Title of Work: *Securing of pilot ladders at intermediate lengths – testing*

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Work for: *International Maritime Pilots Association*

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1. Introduction

This report details the work completed by nC2 Engineering Consultancy at the University of Southampton to support the International Maritime Pilots' Association (IMPA) with a laboratory-based project to investigate the effectiveness and impact of various methods used to secure pilot ladders at intermediate lengths.

Schematics of a typical pilot ladder arrangements are given in Figure 1. The ladder steps are held in place by step fixings (wood or plastic) and either rope seizing or a metal clip, as shown in Figure 3. The top of each ladder side rope end with a shackle (see Figure 2). These shackles are used to secure the ladder to hard points on the ship, when deploying the full ladder length.

Since the pilot ladder cannot always be secured at full length, due to the varying freeboard at specific loading conditions, it has to be secured at intermediate. This can only be done in a safe way when the following conditions are met:

- The weight of the ladder cannot be transferred to the steps, the spreaders (Figure 1) or the chocks (Figure 3), since they are not intended to be used for this purpose.

- The securing arrangement must be such that no damage is done to the structural integrity of the pilot ladder.

It is understood that several securing methods have been applied to rope ladders to achieve an intermediate ladder length. The current tie-off methods seen in practice are:

- Hitches – whereby a short length of rope is secured to the ship via a hard point such as a lug, and secured at the other end to the ladder via either a cow hitch or rolling hitch (Figure 4). In this scenario, the slippage of the rope and possible wear on the ladder is of concern.

- 'D' shackles – The ladder ropes are secured to the hard point without the use of other ropes (Figure 5). In this scenario, the force applied to the step fixing pieces from the shackle may cause damage to the step fixing pieces.

- Loading Straps – Cargo lifting straps have been used to secure the ladder via cow hitches (Figure 6). In this scenario, potential slippage and wear of cargo straps or ladder rope is of concern.

There is concern within the industry, that the use of some methods leads to accelerated damage to the ladder and increases the risks to pilots using them. IMPA would like to clarify the guidance, advice and regulations for the securing of pilot ladders. IMPA have requested a physical laboratory-based test programme that would evaluate the securing methods, both quantitively with measured metrics and qualitatively through expert observation.

nC² performed laboratory-based testing, analysis and evaluation of sample lengths of pilot ladders secured in a variety of methods. The work was broken into the following packages:

- WP1 Baseline testing – To determine the baseline response to loading of thimble secured lengths, with a range of materials.
- WP2 Slip/grip testing – To determine the slip/grip of various attachment securing methods to the ladder side rope pair and evaluate any resultant damage.
- WP3 'D'-Shackle testing – To determine the effect of cyclically loading D-shackles on the ladder components.

IMPA provided all the test materials for the work packages. Two rope types were used throughout (see Figure 7), both meeting the BS ISO 799 requirements:

"Each side rope shall be mildew-resistant manila rope meeting ISO 1181:2004, Quality 1, or a spun thermoset polyester rope with a polypropylene core of a colour that contrasts with the spun polyester. Each side rope shall have a breaking strength of at least 24 kN, and the specification of the diameter of side ropes should be 20 mm (63 mm circumference)."

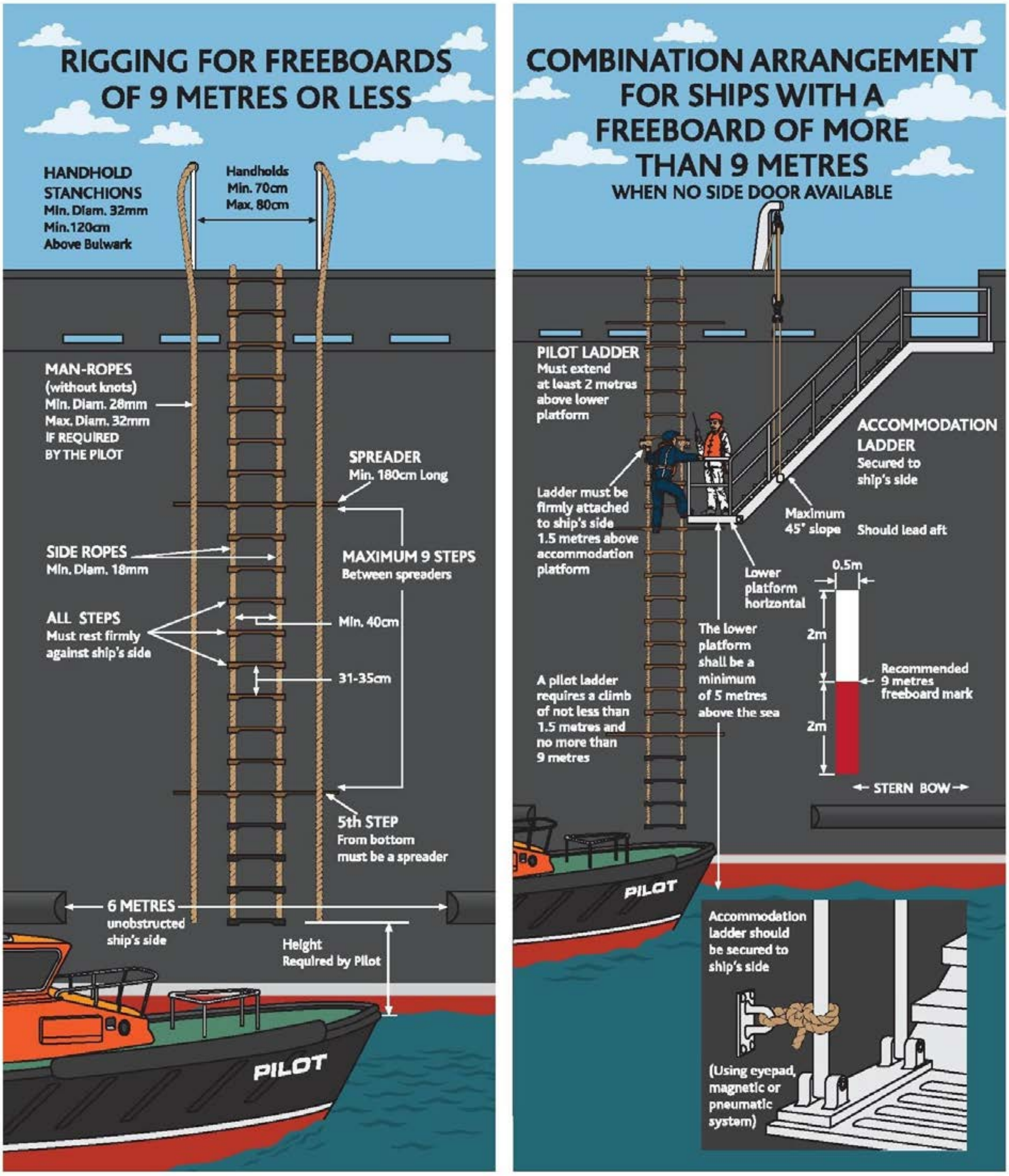
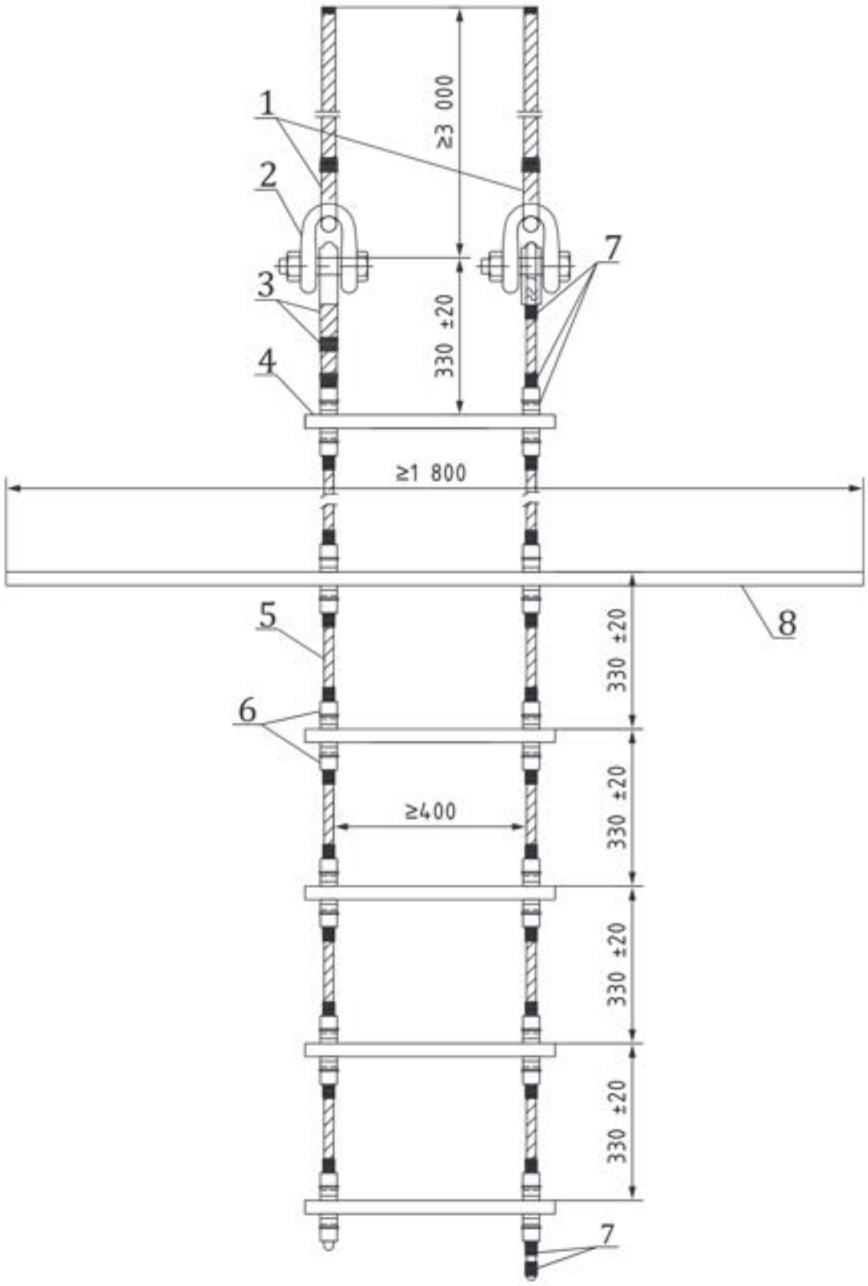


Figure 1: Schematic showing two examples of pilot ladders less than and more than 9 metres in length in-use.



Key

1	securing rope alternative arrangements	5	side rope
2	shackle	6	step fixture
3	splice and rope seizing	7	rope seizing
4	step	8	spreader step

Figure 2: Construction details of a typical pilot ladder from BS ISO 799-1 2019.

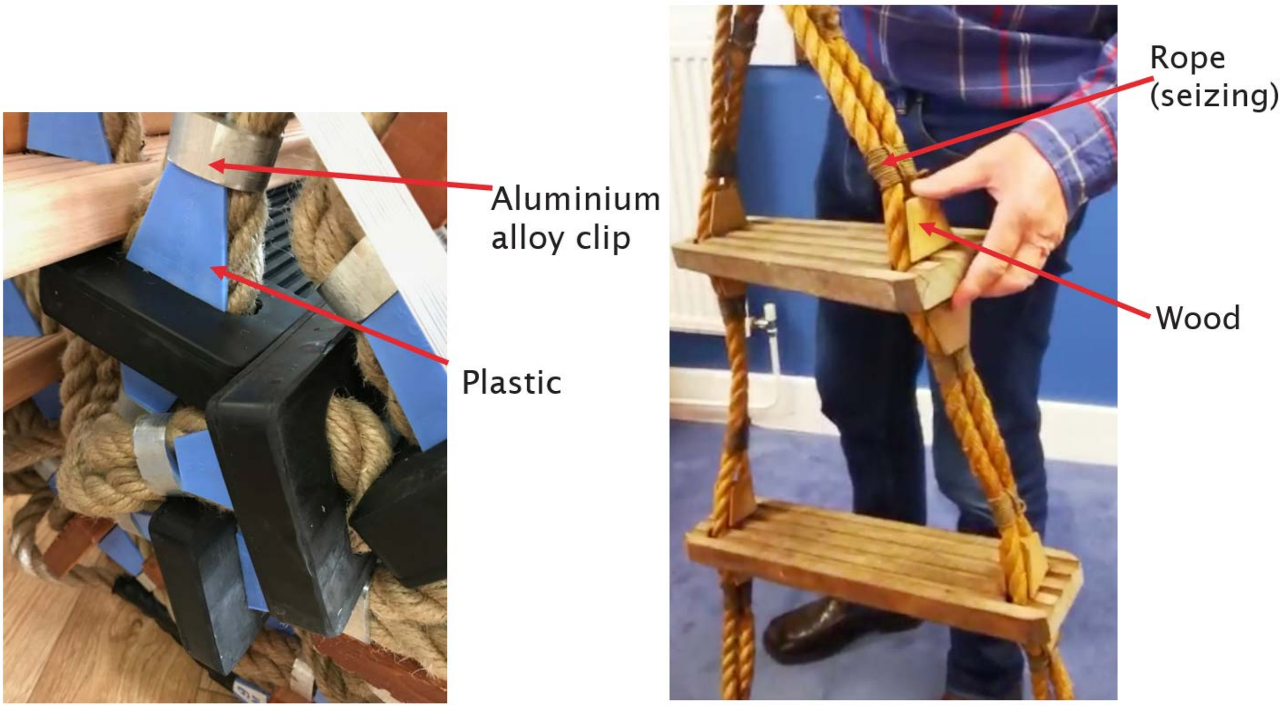


Figure 3: Step fixing (wedge/widget/chocks) with plastic and aluminium construction (left) and with wood (right) with rope seizing construction.

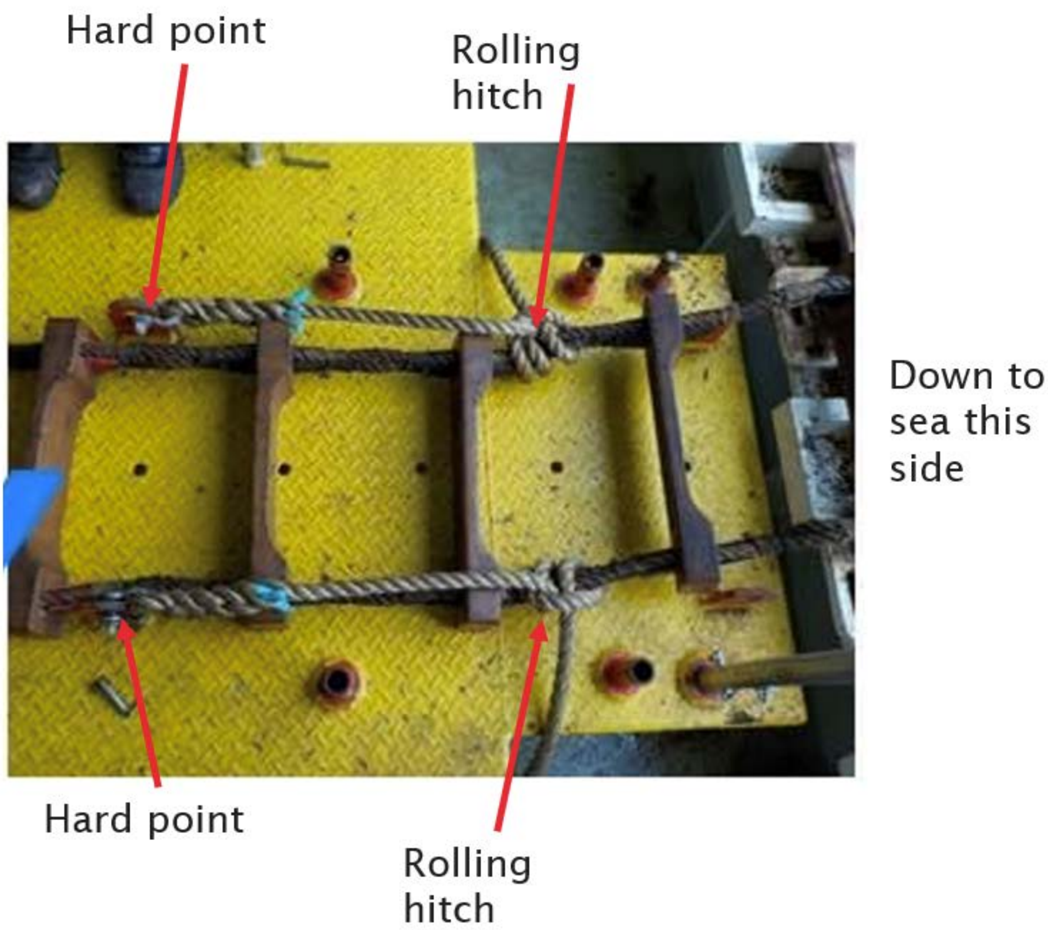


Figure 4: Example of tie-off of intermediate ladder length using rope.

