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Axial fatigue tests on wire rope slings used for offshore containers

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Axial fatigue tests on wire rope slings used for offshore containers

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The offshore industry uses a wide variety of containers for the transportation of equipment. These containers are permanently fitted with their own lifting sets. Different offshore sectors use different types of lifting sets. In the UK sector, 5 legged wire rope sling sets are used. However, elsewhere chain lifting sets are prevalent. These lifting sets are subject to repeated dynamic loading in a hostile corrosive environment.

At present, the selection and use of wire rope lifting sets is covered by BS EN 13414 “Steel wire rope slings - Safety - Part 1: slings for general lifting service” (2003). This superseded BS1290 “Specification for wire rope slings and sling legs for general lifting purposes” (1983), which was the current specification during this programme of work.

Following a proposal to increase the safety factors for these lifting sets. Field Engineering Section of the Health and Safety Laboratory (HSL), measured the dynamic loads resulting from various lifting operations between a semi-submersible installation and a supply vessel. Measurements were deliberately taken in heavy seas to identify the worst loading conditions which could occur. This work was reported in FE/96/06 “Measurement of Dynamic Loads in the Sling legs of offshore container lifting sets” by P Kerry and P McCann.

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EXECUTIVE SUMMARY

The offshore industry uses a wide variety of containers for the transportation of equipment. These containers are permanently fitted with their own lifting sets. In the UK sector, 5 legged wire rope sling sets are used, however, elsewhere chain lifting sets are prevalent. These lifting sets are subject to repeated dynamic loading in a hostile corrosive environment.

Following a proposal to increase the safety factors for these lifting sets. Field Engineering Section of the Health and Safety Laboratory (HSL), measured the dynamic loads resulting from various lifting operations between a semi submersible installation and a supply vessel. This work identified a complex sinusoidal load profile, when lifting from the supply vessel to the deck of the installation. The work concluded that individual load cycles were within the performance envelope of the lifting set. However, the possible effects of repeated load cycles and a corrosive environment were not considered. This work seeks to replicate the measured load profile using an axial fatigue rig and to evaluate the performance of sling sets subjected to cyclic loading and salt water exposure.

The fatigue cycle used during these tests represents loads equal to and above the highest loads (up to twice the safe working load), measured offshore during the earlier work representing a worst case scenario. A summary of the results is shown below.

Summary of Test results

Test	*Type*	*Cycles*	*Peak Load*		*Result*
1	Unused	15,000	67kN	Measured Offshore	No damage
2	Unused	20,000	67kN	Measured Offshore	Collapse of hard eyes
3	Unused	15,000	76.5kN	Proof load	Collapse of hard eyes
4	Unused	5,185	76.5kN	Proof load	Collapse of hard eyes
5	Accelerated Corrosion	11,000	76.5kN	Proof load	Collapse of hard eyes

There was no evidence of fatigue breaks or cracks within the rope on any of the sample tested (even where rope had been subjected to accelerated corrosion). Fatigue damage occurred only in the thimbles, in the hard eyes. No evidence was discovered to account for the relatively premature failure of sample 4.

The damage that occurred was clearly visible and probably non critical. These results indicate that in the context of offshore container lifting operations, fatigue failure of a wire rope sling would be unlikely to occur. This work did not identify any evidence to justify an increase in safety factors or a change from wire to chain slings.

Further proposed work will evaluate the performance of chain sling sets under identical loading and corrosion conditions, and compare the behaviour of wire rope and chain.

1 INTRODUCTION

The offshore industry uses a wide variety of containers for the transportation of equipment. These containers are permanently fitted with their own lifting sets. Different offshore sectors use different types of lifting sets. In the UK sector, 5 legged wire rope sling sets are used. However, elsewhere chain lifting sets are prevalent. These lifting sets are subject to repeated dynamic loading in a hostile corrosive environment.

At present, the selection and use of wire rope lifting sets is covered by BS EN 13414 "Steel wire rope slings - Safety – Part 1: slings for general lifting service" (2003). This superseded BS1290 "Specification for wire rope slings and sling legs for general lifting purposes" (1983), which was the current specification during this programme of work.

