezed against each other. Therefore, they lose their ability to move against each other. This causes interstrand nicking and, eventually, broken wires in the outer strands. In this case, the breaking strength of the rope will be seriously compromised.

This damage mechanism can be explained as follows.

In order to minimize inter-strand nicking between the IWRC and the outer strands, these IWRC ropes are designed in such a way that the wires of the IWRC and those of the outer strands are approximately parallel. This is typically achieved by using a regular lay construction for the outer strands and a Lang lay construction for the IWRC. However, the wires are only approximately parallel. Hence, during each load cycle, the IWRC wires are squeezed into the grooves between the wires of the outer strands and then released. This periodic small deformation of the IWRC wires produces additional bending stresses which, eventually, cause fatigue breaks. In the final stage, the IWRC can break up completely into small wire pieces of approximately equal length.

To assess the severity of the core damage, it is necessary to compare the chart recording of the deteriorated rope section to the recording of an undamaged segment of the rope under test. Typically, that part of a rope that is not bent over a sheave during operation experiences little damage and can be used for comparison. Unfortunately, in the case of Rope 4 this was not possible.

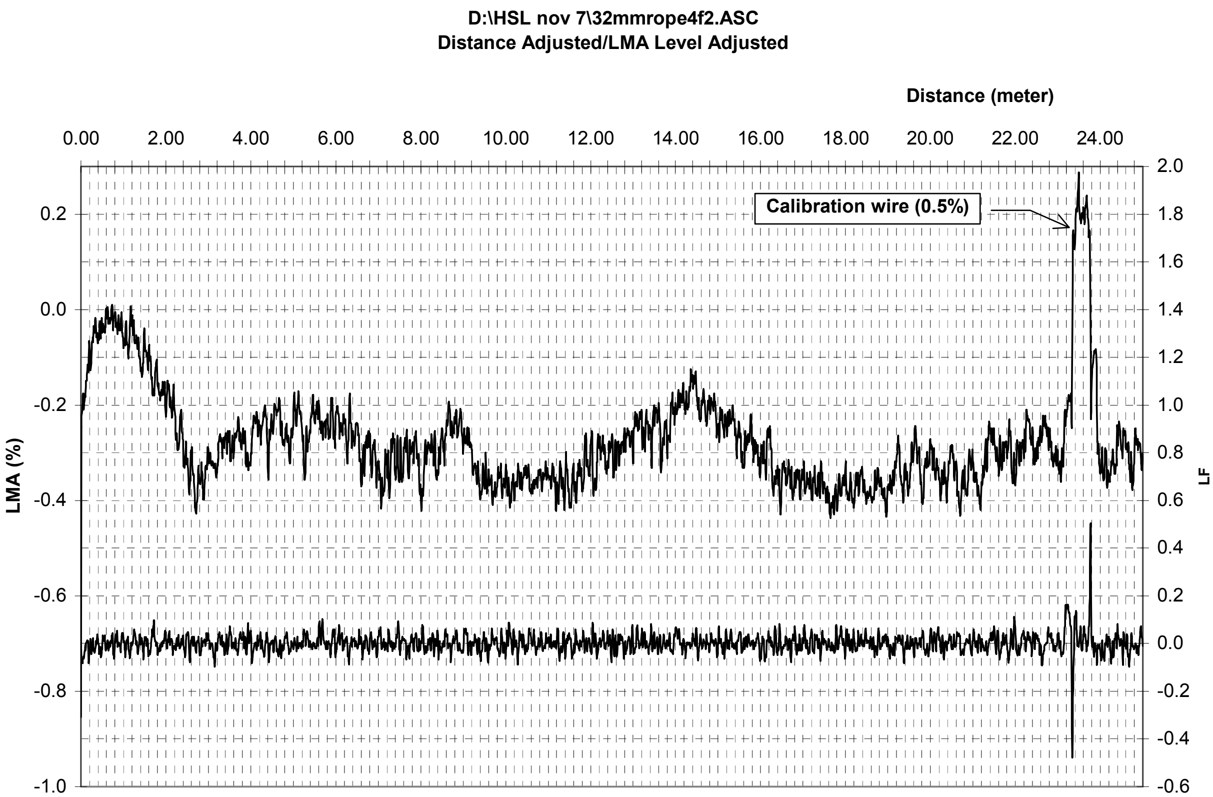

Figure 11 Chart of Rope 6

5. ROPE NO 6 (BLACK / YELLOW), 28 MM PLASTIC FILLED CRANE ROPE, LEFT HAND LANG'S LAY, IWRC

Description of Test Sample

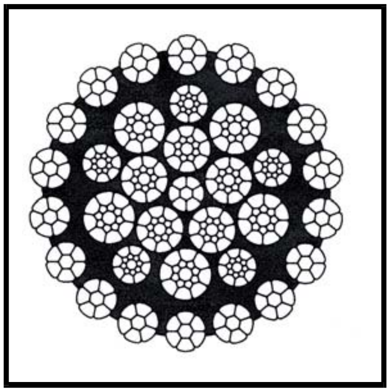

Figure 11 Rope 6 (black/yellow), 28 mm CASAR Powerplast plastic filled crane rope