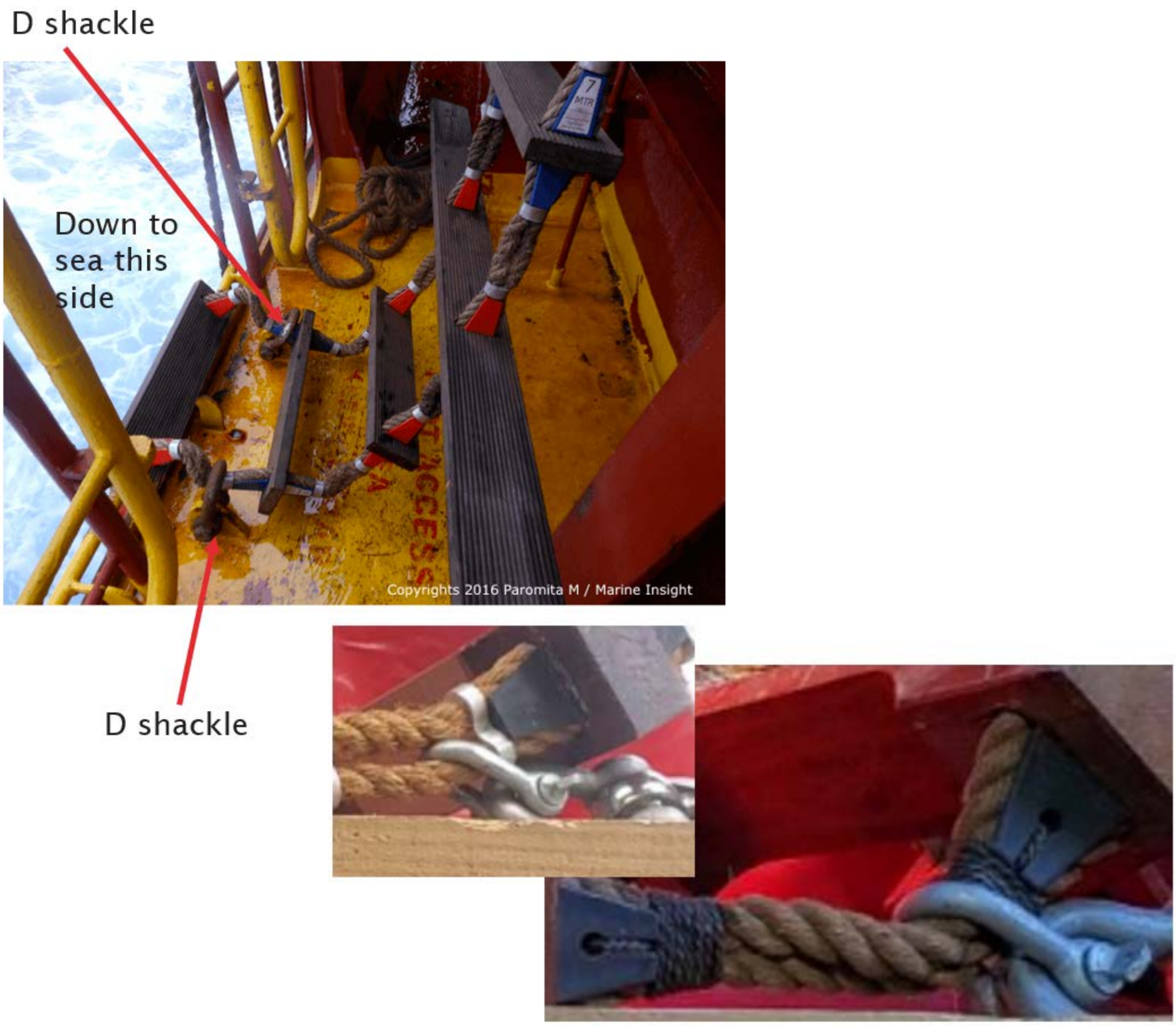
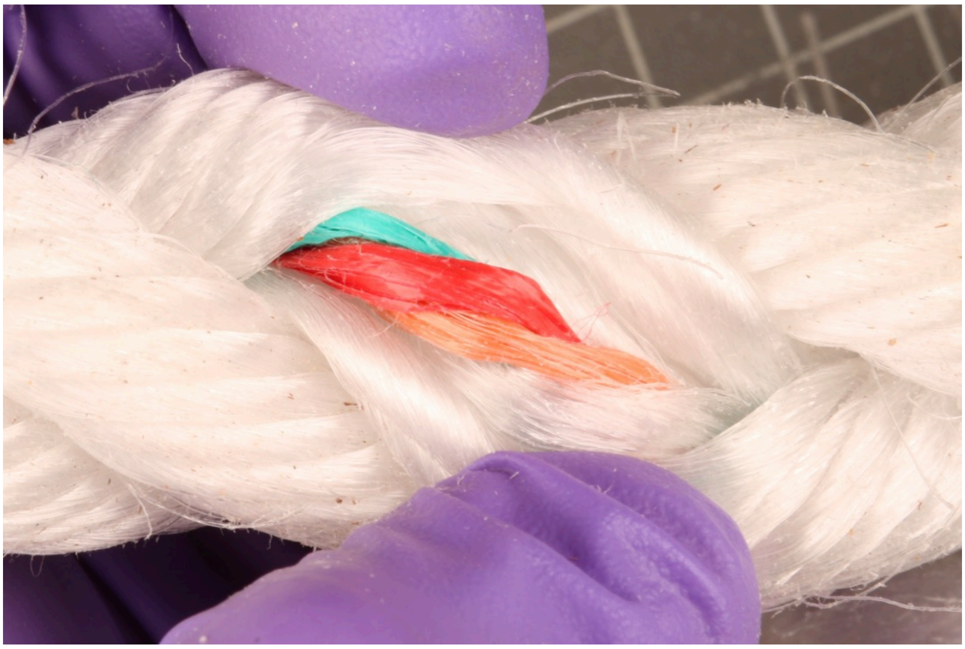


Figure 5: An example of ‘D’ shackles being used as a tie-off method.

Figure 6: An example of loading straps (cargo lifting devices) being used as a tie-off method.

A



B

Figure 7: An example of ropes provided. A: 20 mm, four strand manila. B: 20 mm, three strand polypropylene with an inner core weaving.

2. WP1 – Baseline testing

2.1. Introduction

The aim of Work Package 1 (WP1) was to determine the baseline properties of two ladder ropes, synthetic polypropylene and natural manilla, with and without steps. As a further variable the effect of the seizing applied above and below the step fixing was also investigated. The matrix of test samples is shown in Table 1, it was decided to have two of each unique scenario. Images of the prepared provided samples are shown in Figure 9 and Figure 10.

The objective of WP1 was to collect 'control' data that could be referenced to, at later stages of the testing.

Table 1: Matrix of samples tested within WP1

<table>
<tr><th>ID</th><th>Rope type</th><th>Step</th><th>Seizing type</th></tr>
<tr><td>Manila 1</td><td rowspan="6">20 mm natural manila 4 strands</td><td rowspan="2">No</td><td rowspan="2">n/a</td></tr>
<tr><td>Manila 2</td></tr>
<tr><td>A</td><td rowspan="4">Yes</td><td rowspan="2">Manila seizing</td></tr>
<tr><td>B</td></tr>
<tr><td>C</td><td rowspan="2">Metal clip</td></tr>
<tr><td>D</td></tr>
<tr><td>Polyprop 1</td><td rowspan="6">20 mm Synthetic Polypropylene 3 strands</td><td rowspan="2">No</td><td rowspan="2">n/a</td></tr>
<tr><td>Polyprop 2</td></tr>
<tr><td>I</td><td rowspan="4">Yes</td><td rowspan="2">Polyprop seizing</td></tr>
<tr><td>J</td></tr>
<tr><td>K</td><td rowspan="2">Metal clip</td></tr>
<tr><td>L</td></tr>
</table>

2.2. Test method

The ladder rope samples (Table 1) were attached in turn to an Instron 6025 electromechanical tensile testing machine and loaded via the metal eyes at either end (Figure 11).

The test method adopted for WP1 was created from reference to both BS ISO 2307: 2019 "Fibre ropes - determination of certain physical and mechanical properties" and BS ISO 799-1: 2019 "Ships and marine technology – Pilot ladders". The former detailing the cyclic bedding-in and rate of loading requirements and the latter covering the details of the approval testing of prototype ladders.

Each ladder rope sample was loaded with an initial reference force of 100 N to allow the starting length to be measured. The samples were then subjected to a tensile displacement (30 mm/min) until a force of 10 kN was achieved. The rope was held at 10 kN and measurements of the maximum rope extension were taken (relative to the initial reference start length). The test was repeated 10 times to measure the bedding-in performance of the samples. Measurements were taken during each run to determine the baseline properties and performance of the ladder samples.

2.3. Discussion of results

Run 1 was the first significant loading of the prepared rope ladder samples, as such a significant amount of stretch and permeant plastic extension was expected. The residual (permeant) extension was measured after run 1 for all scenarios, the results are plotted in Figure 12. As this is the result of the very first bedding-in, no discernible conclusions should be drawn, however it was interesting to note that in general there were greater values of permeant extension on the natural (manila) rope samples.

The residual extension was measured after each run (Figure 13). A reduction in residual extension was seen after the first loading cycle for all ladder samples. Suggesting that the rope ladder samples had not undergone any pre-stretch prior to receipt. After run 6, the ropes no longer experienced additional residual extension after a loading cycle. The manilla ropes permanently stretched more than the polypropylene ropes after the first cycle (Figure 14). Polypropylene ropes without the steps experienced more residual extension than the same ropes with the steps (Figure 15). Conversely, the manilla ropes both with and without steps showed a similar amount of residual extension (Figure 16). The manilla with steps stretched more after the first cycle than the polypropylene with the exception of a natural-natural step. It is not clear whether metal or rope fasteners have any impact on the residual extension of either rope material with steps (Figure 17).

The total maximum extension of the ropes was measured as a percentage of the original length whilst the ropes were experiencing a load of 10 kN. While under load, the polypropylene rope stretched more than the manilla rope overall, see Figure 18. As with the residual extension, the percentage extension under load also stabilised after run 6, signifying a true elasticity between 8 - 9 % extension for polypropylene, and 4 – 5 % extension for manilla. The sample stretched less with the inclusion of the steps for the polypropylene ropes (see Figure 19). The manilla samples had a similar elasticity regardless of whether steps were included or not (see Figure 20).

Plotting the extension under load on run 10 (i.e., after bedding in is complete) showed that the polypropylene ropes had a higher overall stabilised extension than the manilla rope, regardless of the inclusion of steps (Figure 21).

The force versus extension graph in Figure 22 suggests a stiffening of the material with increasing force, this is consistent with the reducing slack in the rope with increasing load. Polypropylene extends more than the manilla at the same load, despite different original rope lengths (Figure 23). The fastening method, metal fastener or rope seizing, does not appear to influence the elastic behaviour of the rope (Figure 24).

The modulus of elasticity for the rope with and without the steps are displayed in Figure 25, the natural manilla is stiffer than the polypropylene synthetic fibre, also compared in Figure 26. Independently from the rope material, the presence of a step slightly reduces the stiffness of the ladder (Figure 27 and Figure 28). The difference between the types of fastener used (rope seizing or metal clip) does not measurably impact the stiffness of the ladder.

2.4. Summary

From the samples tested:

- Where multiple examples were provided – there was consistency.
- All ropes needed to bed in to obtain a consistent extension under load.
- Under 10 kN tension:
  - Polyprop extended by 8-9%,
  - Manila extended by 4-5%,
  - Adding steps made them slightly more ‘stretchy’,
  - No measurable effect of metal or rope/fibre fixing was observed.

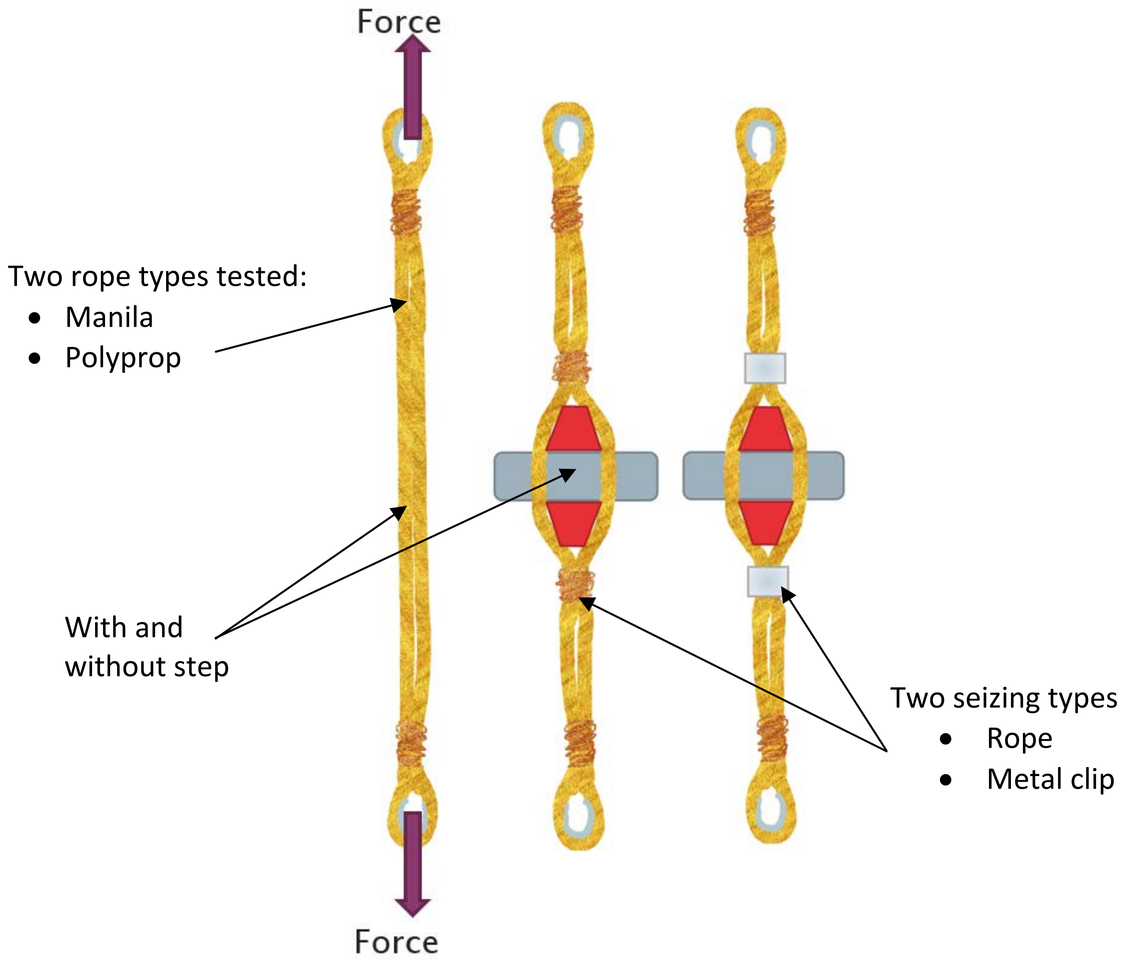


Figure 8: Schematic showing the baseline tensile testing of the rope, the rope with step and rope seizing, and the rope with step and aluminium clip.

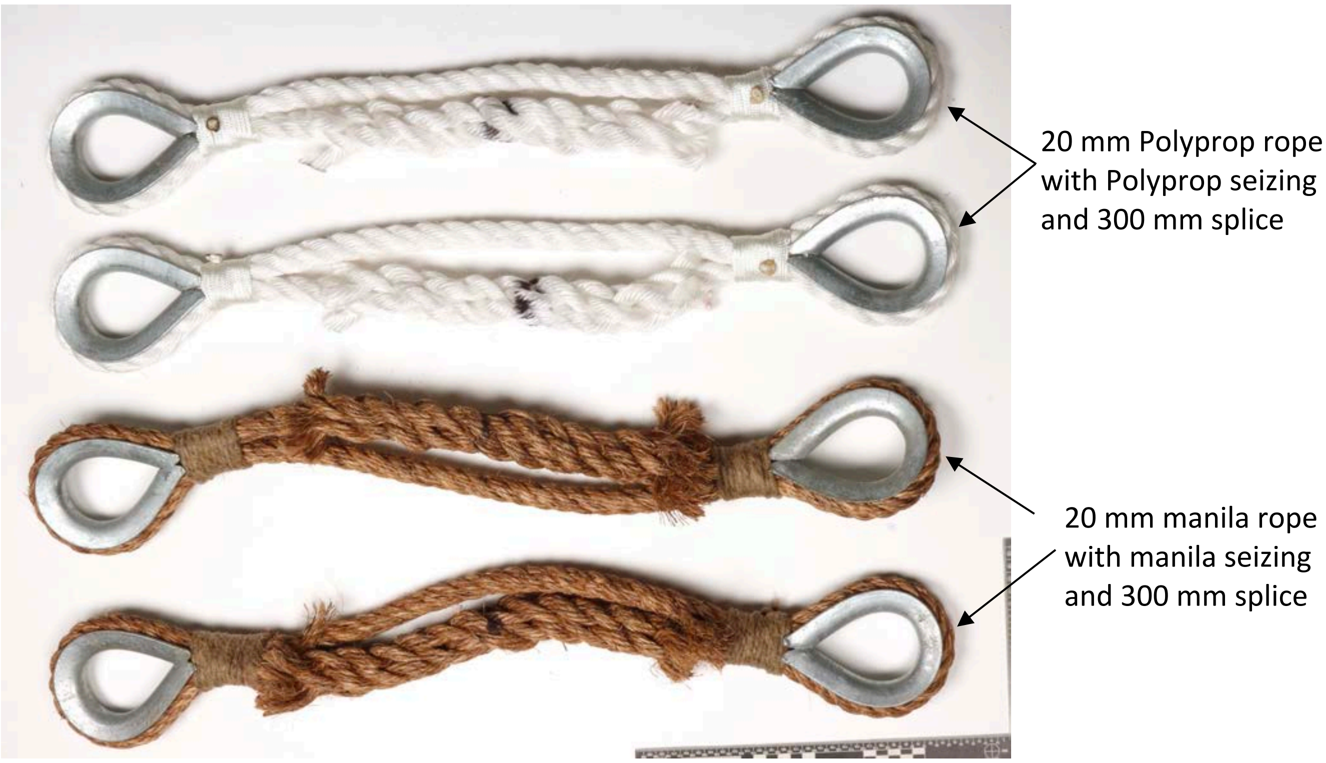


Figure 9: As received condition of samples (no step) for WP1.

A: 20 mm manila rope, with step and manila rope seizing (sample B the same)

C: 20 mm manila rope, with step and metal clip seizing (sample D the same)

I: 20 mm polypropylene rope, with step and polypropylene seizing (sample J the same)

K: 20 mm polypropylene rope, with step and metal clip seizing (sample L the same)

Figure 10: As received condition of samples (with step) for WP1.