Following a proposal to increase the safety factors for these lifting sets. Field Engineering Section of the Health and Safety Laboratory (HSL), measured the dynamic loads resulting from various lifting operations between a semi-submersible installation and a supply vessel. Measurements were deliberately taken in heavy seas to identify the worst loading conditions which could occur. This work was reported in FE/96/06 "Measurement of Dynamic Loads in the Sling legs of offshore container lifting sets" by P. Kerry and P. McCann.

This work identified a complex sinusoidal load profile when lifting from the supply vessel to the deck of the installation. Dynamic loads were measured up to 88% of the sling proof load and 36% of the minimum breaking load of the rope. Measured dynamic loads were substantially greater (up to 430%) than the static mass of the payload lifted.

The previous work concluded that individual load cycles were within the performance envelope of the lifting set. However, the possible effects of repeated load cycles and a corrosive environment were not considered. This current work seeks to replicate the measured load profile using an axial fatigue rig and to evaluate the performance of sling sets subjected to cyclic loading and salt water exposure.

2 TEST FACILITY

2.1 THE AXIAL FATIGUE FACILITY

Fatigue tests were carried out using the HSL axial fatigue facility. This consists of a vertical frame with a fixed crosshead and a 500 kN, 500 mm stroke RDP servo-hydraulic actuator. The actuator is controlled by RDP hardware. The facility is mounted vertically to overcome problems of rope sag and is shown in Figure 1.

Figure 1 The axial fatigue facility with a wire rope sling leg specimen installed

Integral load and displacement measurement systems are mounted at the actuator head. These systems are calibrated on an annual basis, against reference sources by the manufacturer.

For this test programme, the actuator was controlled using software and hardware designed by Control and Instrumentation Section, HSL. This allowed an external wave-form to be externally input into the system. The wave-form used, was based on the load profile for payload, PSH06, recorded during the FE 96/06 programme. This cycle represents the most demanding lift measured during this work, with a peak load of 67.0 kN. The cycle is shown in Figure 2. It was necessary to raise the "zero point" to 4 kN to allow the servo system to maintain load control.