This rope was manufactured by CASAR, Germany. It is known as a Powerplast multistrand crane rope. The rope had been in service as a crane rope at a UK factory. It was manufactured with a plastic filling in the gaps between outer and internal strands. A typical rope construction for this type of rope is shown in Figure 11.

Examination after Dismantling

A number of broken wires were clearly visible on the outer surface of this rope over a distance of less than 4 metres. On dismantling, 267 local defects were found within a 4.9 m length of rope. All defects were in the outer wires of the outer strands of the rope. Defects consisted of both broken wires and cracked wires that separated completely on removal from the body of the rope, therefore NDT instruments may not necessarily have been expected to detect as many breaks. No significant local defects were found at any other position. There was evidence of only limited metal contact through the plastic along the whole length dismantled. There was no corrosion present on this rope.

Findings of Electromagnetic NDT Inspection

Chart 12 shows the results of the EM inspection. Note that, similar to the Charts of Rope 4, the scale of the LMA axis is greatly enlarged.

The Chart shows subtle but significant global and localized cross-sectional area changes along the inspected length of the rope.

For multistrand ropes of the conventional design (without plastic filling), this would indicate damage to the second layer of strands with interstrand nicking, wear, and - possibly numerous - broken wires. Typically the wires of the outer strand would not be affected by this deterioration mode.

In the present case, the plastic filling evidently (and by design) protects the second layer of strands, and there is only moderate interstrand nicking and wear.

However, the LMA of Figure 12 trace clearly shows 8 broken wires as marked. Further, the LMA trace shows additional metal loss in the defect area, indicating additional internal rope damage.