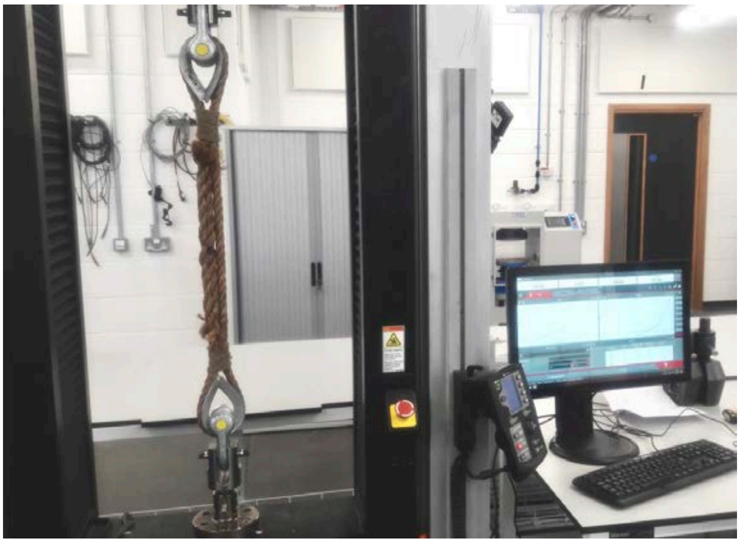


Figure 11: Tested in tension on an Instron 6023 Electromechanical test machine, operating with Instron Bluehill Universal software and fitted with a 100 kN load cell.

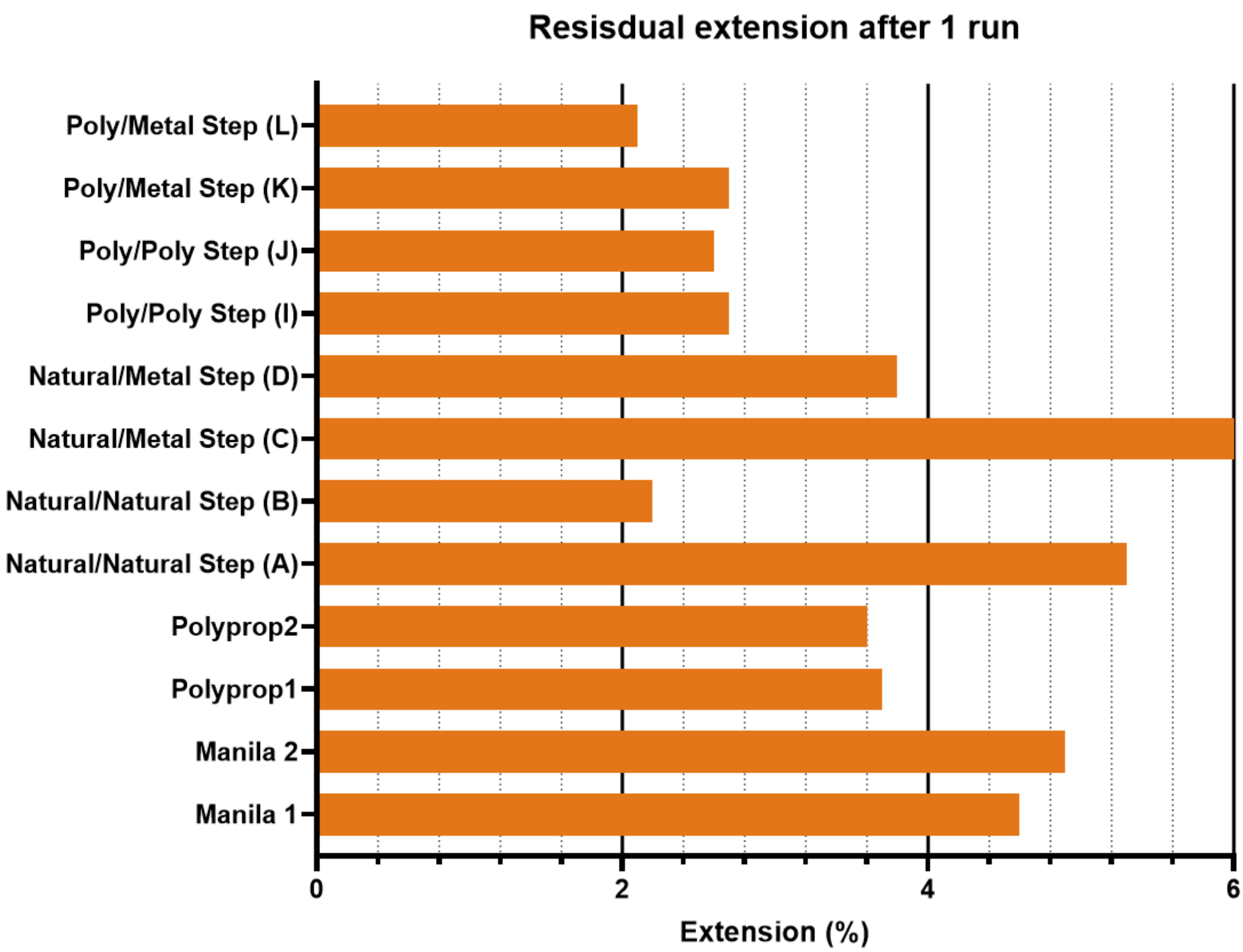


Figure 12: Residual extension in % after the first run for the ropes with and without the steps.

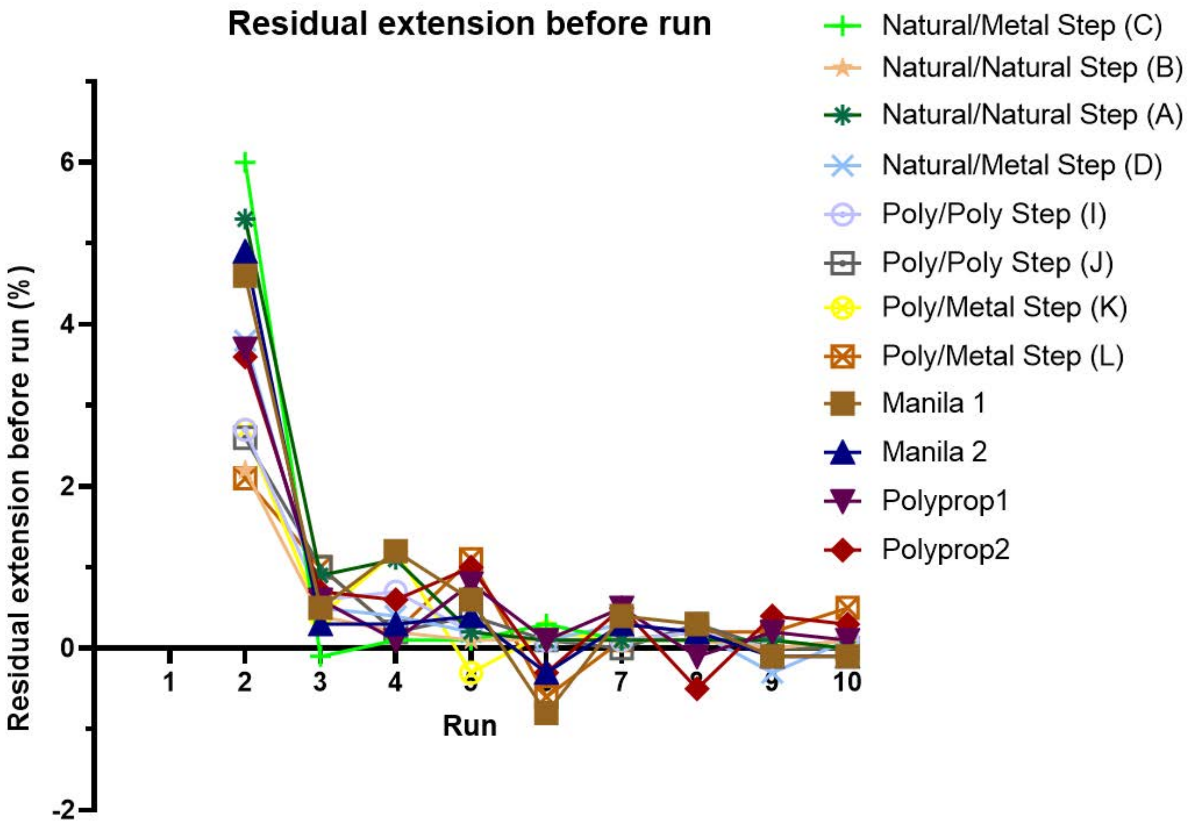


Figure 13: The residual extension in % before a run.

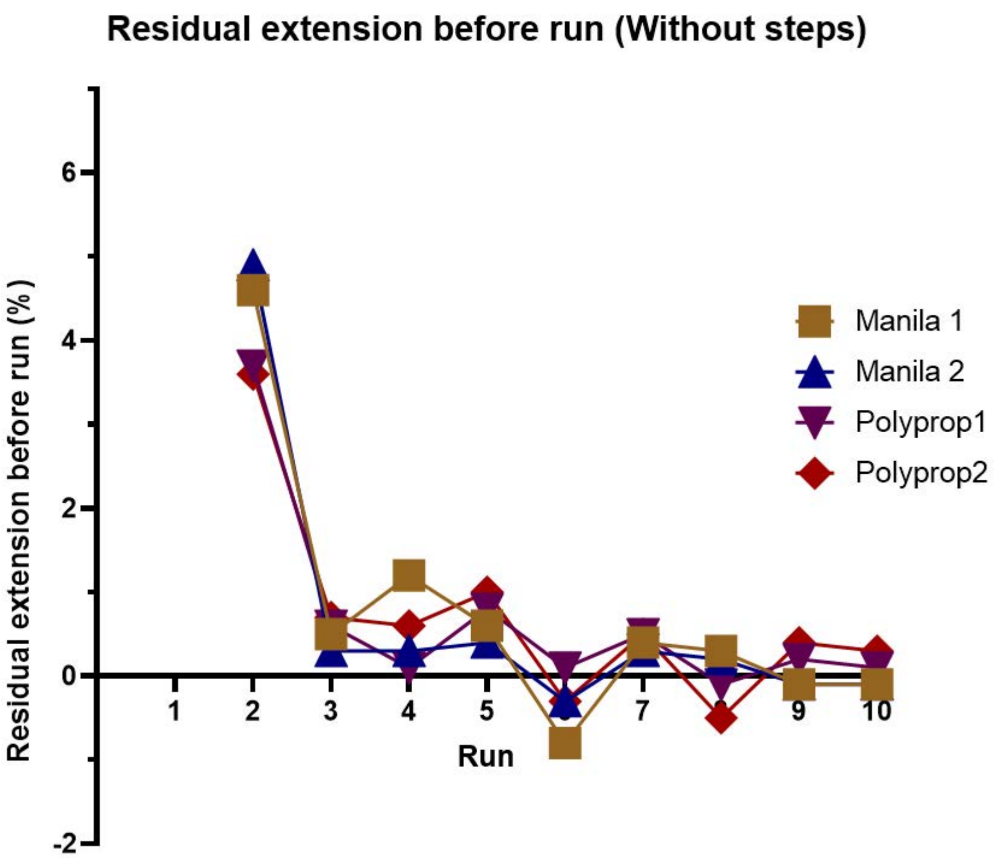


Figure 14: The residual extension in % before a run for the ropes only.

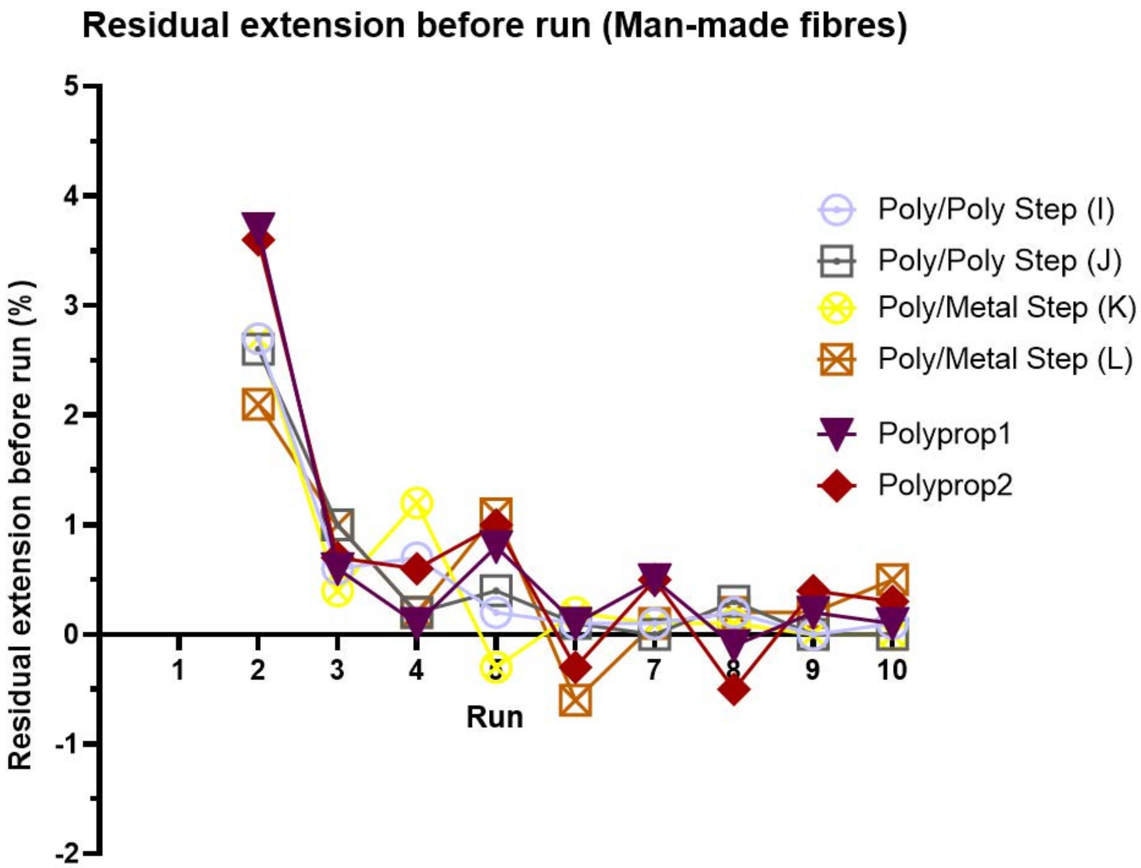


Figure 15: The residual extension in % before a run for the ropes made from synthetic fibre with and without steps.

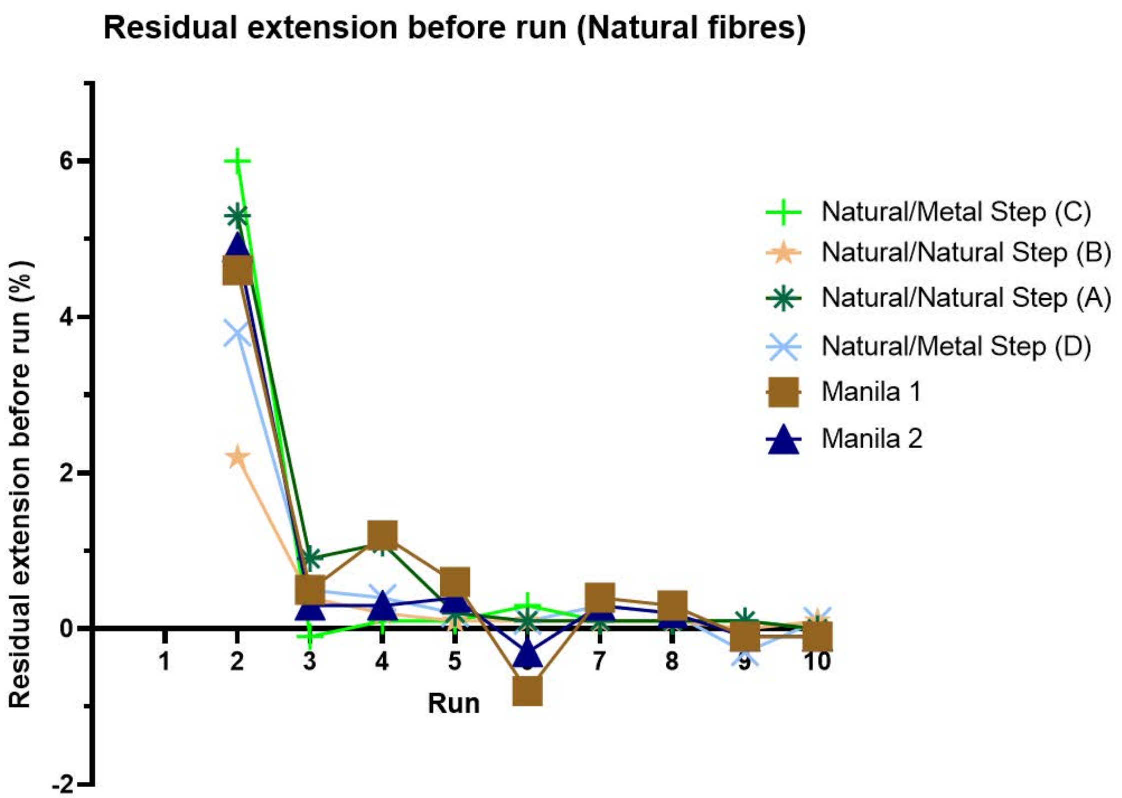


Figure 16: The residual extension in % before a run for the ropes made from natural fibres with and without steps.