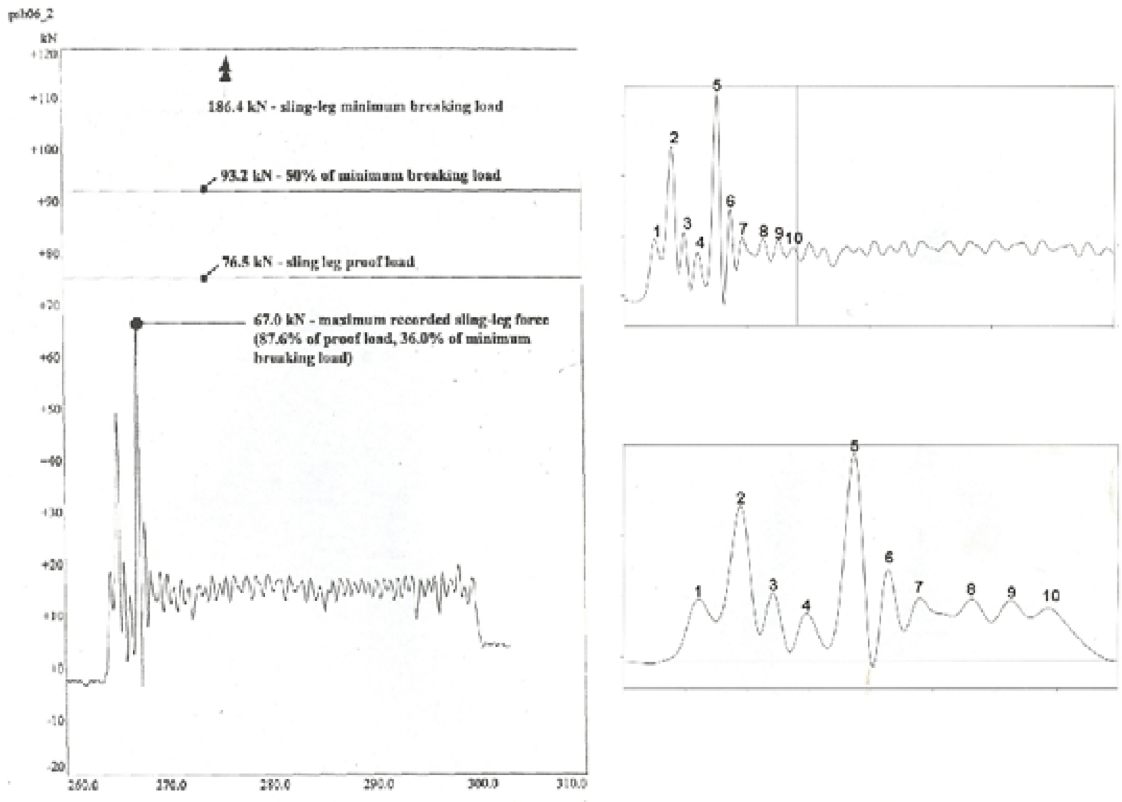

Figure 2 Measured loads from offshore payload PSH06, with peaks identified and expanded.

2.2 THE CYCLIC CLIMATIC CHAMBER

Samples were subjected to salt water exposure using a purpose built Ascott CCT cyclic corrosion test cabinet, serial number 256. The cabinet control hardware was calibrated by the manufacturer in accordance with Field Engineering calibration procedure FE/CP/41.

The test set-up used was based on procedures described in ASTM B117 – 97 "Standard practice for operating salt spray (Fog) Apparatus" and ASTM G85 – 98 "Standard practice for modified salt spray (fog) testing". Details of the corrosion programme used are shown in Table 1.

Table 1 Details of the corrosion cycle

Phase	*Temperature*	*Duration*
Salt Spray	35°C	24 hours
Dry	40°C	24 hours
Humidity	40°C	96 hours
Dry	35°C	24 hours
This cycle repeated 5 times then held at 35°C		

The salt spray was set so that 1 to 2 ml of solution gathered in an 80 cm^{-2} container per hour, as recommended by ASTM B117 – 97 and ASTM G85 - 98.The synthetic sea water used during these tests conformed with ASTM D1141 "Specification for substitute ocean water", the full composition is shown in Table 2.

Table 2 Composition of synthetic sea water used

Compound	*Conc. g/L*
NaCl	24.53
Sodium Acetate 3H20	6.0
MgCl2.6H2O	5.20
Na2SO4	4.09
CaCl2	1.15
KCl	0.695
NaCO3	0.201
KBr	0.101
H3BO3	0.027
SrCl2.8H20	0.026
NaF	0.003
Glacial Acetic Acid	10 mls
Final pH value	2.92

Salt water exposure was not uniform across the sample but was limited to a nominally 0.9 m long section at the centre of sample. This allowed comparison between the performance of "good" and "bad" areas of the same sample and protected the attachment points. For comparison purposes, both new and used ropes were subjected to accelerated corrosion tests.

3 TEST SAMPLES

The test sample consisted of a single sling leg. This leg was constructed from 19 mm diameter 6 x 36 FC wire rope. This means that the rope contained 6 strands, each containing 36 individual wires around a fibre core. A typical construction for this type of rope is shown in Figure 3.

Each sample was nominally 2.4 m long (between bearing surfaces) and terminated, at each end, with a hard eye (with a galvanised thimble) secured by a ferrule.