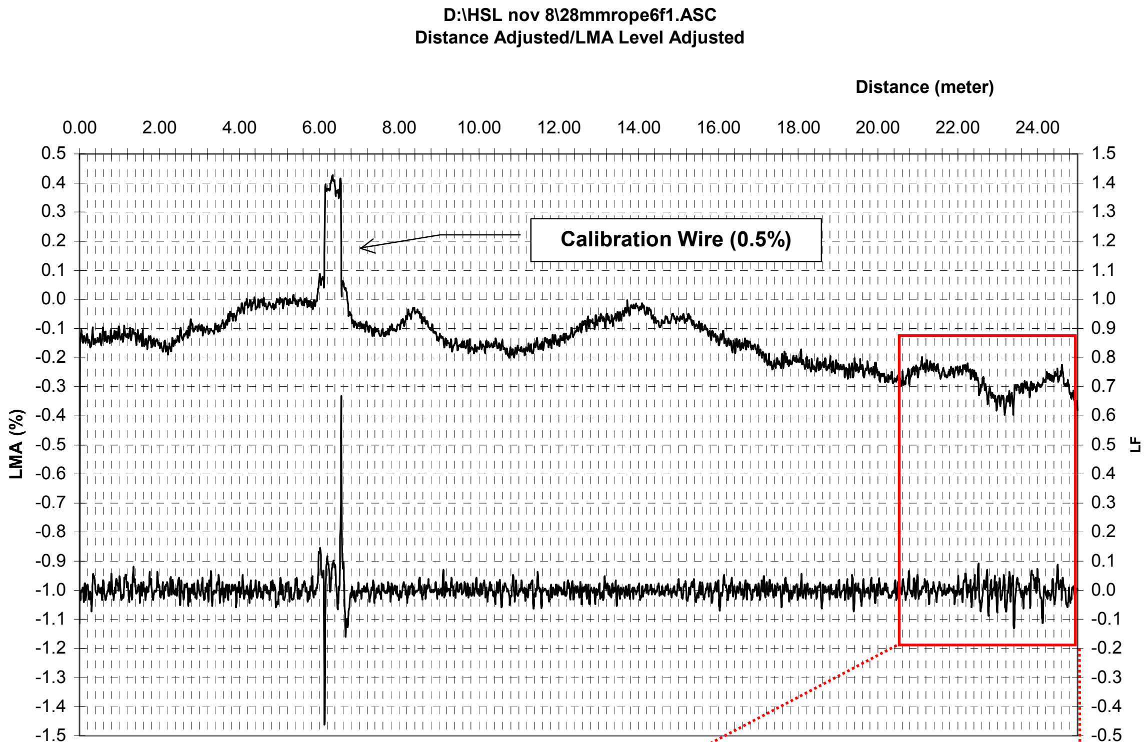

Figure 12a
NDT_CARE™ Chart of Rope 6

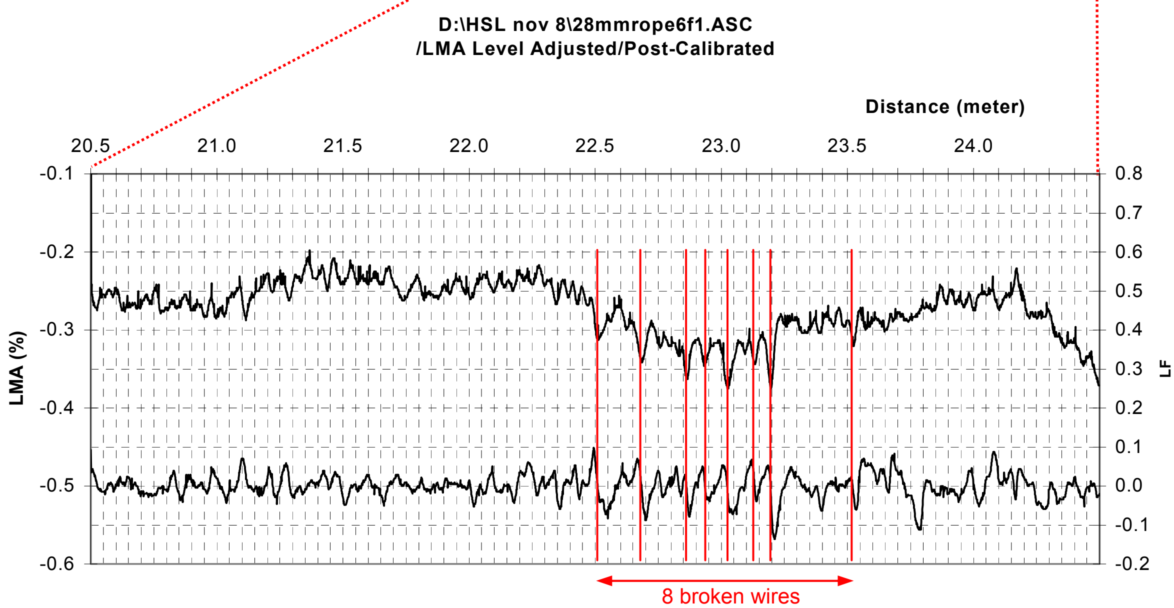

Figure 12b NDT_CARE™ Chart of Rope 6 (Enlarged)

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