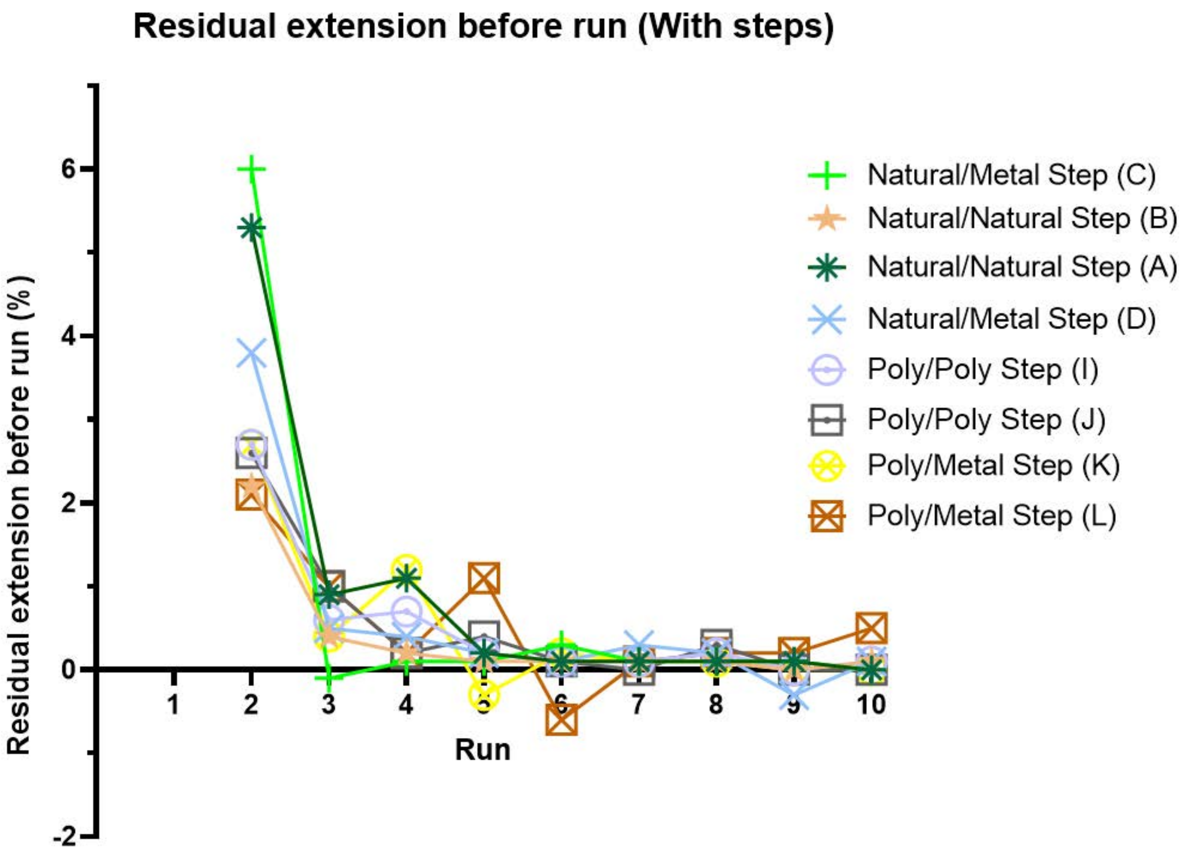


Figure 17: The residual extension in % before a run for the ropes with steps.

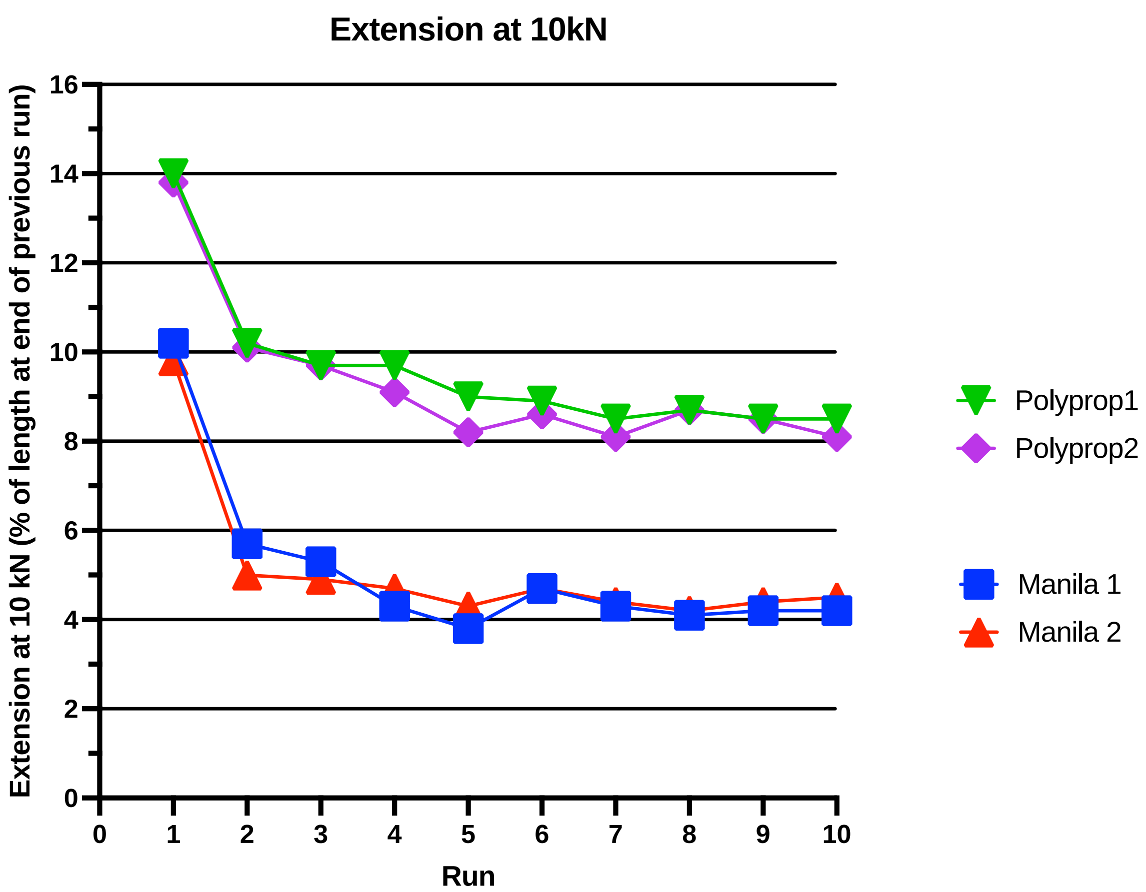


Figure 18: Extension in percentage of original length for each run to 10 kN of the polypropylene and manilla rope.

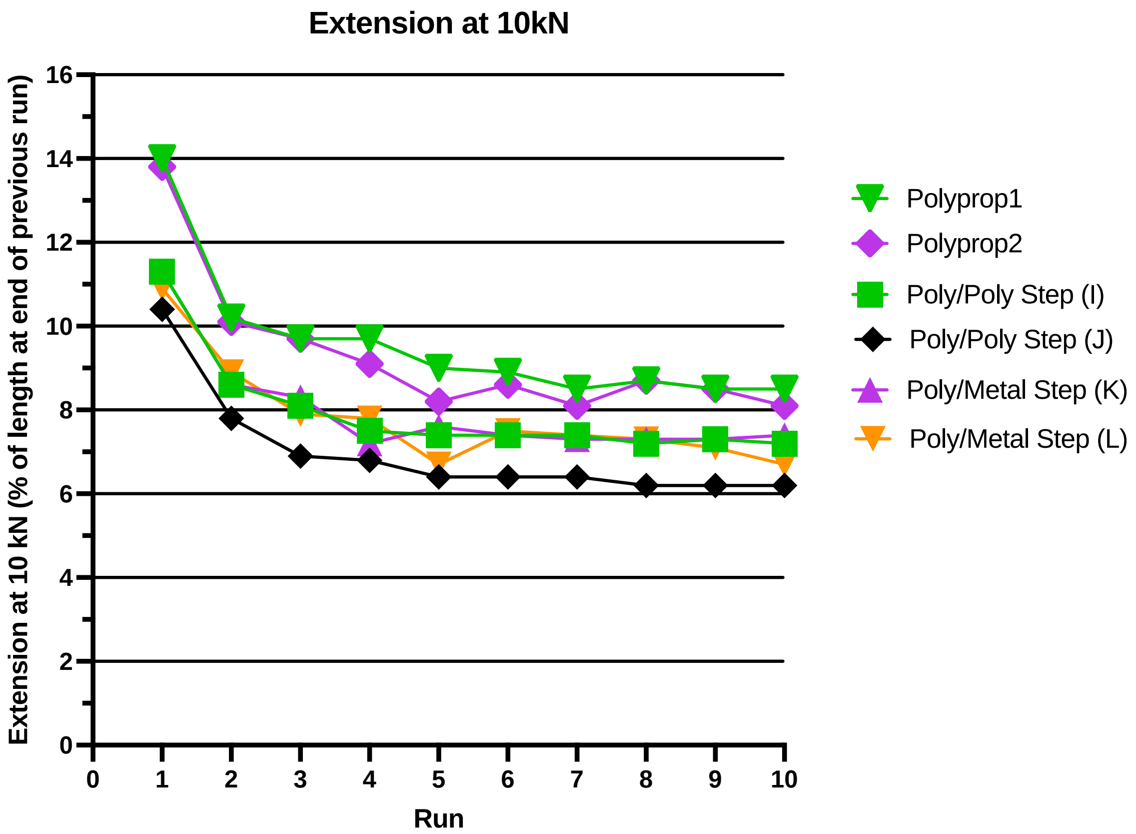


Figure 19: The extension in % with a force of 10 kN applied for the polypropylene ropes with steps.

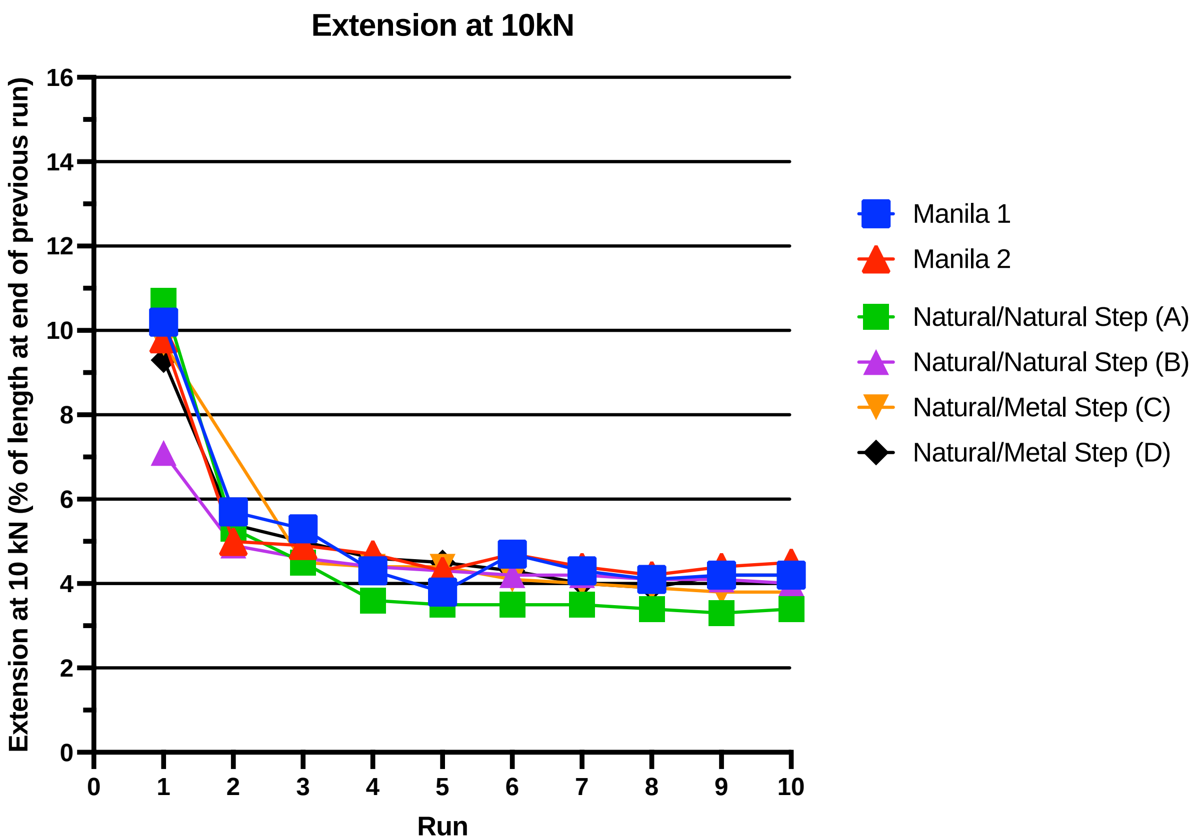


Figure 20: The extension in % with a force of 10 kN applied for the manilla ropes with steps.

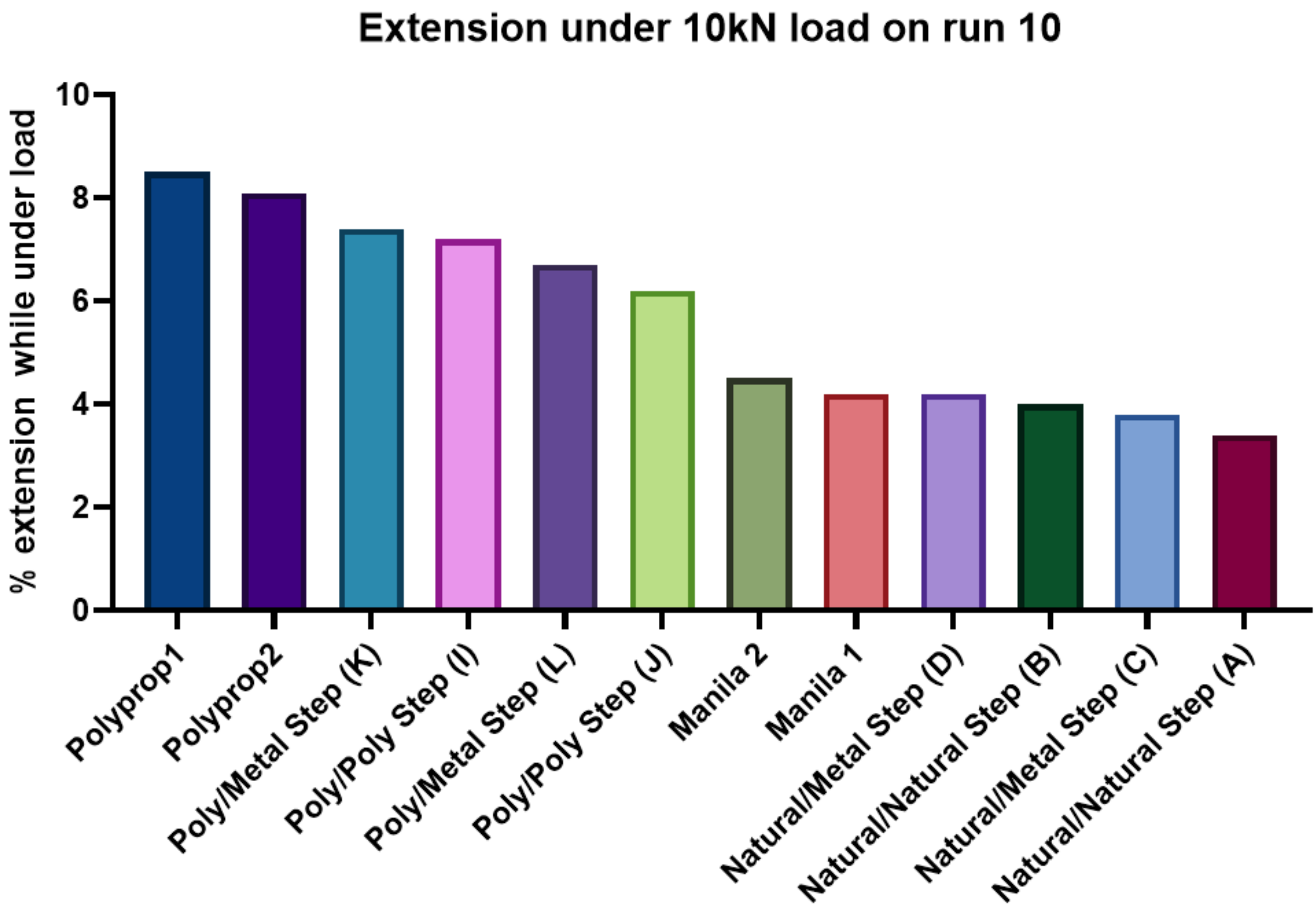


Figure 21: The stabilised extension in % under a force of 10 kN for the ropes and rope with steps combination in order from largest extension in % to lowest.

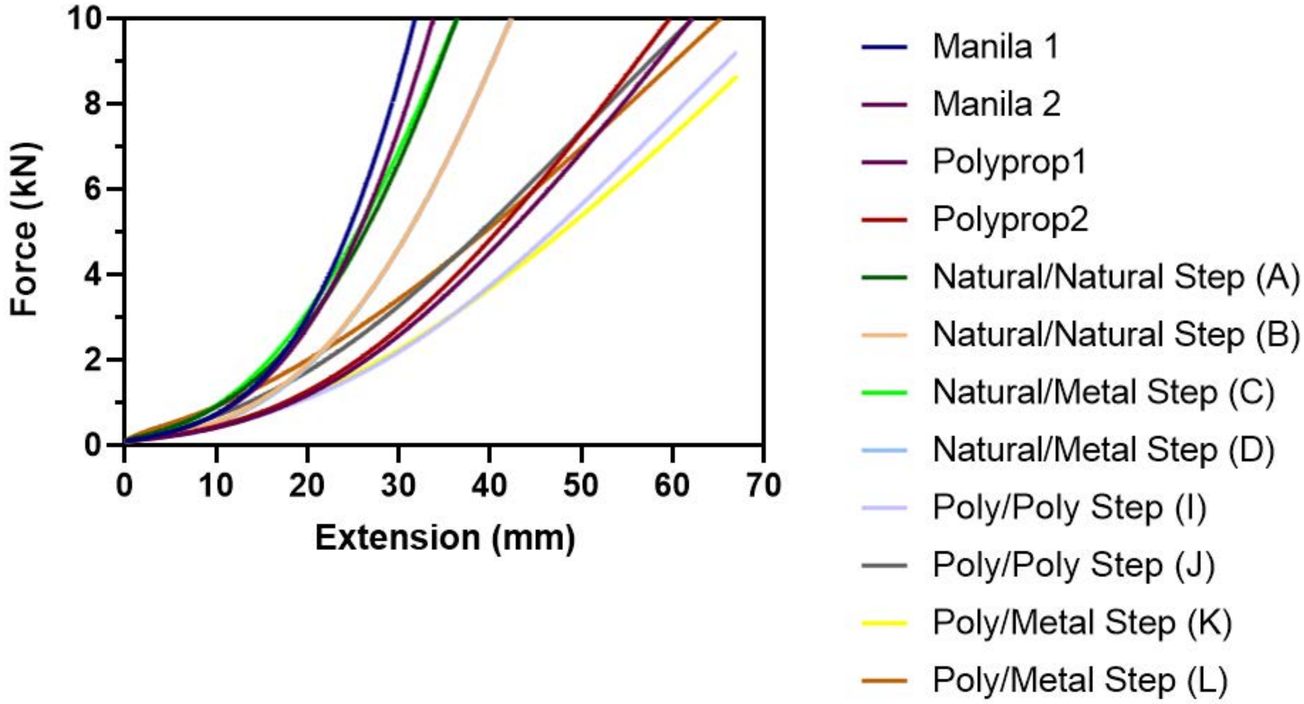


Figure 22: Performance after bedding in stress-strain graph (force-extension) of the behaviour of the ropes under test during run 10 with steps and without steps under test during test 10.