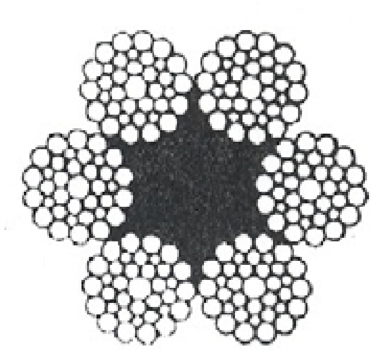

Figure 3 Construction of 6 x36 FC rope

All slings were originally supplied to BS1290 (1983). New slings were purchased directly from the manufacturer. These were supplied as single legs with master link. The specified safe working load (SWL) of these slings was 4.3 tonnes, with a proof load of 2 x SWL. Five legged used slings were supplied by Grampian Testing of Aberdeen. These had been removed from service due to excessive corrosion. These slings had an original SWL of 8 tonnes (for the full sling) and a proof load of 7.6 tonnes per leg. All slings were supplied with the appropriate test certificate.

Although both new and used slings were supplied, only new sling legs were used for fatigue testing.

The wire rope used in these slings complied with BS 302 “Stranded steel wire ropes, Part 2: Specification for ropes for general purposes” (1987). The specified minimum breaking force for this rope is given in Table 3.

Table 3 Properties of 19 mm 6 x 36 fibre core rope

Min. breaking force (kN)	*Min. breaking load (t)*	*Mass (kg/100m)*
211	21.5	130

The upper eye was attached to a master link (type 28B7) while the lower eye was attached to a bow shackle. These attachments were comparable with those used in service, attachments are shown in Figure 4. Lateral movement at the upper attachment was reduced by using spacer plates.

Figure 4 Attachments to the fatigue rig

4 TEST RESULTS

4.1 TEST 1

Test sample 1 completed 15,000 cycles, using the full waveform shown in Figure 2. The test sample was found to have an unexpectedly high compliance and it was necessary to reduce the frequency of the waveform, to the extent that a single cycle took ten minutes to complete and the first test took seven weeks to complete.

On completion of fatigue loading, this sample was removed from the rig and cut into sections. Individual wires were unwound from each strand and examined. The rope appeared to be in good condition and no evidence of fatigue cracks or breaks was found.

4.2 TEST 2

Test sample 2 was subjected to a simplified version of the original waveform. To reduce the cycle time, it was necessary to concentrate on the most significant load peaks and ignore subsequent minor peaks. The waveform was reduced to the first six peaks as identified in Figure 2. This reduced cycle took approximately five minutes to complete.

To reduce compliance, master links were removed from the test samples and replaced with an additional bow shackle (ie the sample was connected by bow shackles at both ends).

Test sample 2 completed 18,000 cycles without any signs of obvious damage. After 20,000 cycles there was a general collapse of the thimbles, in the hard eyes, at both ends and the sample was removed. These thimbles are shown in Figure 5. Subsequent examination did not reveal any evidence of fatigue cracks or breaks in the rope itself.