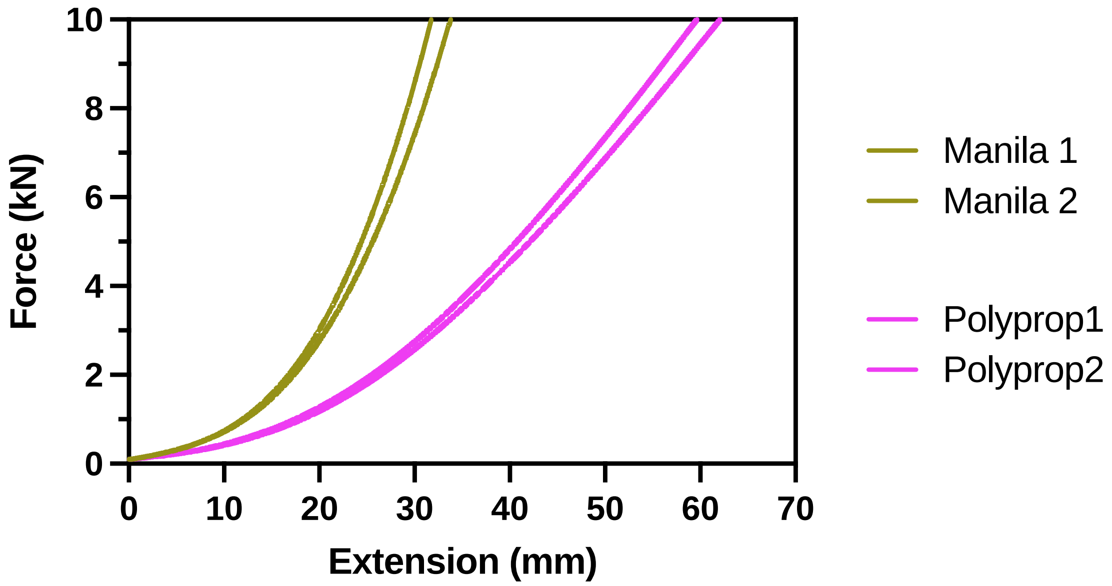


Figure 23: Performance after bedding in stress-strain graph (force-extension) of the behaviour of the Manila and Polyprop ropes without steps under test during run 10.

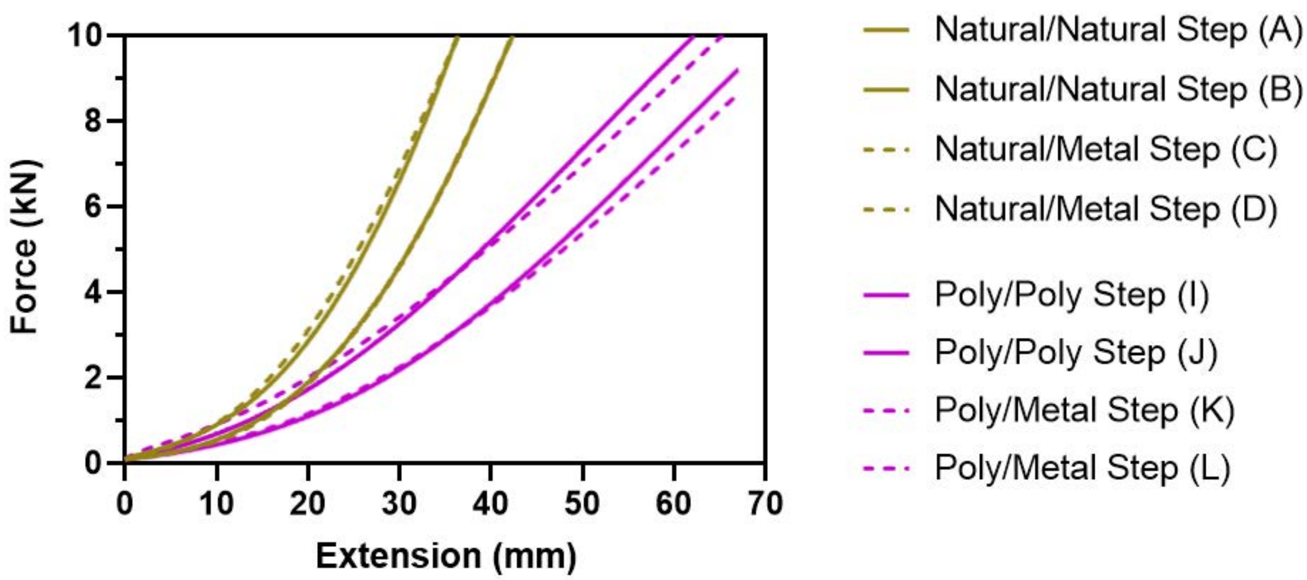


Figure 24: Performance after bedding in stress-strain graph (force-extension) of the behaviour of the Manila and Polyprop ropes with steps under test during run 10.

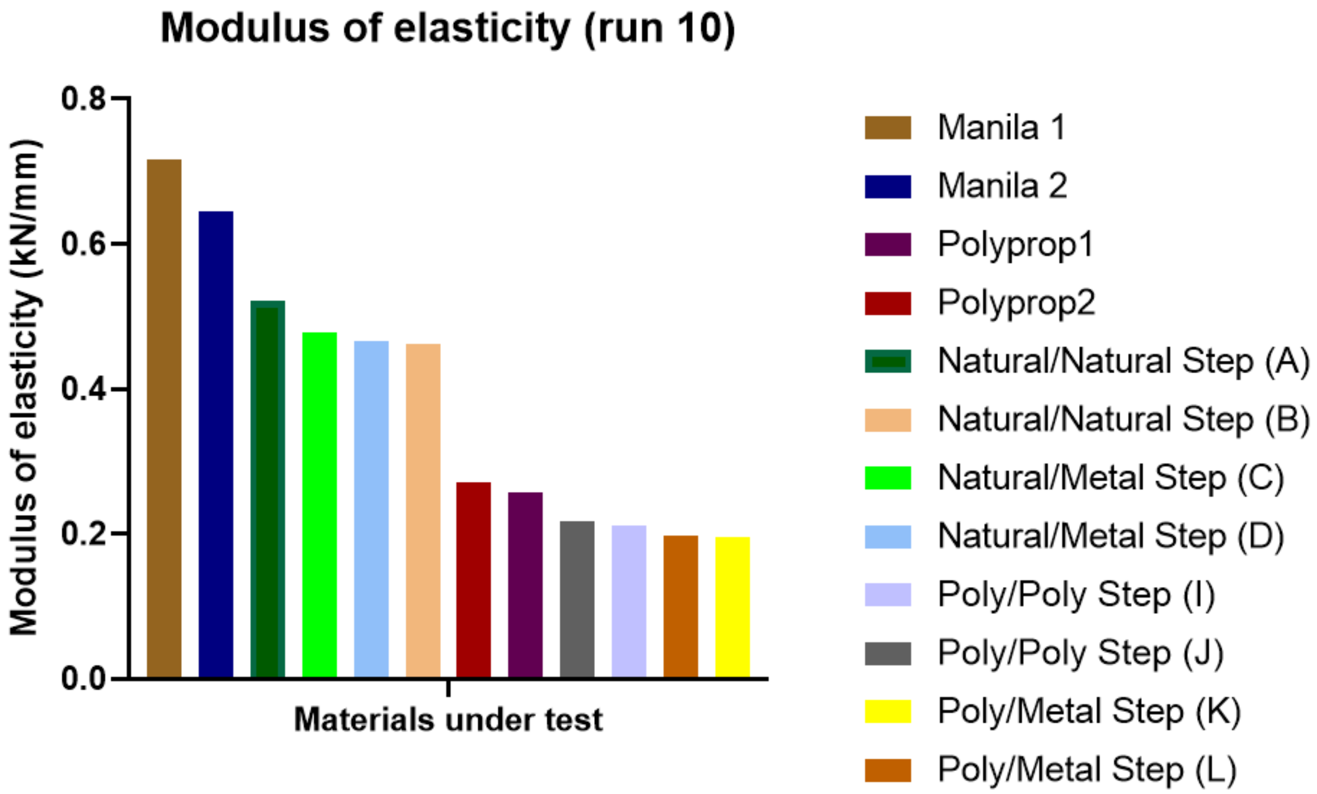


Figure 25: Stiffness data (modulus of elasticity) recorded during run 10 (linear section of data when force > 6 kN). The results are presented from highest modulus of elasticity to the lowest from left to right.

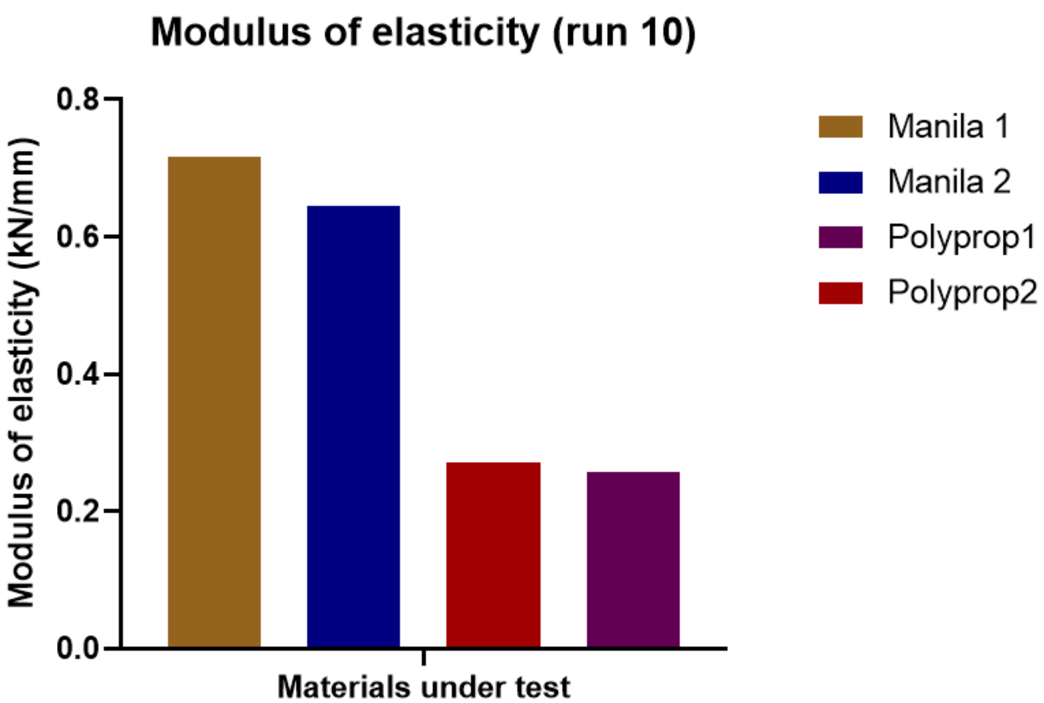


Figure 26: Stiffness data (modulus of elasticity) recorded during run 10 (linear section of data when force > 6 kN) for the ropes without steps.

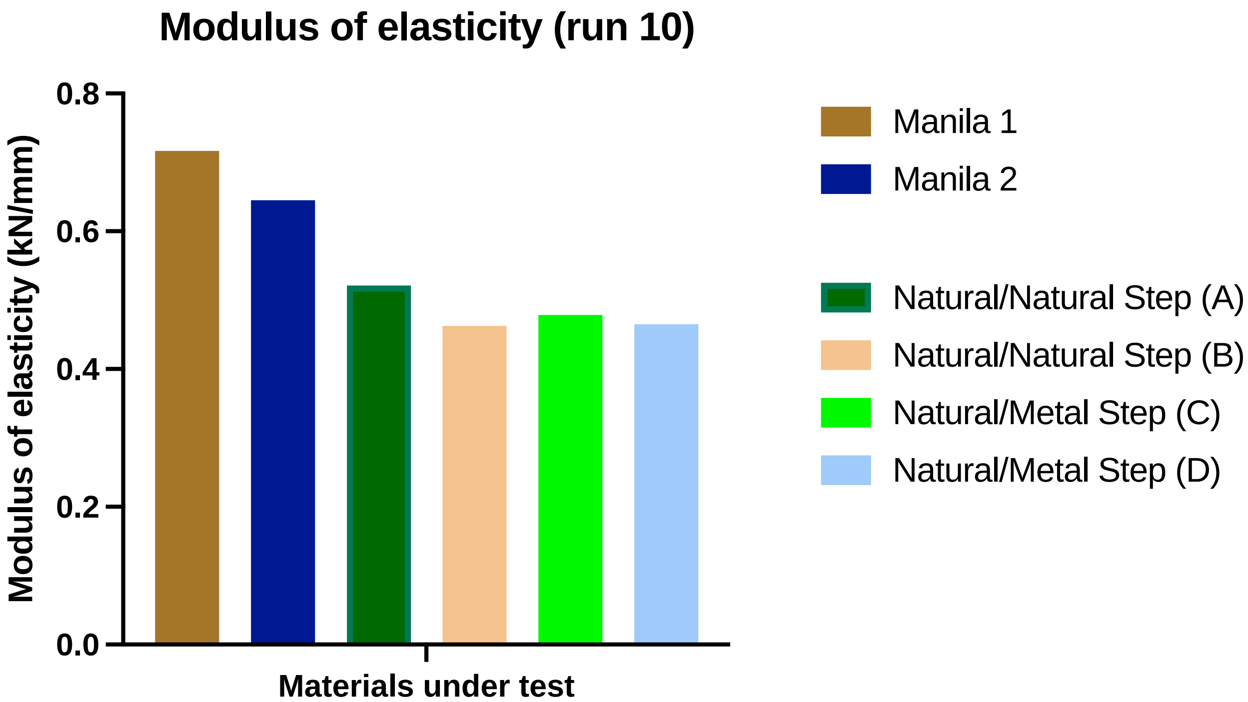


Figure 27: Stiffness data (modulus of elasticity) recorded during run 10 (linear section of data when force > 6 kN) for the ropes made from natural fibres.

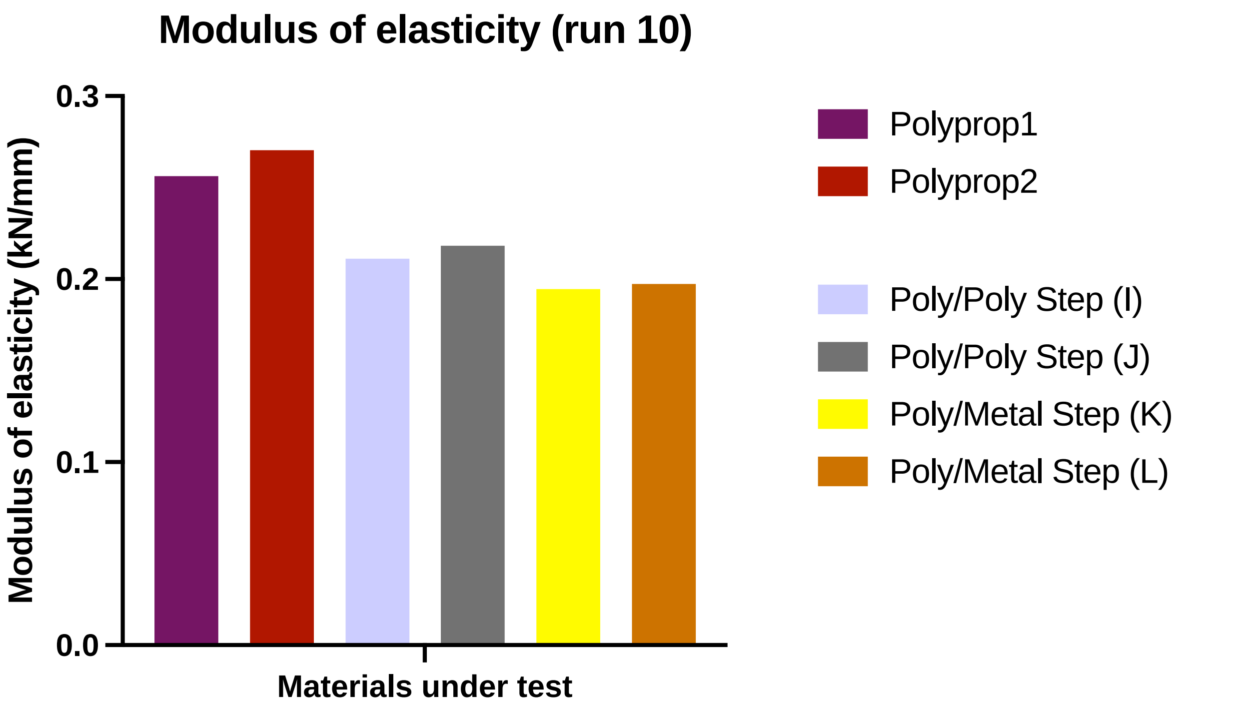


Figure 28: Stiffness data (modulus of elasticity) recorded during run 10 (linear section of data when force > 6 kN) for the ropes made with synthetic fibres.

3. WP2 – Slip and Grip Testing

3.1. Introduction

Ladder ropes are secured at intermediate lengths using a variety of tie-off methods as discussed in Section 1 of this report (Figure 4 to Figure 6). WP2 investigated the slip/grip properties of intermediate ladder arrangements that are secured with cow hitches and rolling hitches with secondary ropes and cargo straps.

A schematic of the testing arrangement is presented in Figure 29 and a matrix of the test scenarios is given in Table 2. Images of the provided materials are given in Figure 30 and Figure 31. Recorded details of the two cargo straps are given in Table 3.

The aim of this work package was to establish the gripping strength of each of the hitch knots in various scenarios and investigate any wear that may occur on the ladder due to slippage.

Table 2: Matrix of samples tested within WP2.

ID No.	Secured with	Securing system	Ladder rope pair tied to
S1	Rolling Hitch	Polyprop	Polyprop
S2		Manila	
S3		Polyprop	Manila
S4		Manila	
S5	Cow Hitch	Polyprop	Polyprop
S6		Manila	
S7		Polyprop	Manila
S8		Manila	
S9	Strap – Cow Hitch	Purple cargo strap	Polyprop
S10		White cargo strap	
S11		Purple cargo strap	Manila
S12		While cargo strap	

Table 3: Details of cargo straps provided for testing within WP2

Sling type	Width	Folded length	Depth
1000KG 1 MTR circ endless web sling (white) LGD23297 001	50 mm	495 mm	3 mm
1000KG 1 MTR circ endless web sling (white) LGD23297 002	50 mm	499 mm	3 mm
1000KG 1 MTR circ round sling (purple) 210600592	47 mm	540 mm	6 mm
1000KG 1 MTR circ round sling (purple) 210600557	46 mm	525 mm	6 mm

3.2. Test method

The secured (rolling hitch or cow hitch) system scenarios of ropes and cargo straps (Figure 29 and Table 2) were attached in turn to an Instron 6025 electromechanical tensile testing machine and loaded via the metal eye (thimble) in the rope pair and through the knot/hitch and to the lower hard point on the rig (Figure 32).

The aim of the testing was to identify if the securing method gripped or slipped on a typical pilot ladder side pair of ropes, and if it produced any significant wear. The test procedure was therefore designed to apply a steady displacement of the lower hard point (200 mm/min), recording the force required to do so. But also, for the hitch to be loosened off and reset, then pulled again (x50) to create accelerated wear conditions at the same position on the rope pair. Video footage was recorded of example runs (provided to IMPA).

Scenario 1 (polypropylene with polypropylene rolling hitch) was the first to complete the 50 test runs, the results of a typical run are shown in Figure 33. It was noted that the hitch slipped down the rope pair with very little resistance. However, it was known that rolling hitch knots are designed to tighten, but the 200 mm/min was not creating this desired effect. It was therefore decided that the rolling hitch (S1 to S4 see Table 2) should have a tightening force applied by hand before testing, to simulate a shock loading event, such as the ladder being unravelled down the side of the ship, to reduce the slack in the knot. In this case the rope continued to tighten causing a much larger tensile force and a small amount of slippage was observed (Figure 34 and Figure 35). S1 completed a further 50 runs all with a pre-test tightening force. All scenarios featuring a rolling hitch (S1 to S4 see Table 2) were subjected to a pre-test tightening force to reduce slack in the rolling hitch knot before testing.

3.3. Discussion of results

Images recorded showing scenarios S1-S4 loaded on the tensile test rig are given in Figure 36. All four set-ups were given a tightening force prior to initiating a 100 mm lowering of the lower hard point attachment. This was repeated 50 times, each time the force-displacement was recorded. Typical force-displacement curves for S1-S4 are shown in Figure 37. The curves were generally smooth and increasing with distance, indicating that the knot was getting tighter.

All the scenarios involving the cow hitch rope knot (S5-S8) slid easily without any visible tightening; therefore, the test was set to move 250 mm (rather than the 100 mm used on S1-S4). This movement can be seen in Figure 38 for S5 (polypropylene with polypropylene cow hitch).

Images of the setup of S6-S8 are given in Figure 39. Typical force-displacement curves for S5-S8 are shown in Figure 40. The curves were ‘wavy’ and the inspection of the video footage showed this to be a direct influence of the knot movement sliding down the rope. The curves did not generally go above 1 kN, i.e., lower than from S1-S4.

The scenarios involving the cow hitch cargo strap knot (S9-S12) also all slid easily without any visible tightening; therefore, they too were set to move 250 mm (as S5-S8). Images of the setup of S9-S12 are given in Figure 41 and typical force-displacement curves are presented in Figure 42. The shape and force levels of the curves were very similar to those seen within S5-S8.

The maximum force measured for each scenario is shown in Figure 43. The error range shows the maximum and minimum ‘max force’ for each run. The rolling hitch knot produced the greatest gripping force over the cow hitch knots by a considerable margin (Figure 44). There was a slight reduction in grip of the rolling hitch knot when it was polypropylene on polyproylene (S1), see Figure 45. The polypropylene loop cow hitch on manila (S7) had the greatest gripping strength, but it was still a poor gripping strength compared to the rolling hitch knots (Figure 46). The purple strap had a slightly larger gripping strength with purple on manilla (S11) having the greatest gripping strength of the cargo straps (Figure 47). The cargo straps had a better gripping strength than the cow hitch with the cow hitch polypropylene on manilla (S7) being an exception (Figure 48).

The ladder rope pairs were subjected to post-test inspection to identify signs of wear (Figure 49 to Figure 54). Scenarios 5 – 12 (secured via cow hitch arrangements) did not show any signs of wear after 50 runs. Some visible signs of tightening and squashing of the ladder rope pair was observed in scenarios 1 – 4 (secured via rolling hitch arrangements). The manilla on polypropylene produced a discolouration on the ladder rope pair from the manilla rope.

3.4. Summary

From the samples tested:

- Rolling hitch knot grips significantly more than cow hitch knot.
- Rolling hitch knots tended to tighten and grip, whereas cow hitch knots tended to slide.
- Rolling hitch combinations were similar with slightly more chance of sliding with polypropylene-on-polypropylene.

- The purple cargo strap grips slightly more than the white cargo strap.
- No signs of wear were observed on the ladder rope pairs secured with the cow hitch after 50 runs.
- Some signs of squashing and discolouration were observed on ladder rope pairs secured via rolling hitch knots after 50 runs.

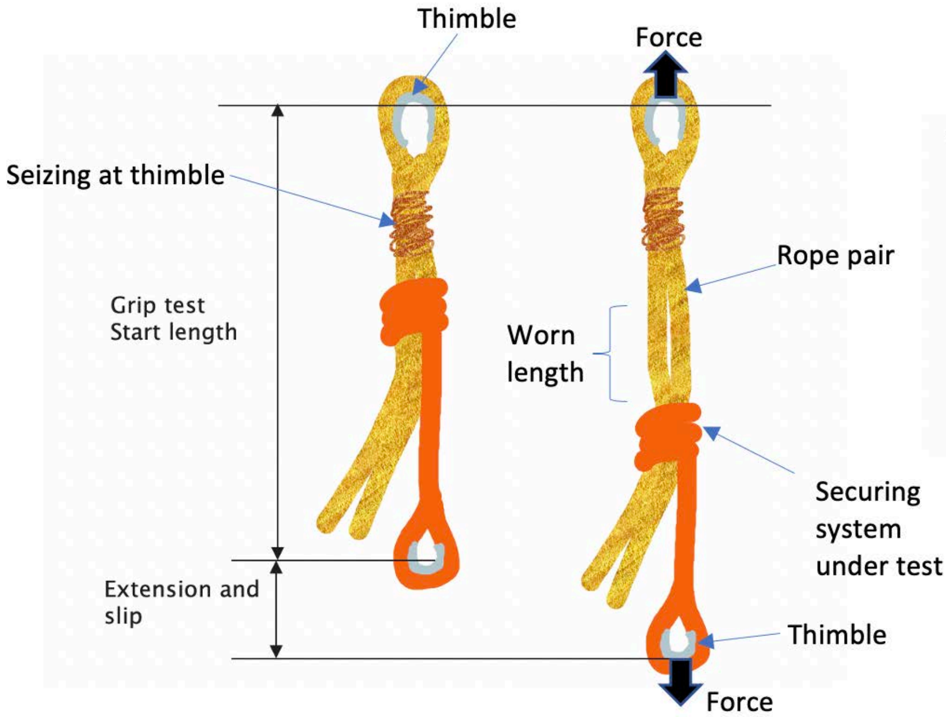


Figure 29: Schematic showing the pre-test arrangement (Left) and the expected post-test arrangement.

Figure 30: Examples of the polypropylene rope pairs provided for WP2 (manila pairs also provided).

A

B

C

D

Figure 31: Examples of the securing systems under test. A: Polypropylene single rope to be tied as a rolling hitch (manila also provided). B: Polypropylene hoops to be tied as a cow hitch to the ladder pair. C: Manila hoops to be tied as a cow hitch to the ladder pair. D: Cargo straps, two types identified as purple and white.

Figure 32: Slip and Grip Scenario 1 being tested on the Instron 6025 electromechanical testing machine.

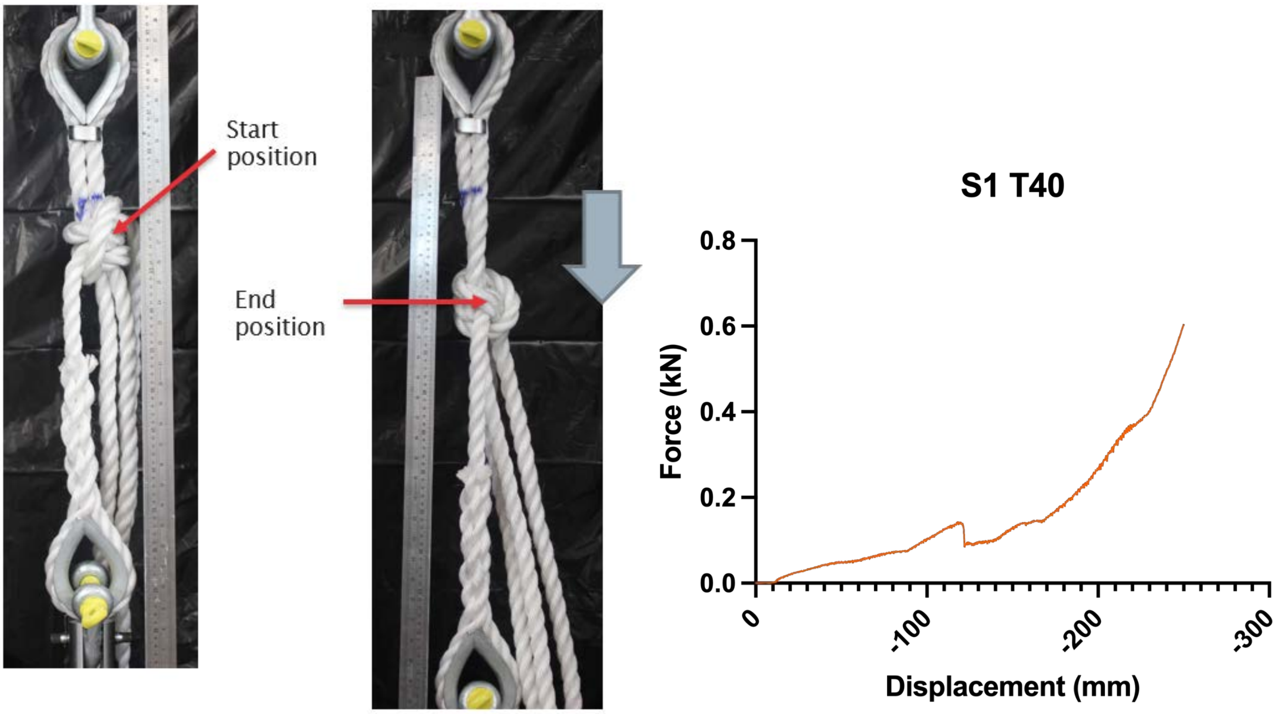


Figure 33: Scenario 1 tested without an initial tightening force and the corresponding force versus displacement graph (Right).

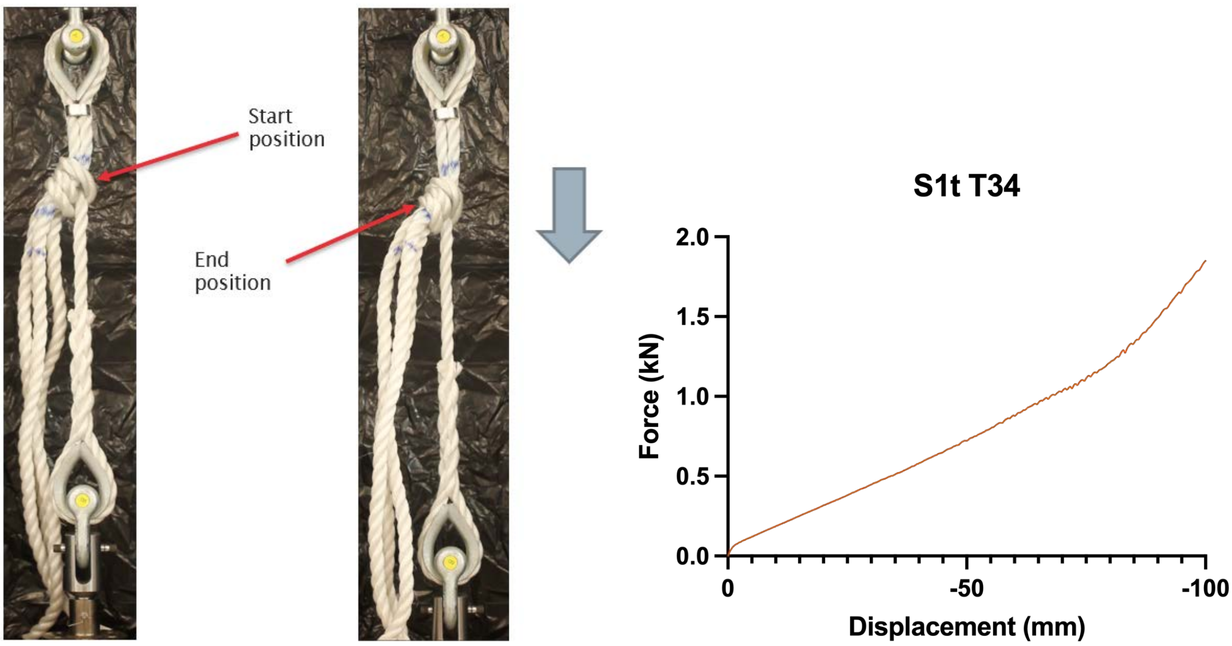


Figure 34: Scenario 1 tested with an initial tightening force and the corresponding force versus displacement graph (Right).

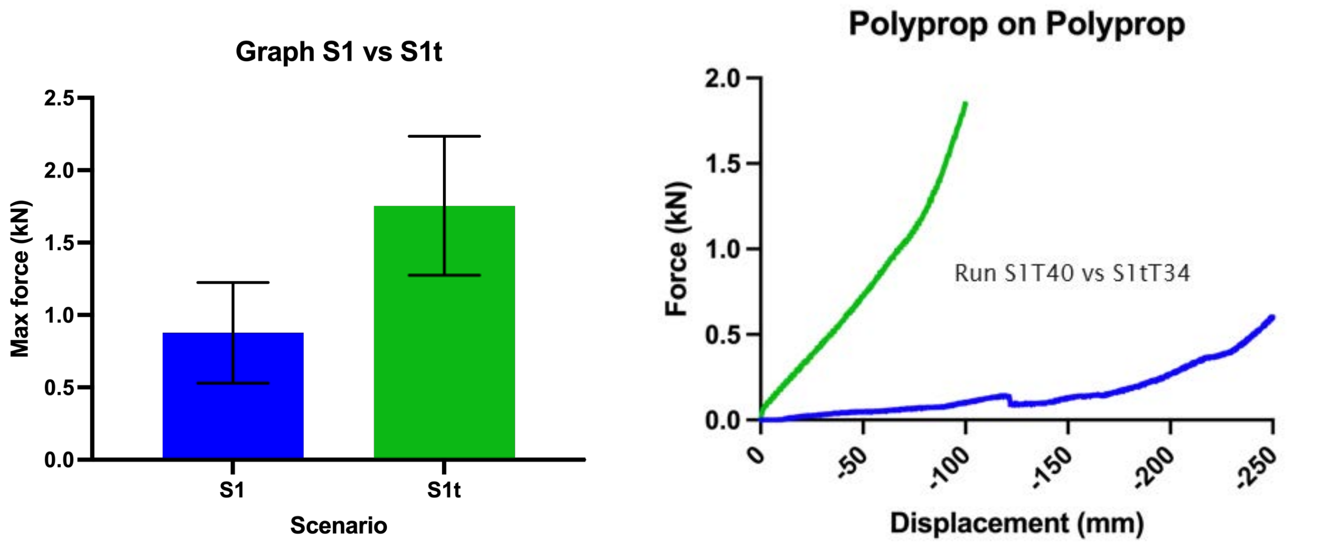
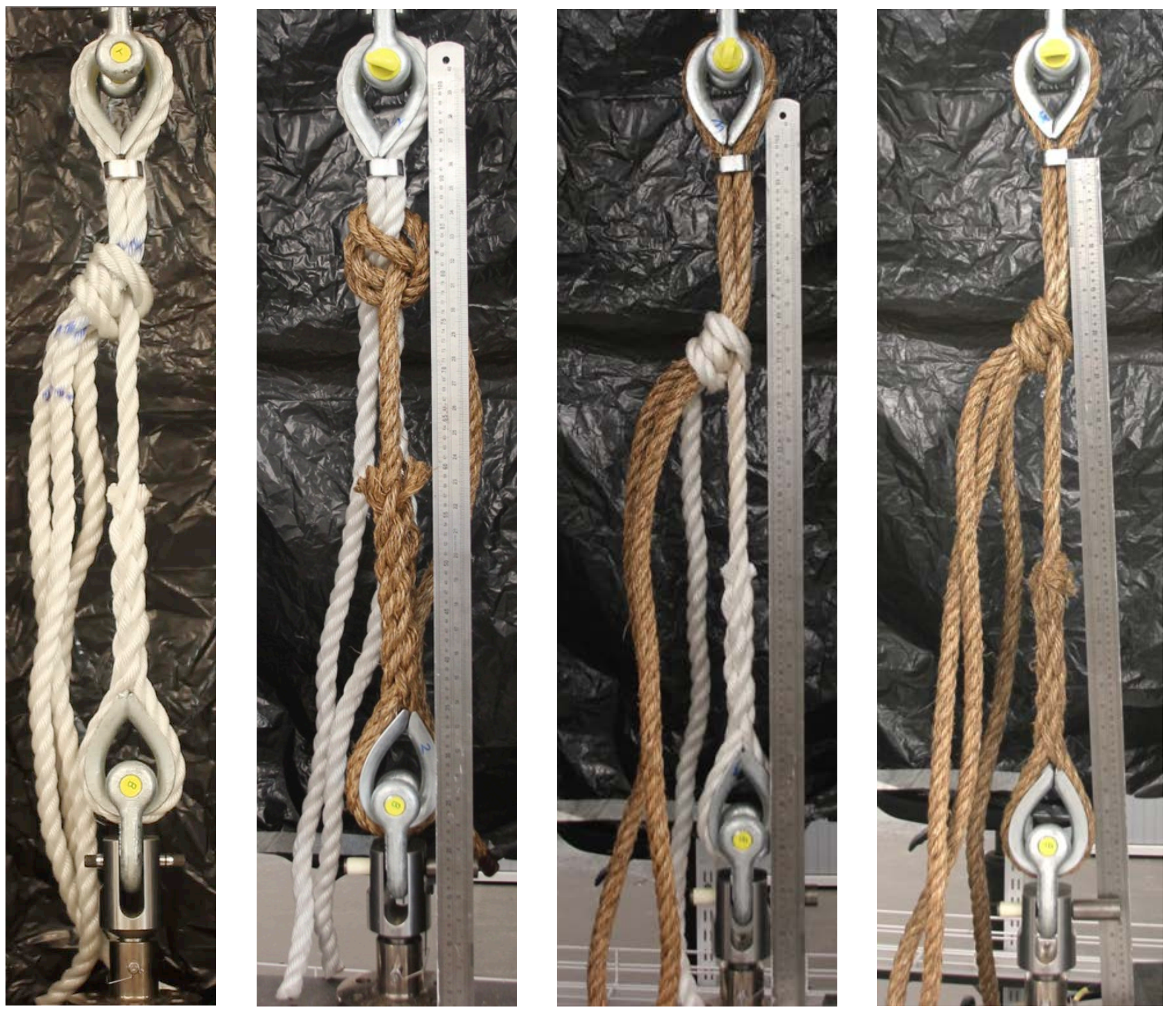


Figure 35: Scenario 1 maximum force recorded during the test for no pre-test tightening force (S1) and with tightening force (S1t). Force versus displacement graphs of one typical test run of each type.