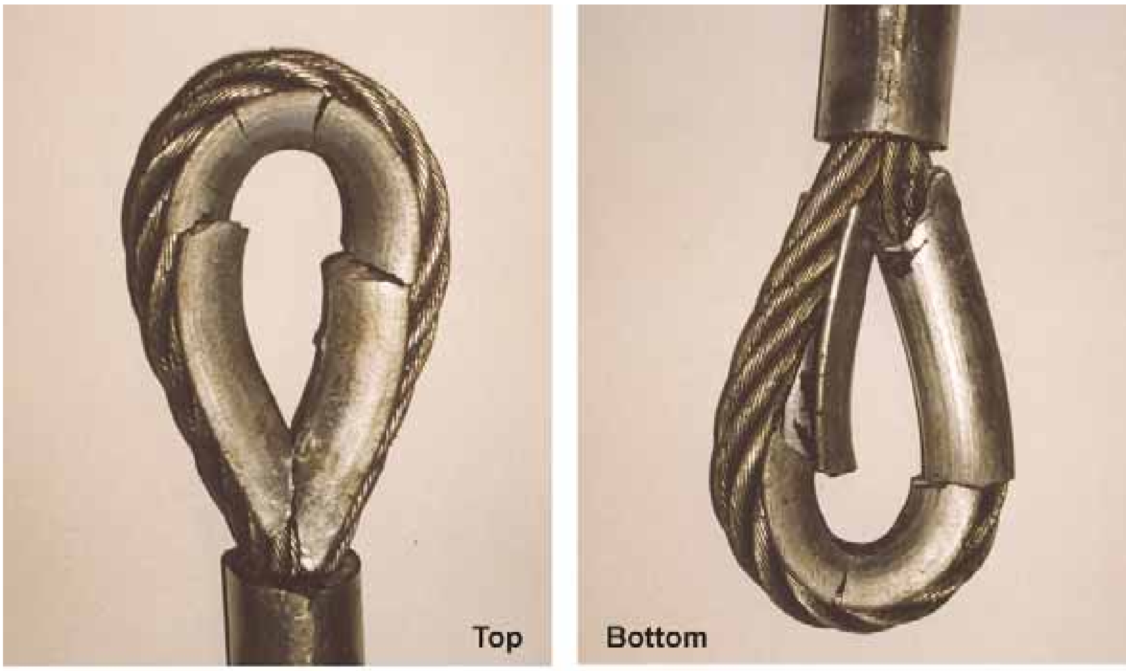

Figure 5 Collapsed thimbles on sample 2 after 20,000 cycles

4.3 TEST 3

Test sample 3 was subjected to the same simplified version of the waveform shown in Figure 2, however the maximum load (peak 5) was increased from 67 kN to 76.5 kN, which represents the proof load of the sling. All other peaks were increased proportionally.

Test sample 3 completed 12,000 cycles without any signs of obvious damage. After 15,000 cycles there was a general collapse of the thimbles, in the hard eyes, at both ends and the sample was removed. These thimbles are shown in Figure 6. Subsequent examination did not reveal any evidence of fatigue cracks or breaks in the rope itself.

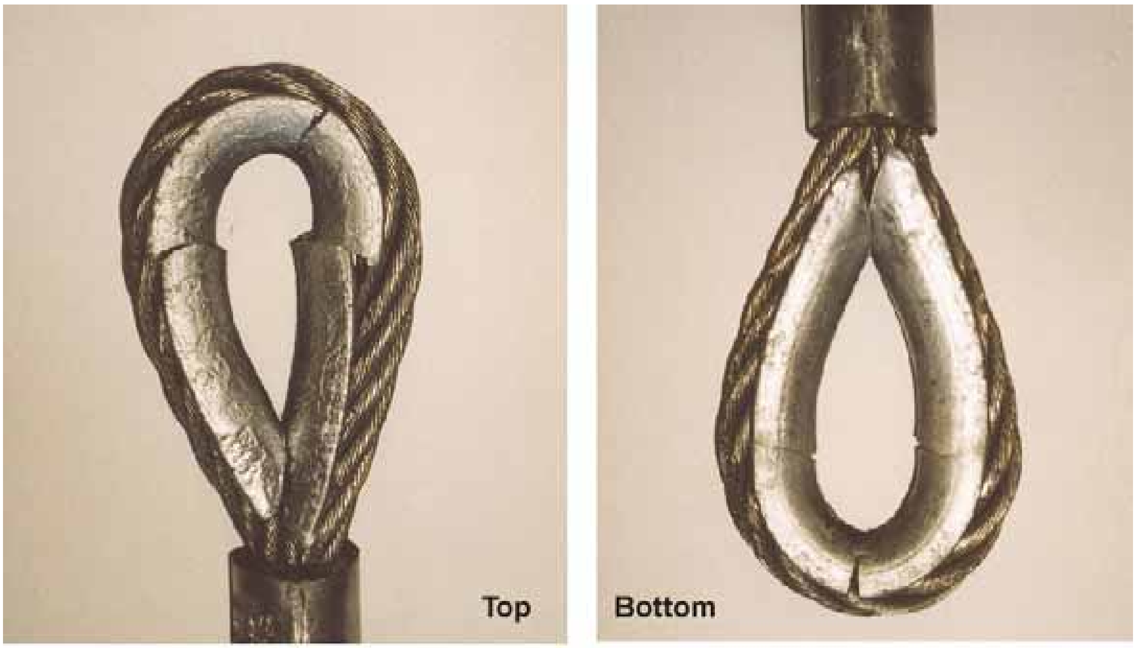

Figure 6 Collapsed thimbles on sample 3 after 15,000 cycles

4.4 TEST 4

Test 4 was an exact repeat of Test 3, with loads and set up remaining the same.