S1 S2 S3 S4

Figure 36: Initial starting positions of test runs for scenarios S1-S4.

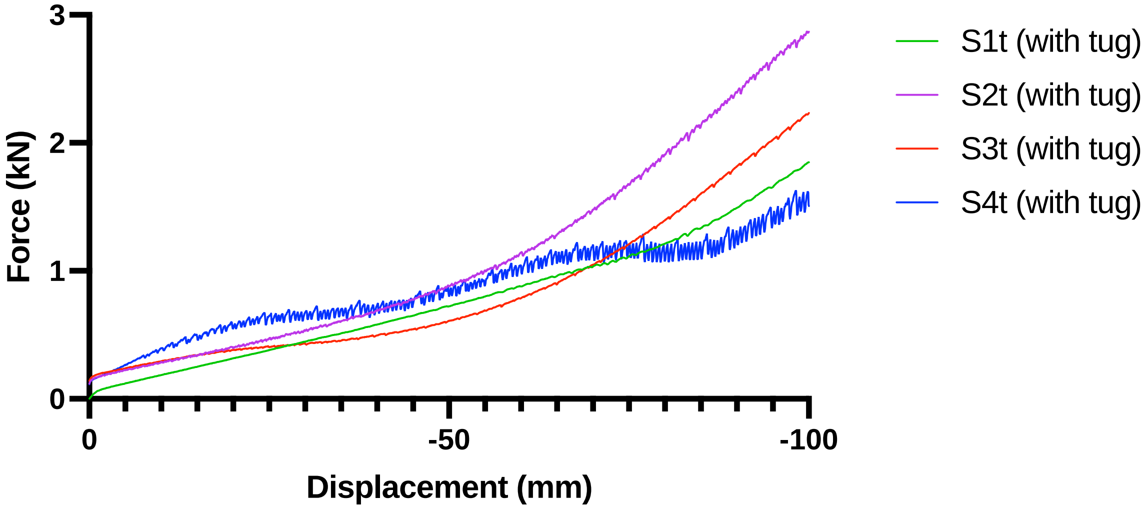


Figure 37: Examples of force displacement curves produced during test runs from S1-S4.

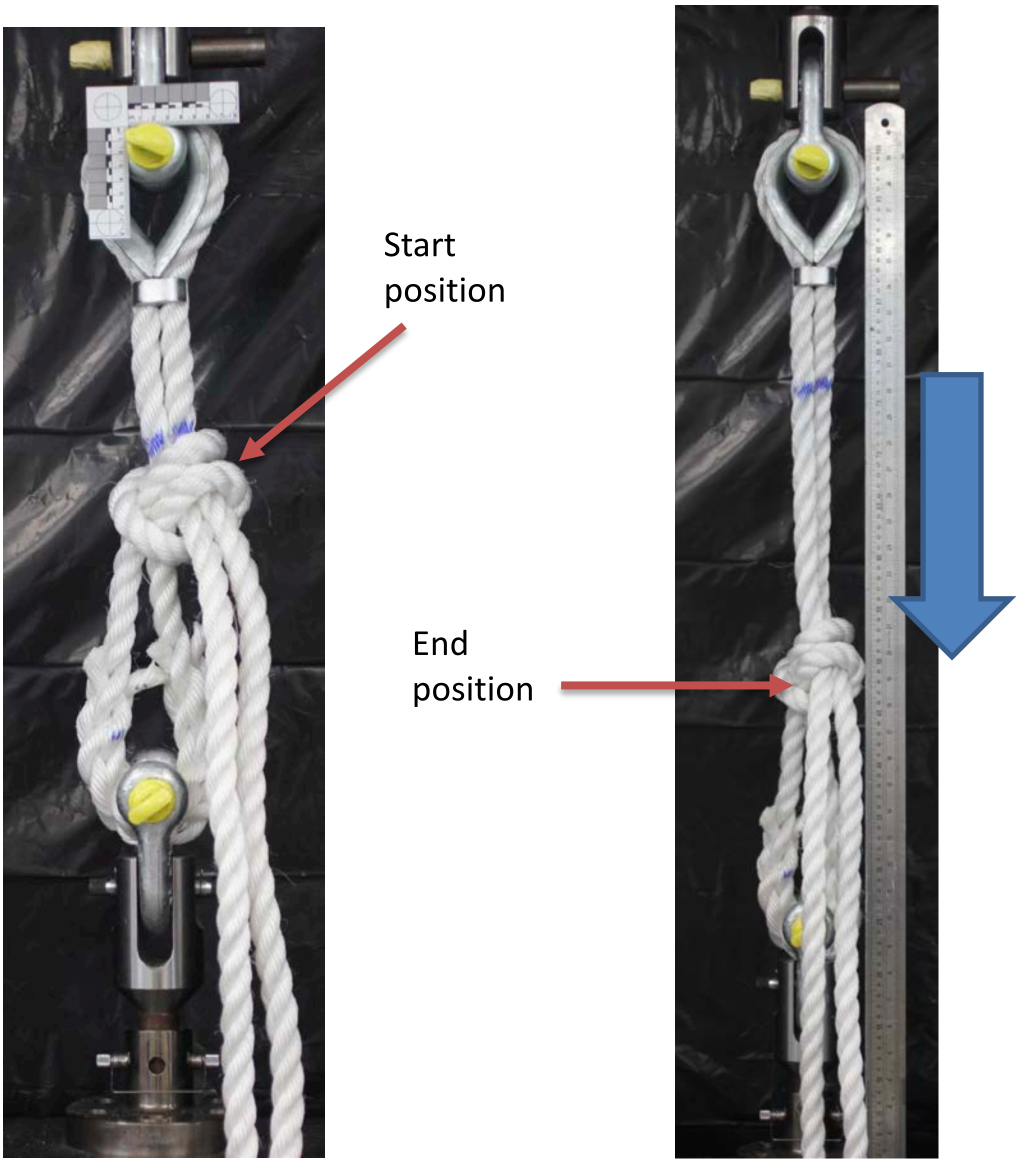


Figure 38: Images showing start and end position of cow hitch S5, that slid 250 mm.

S6 S7 S8

Figure 39: Views of cow hitch scenarios S6-S8.

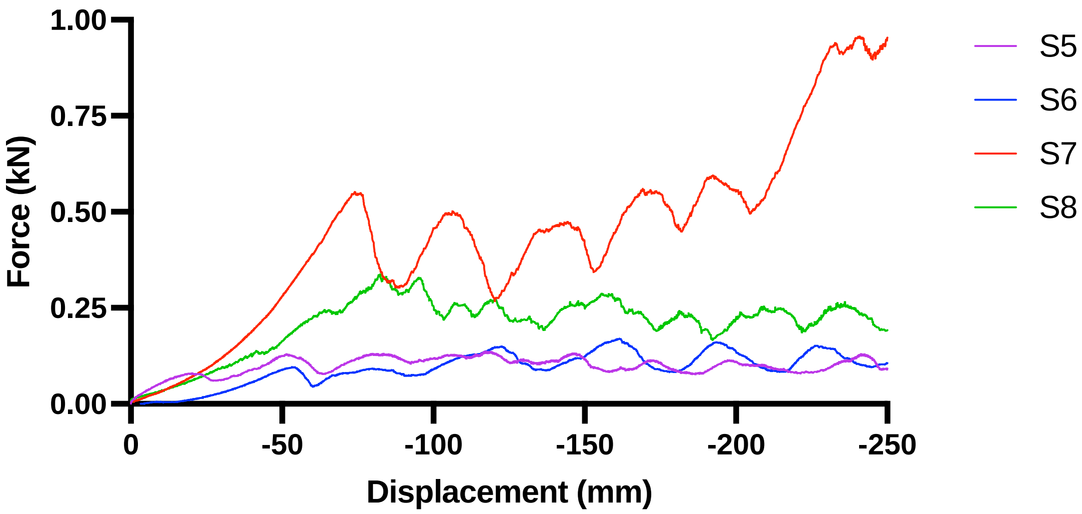


Figure 40: Examples of force displacement curves produced during test runs from S5-S8.

S9 S10 S11 S12

Figure 41: Views of cow hitch cargo strap scenarios S9-S12.

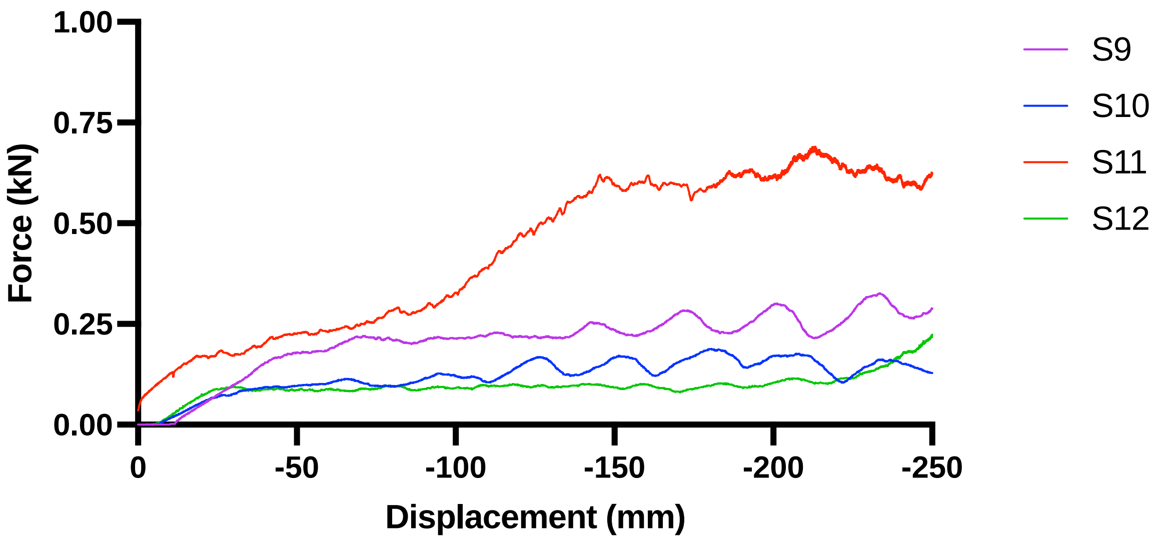
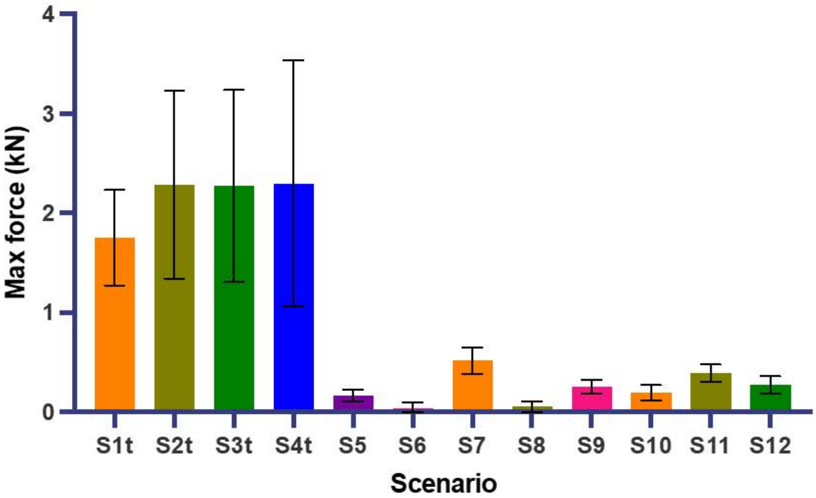


Figure 42: Examples of force displacement curves produced during test runs from S9-S12.



No.	Secured with	Made of	Ladder pair
S1	Rolling Hitch	Polypropylene	Polypropylene
S2	Rolling Hitch	Manila	Polypropylene
S3	Rolling Hitch	Polypropylene	Manila
S4	Rolling Hitch	Manila	Manila
S5	Cow Hitch	Polypropylene	Polypropylene
S6	Cow Hitch	Manila	Polypropylene
S7	Cow Hitch	Polypropylene	Manila
S8	Cow Hitch	Manila	Manila
S9	Strap	Purple	Polypropylene
S10	Strap	White	Polypropylene
S11	Strap	Purple	Manila
S12	Strap	While	Manila

Figure 43: Max Force measures for each scenario.

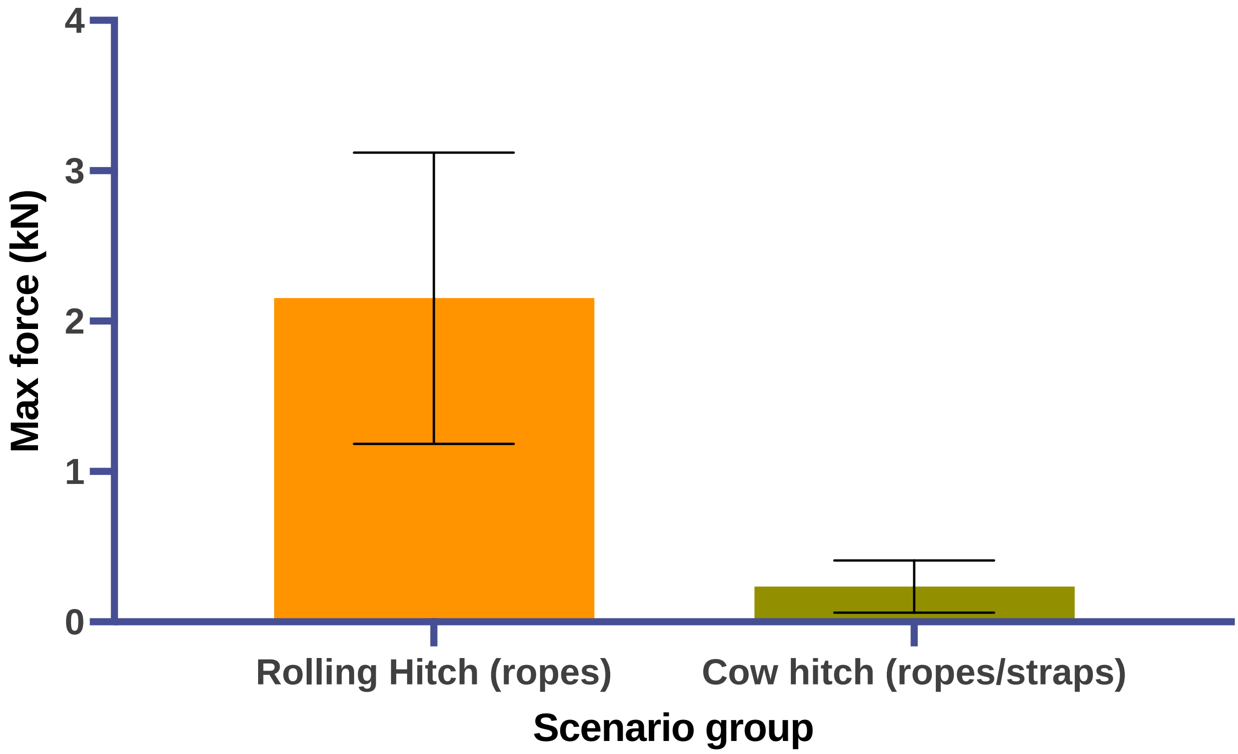


Figure 44: Average max force for rolling hitch compared with cow hitch securing methods.