After 2,200 cycles, a single crack was detected in the thimble, in the lower hard eye. After 4,500 cycles a number of cracks had developed, in both hard eyes, in a similar manner to those on samples 2 and 3. Deterioration of the thimbles continued and after 5,185 samples a significant portion of the thimble was ejected from the upper hard eye. At this point, the sample was removed. These thimbles are shown in Figure 7.

Subsequent examination did not reveal any evidence of fatigue cracks or breaks in the rope itself. No evidence was discovered to account for the differences in performance between samples 3 and 4.

Figure 7 Collapsed thimbles on sample 4 after 5,185 cycles

4.5 TEST 5

Test sample 5 was an unused sling leg, which prior to fatigue testing was subjected to a five week long programme of accelerated corrosion, as described in Section 2.2. The corrosion test batch consisted of three samples, two of which were unused while the third had been removed from service due to excessive corrosion. A comparison of the new and old samples after 5 weeks of corrosion is shown in Figure 8.

Test sample 5 was subjected to the same fatigue cycle as samples 3 and 4 (with peak load equal to the proof load).

The test was temporarily halted after 2,900 cycles when the bow shackle securing the test sample at its upper attachment failed due to fatigue. This shackle had completed 58,100 cycles. The damage to this shackle is shown in Figure 9.

After 11,000 cycles, the thimble in the lower hard eye began to break up, in the same way as for previous tests. Deterioration continued in both hard eyes and the test was halted after 12,900 cycles and the sample was removed. Subsequent examination did not reveal any evidence of fatigue cracks or breaks in either the corroded or non-corroded parts of the rope.

Figure 8 Rope samples after accelerated corrosion for 5 weeks

Figure 9 Failure in the upper attachment shackle after 58,100 cycles

5 SUMMARY

The fatigue cycle used during these tests represents loads equal to and above the highest loads (up to twice the safe working load), measured offshore during the earlier work, reported in FE 96/06. These loads were measured during a single payload (PSH06), in heavy seas and were substantially above loads measured during the lifting of other payloads. Clearly, this represents a worst case scenario.

None of the samples tested, exhibited any evidence of fatigue breaks or cracks within the body of the rope itself. Even where rope had been subjected to accelerated corrosion there was no evidence of fatigue damage

Fatigue damage occurred only in the thimbles, in the hard eyes. In most cases, damage occurred after more than eleven thousand lifting cycles. No evidence was discovered to account for the premature failure of sample 4.

The damage that occurred was clearly visible and probably non critical. This type of damage would be likely to be detected during any inspection and unlikely to cause an imminent catastrophic failure.

These results indicate that in the context of offshore container lifting operations, fatigue failure of a wire rope sling would be unlikely to occur. This work did not identify any evidence to justify an increase in safety factors or a change from wire to chain slings.

Further proposed work will evaluate the performance of chain sling sets under identical loading and corrosion conditions, and compare the behaviour of wire rope and chain.

6 REFERENCES

BS EN 13414	Steel wire rope slings - Safety – Part 1: slings for general lifting service (2003)
BS1290	Specification for wire rope slings and sling legs for general lifting purposes (1983),
FE 96/06	Measurement of dynamic loads in the sling legs of offshore container lifting sets (1996) PR. Kerry and PD. McCann
ASTM B117 – 97	Standard Practice for operating salt spray (fog) apparatus (1997)
ASTM G85 – 98	Standard practice for modified salt spray (fog) testing (1998)
ASTM D1141	Specification for substitute ocean water
BS 302	Stranded steel wire ropes - Part 2: Specification for ropes for general purposes (1987)

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