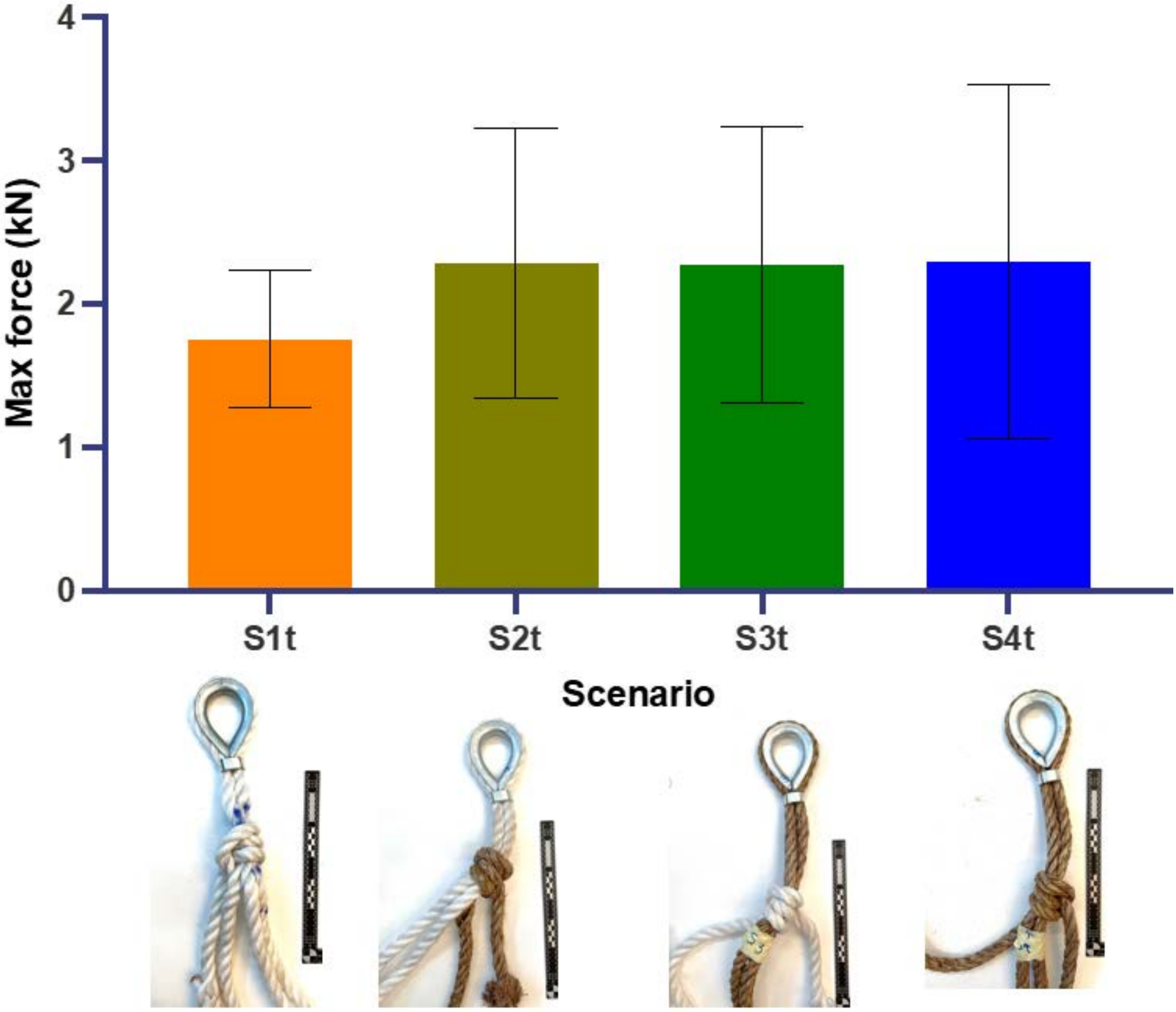


Figure 45: Max force for each rolling hitch scenario.

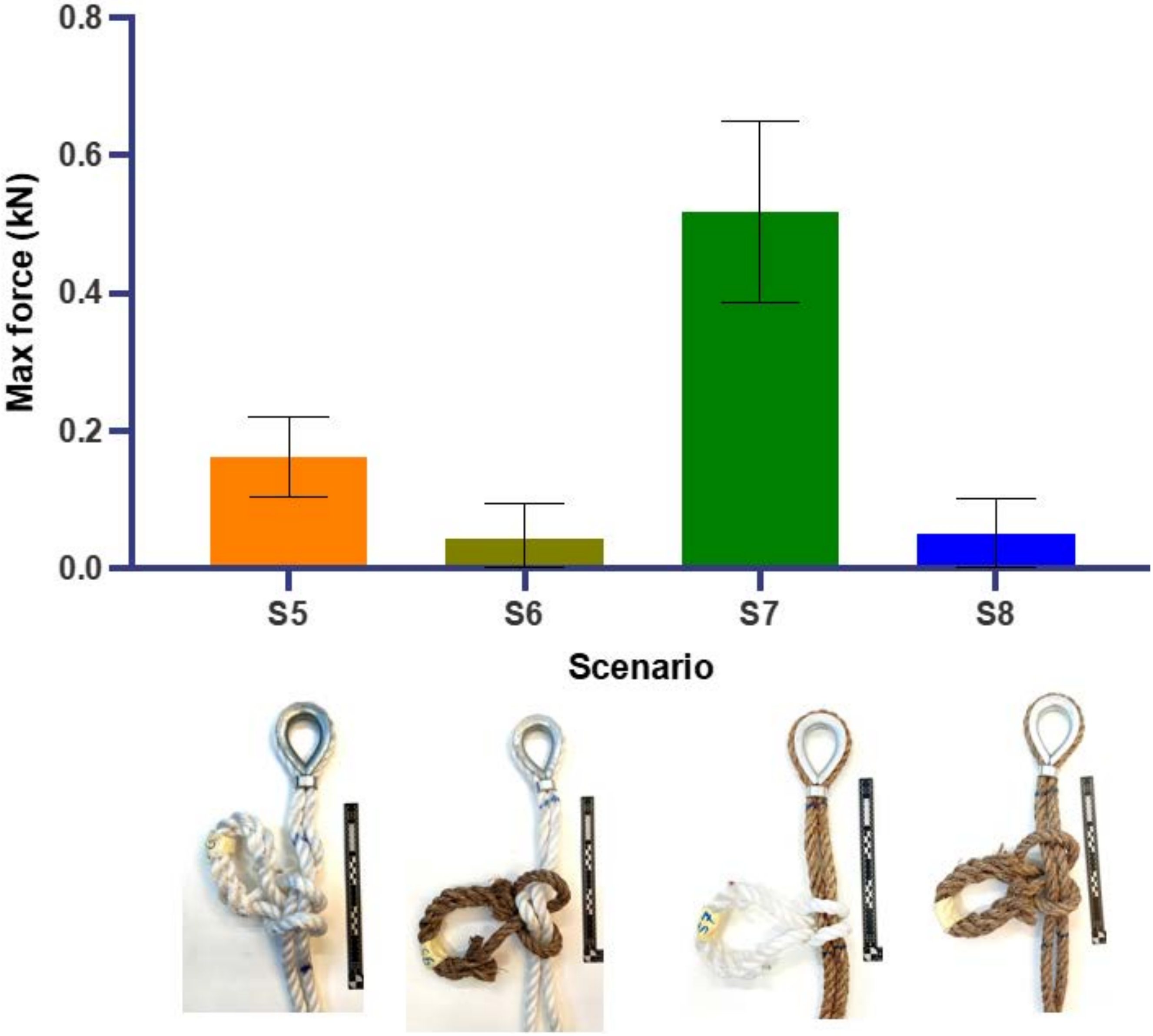


Figure 46: Max force for cow hitch scenarios involving polypropylene and manilla loops.

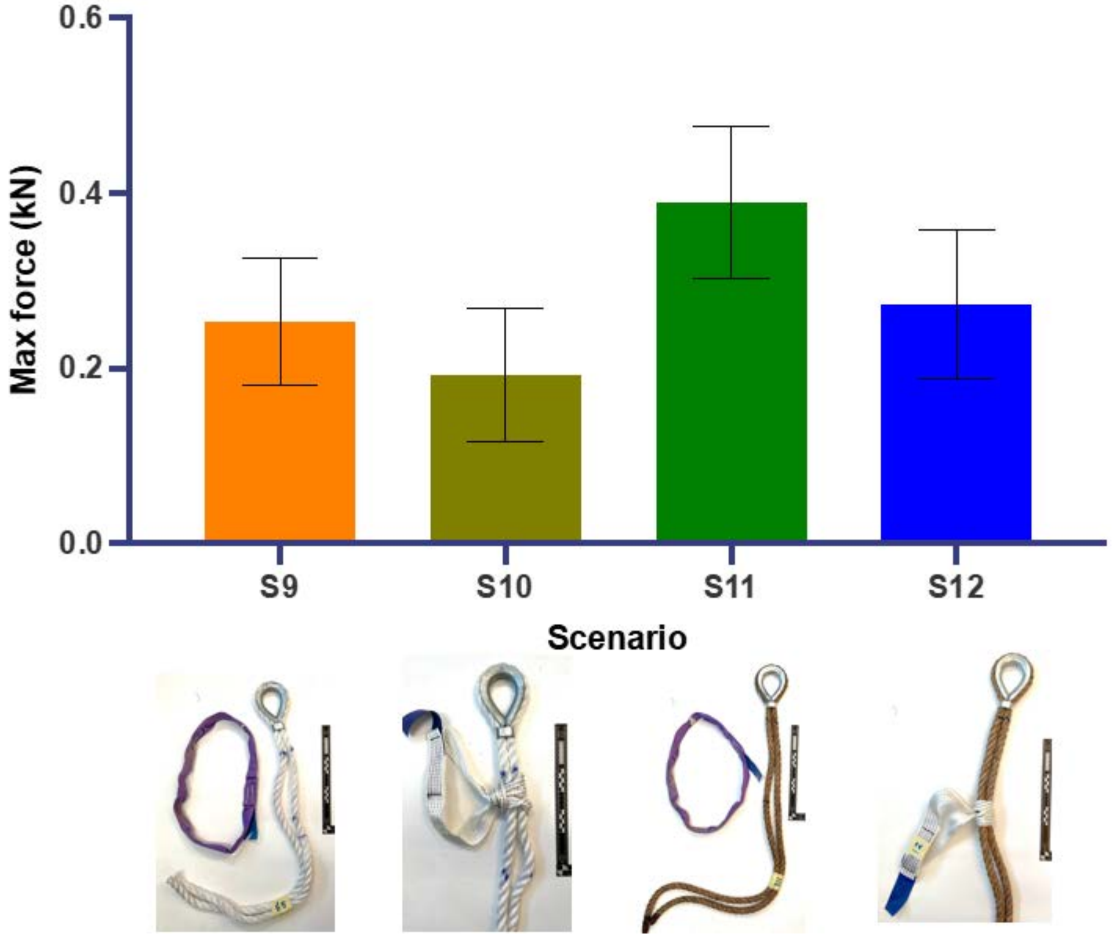
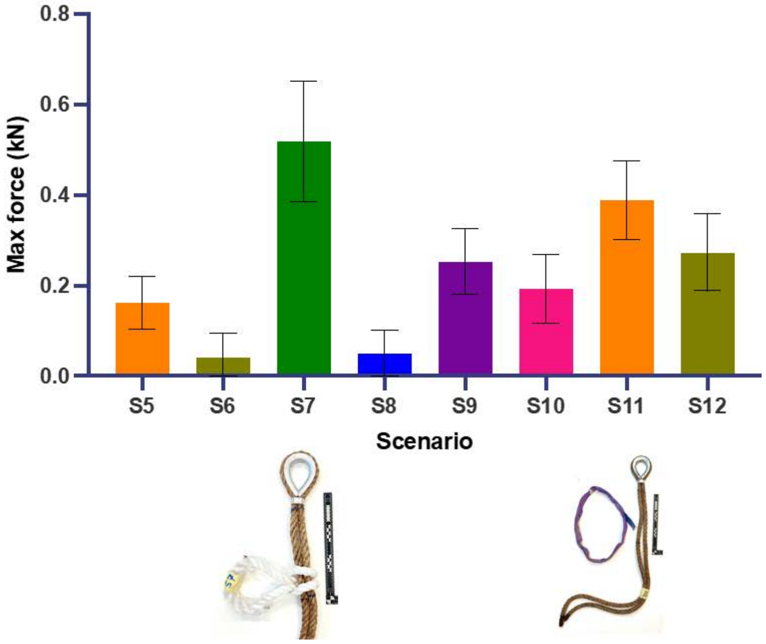


Figure 47: Max force for each cow hitch scenario with white and purple straps.



No.	Secured with	Made of	Ladder pair
S5	Cow Hitch	Polypropylene	Polypropylene
S6	Cow Hitch	Manila	Polypropylene
S7	Cow Hitch	Polypropylene	Manila
S8	Cow Hitch	Manila	Manila
S9	Strap	Purple	Polypropylene
S10	Strap	White	Polypropylene
S11	Strap	Purple	Manila
S12	Strap	While	Manila

1

Figure 48: Max force for each cow hitch scenario.

Figure 49: Scenarios 1 and 2 post-test (Left) and the examined worn section of the double rope (Right).

Figure 50: Scenarios 3 and 4 post-test (Left) and the examined worn section of the double rope (Right).

Figure 51: Scenarios 5 and 6 post-test (Left) and the examined worn section of the double rope (Right).

Figure 52: Scenarios 7 and 8 post-test (Left) and the examined worn section of the double rope (Right).

Figure 53: Scenarios 9 and 10 post-test (Left) and the examined worn section of the double rope (Right).

Figure 54: Scenarios 11 and 12 post-test (Left) and the examined worn section of the double rope (Right).

4. WP3 – D-Shackle Testing

4.1. Introduction

Rope ladders used in-service are frequently being secured with the use of D shackles in a shackle within shackle arrangement, see Figure 5. The aim of Work Package 3 (WP3) was to design and perform a repetitive test in the laboratory that would simulate the loading from D-shackle attachments on a section of a pilot ladder. The aim of the work was to investigate this securing method and determine the wear of the pilot ladder over its intended life in-service. Focus was made on one side of the ladder. It was assumed that the D-shackle would be attached across the rope pair between two steps and that this shackle would in turn have another floating shackle connected to this – which in service may be a hard point or thimble connection for further securing the rope length.

Similarly to WP1, combinations of rope type and seizing methods were investigated (Figure 55), additionally two shackle sizes were tested (Figure 56). The matrix of test samples is shown in Table 4.

Table 4: Matrix of samples tested within WP3

<table>
<tr><th>Specimen ID</th><th>Rope Material</th><th>Fastener Type</th><th>Shackle Size</th></tr>
<tr><td>E</td><td rowspan="4">20 mm
natural
manila
4 strand</td><td rowspan="2">Manila seizing</td><td>Small</td></tr>
<tr><td>F</td><td rowspan="2">Large</td></tr>
<tr><td>G</td><td rowspan="2">Metal clip</td></tr>
<tr><td>H</td><td rowspan="2">Small</td></tr>
<tr><td>M</td><td rowspan="4">20 mm
Synthetic
Polypropylene
3 strand</td><td rowspan="2">Polyprop seizing</td></tr>
<tr><td>N</td><td rowspan="2">Large</td></tr>
<tr><td>O</td><td rowspan="2">Metal clip</td></tr>
<tr><td>P</td><td>Small</td></tr>
</table>

4.2. Test method

The test was designed to apply a force-time sequence that captured the full range of expected loading. The application of loading arises from the typical use of the pilot ladder in service. This involves a pilot with kit ascending and descending the pilot ladder as required. The assumptions used in the calculations are given in Table 5.

The sequence of the ladder use was assumed to be the following:

- The ladder is to be stored away when not being used and so the load begins at 0 N.
- The ladder is then thrown over the side of the ship/boat/vessel and is subject to a shock loading estimated to be approximately four times the gravitational constant.
- The ladder stabilises and hangs from the fixed point.
- The pilot then steps on the bottom step. The majority of the weight is assumed to be ¼ of the width away from one side of the ladder and therefore 75 % of the total weight of the person plus the weight of the kit will apply to one shackle.
- The pilot then applies an additional acceleration of approximately 0.5 the gravitational constant to allow movement in the upwards direction and climb the ladder to the next step.
- The weight is then shifted to the other side of the ladder and the shackle now only sees 25 % of the weight of the pilot plus the weight of the kit.
- The pilot then applies an additional acceleration of approximately 0.5 the gravitational constant to allow movement in the upwards direction and climb the ladder to the next step. This cycle continues until the person has reached the top of the ladder.
- The pilot reaches the top and gets off. The ladder is left hanging by the shackles.
- The person then descends the ladder following the same cycle until the person reaches the bottom and gets off the ladder.
- The ladder is then put away into storage removing the load.

The loads for each part of the sequence are listed in Table 6. This complete cycle of one use (also shown schematically in Figure 57) was applied to each sample 1500 times, representing an extreme usage of the ladder.

A jig was designed and made for the purpose of testing in WP3, see Figure 58. One shackle was secured to the top plate using screws in threaded holes, this was known as the 'fixed shackle'. A 'floating shackle' (Figure 59) was then attached. The 'floating shackle' reduced the length of the clearance space within the fixed shackle (Figure 56) representing a common in-service loading scenario (Figure 5). The shackle arrangement was loaded onto one side of the ladder step assembly – to prevent large slippage of the whole step assembly off the rope a clamp was used below the lower seizing, see Figure 59.

Blue permanent marker was used to mark the location of features such as the fasteners, wooden step and chocks prior to testing. Misalignment would then show slippage of any of these features/assembly. The specimens were installed in the rig which was secured to an electromechanical tensile testing machine (Figure 61).

During each full use cycle, preparation was made to apply a release force to the rope at the bottom end (releasing the shackles) to simulate the shackle being taken off the rope before being put away into storage. This process was to promote some level of in-service worst-case wear. Manual application of a release force was required for specimens with the small shackles. Weights provided the release force process for specimens which involved the use of the large shackles.

Table 5 : The estimated weights of the ladder, pilot and equipment. The gravitational constant is assumed to be 10 $kgms^{-2}$.

Description	Result
Weight of Ladder	110 kg (1100 N)
Weight of Pilot	125 kg (1250 N)
Weight of kit	25 kg (250 N)
Length of ladder	9 metres

Table 6: Tabulated loads applied for single cycle of the loading sequence.

Event	Description	Force (N)
Start	Ladder stored away	0
Initial shock	Initial shock by ladder during deceleration estimated to be 4 x ladder weight	2200
Hanging ladder	Half weight of ladder	550
Pilot steps on near side of ladder	Half weight ladder, plus weight of pilot + kit.	2050
Max cyclic load of pilot weight	Half weight ladder, plus weight of pilot + kit, plus 0.5 g by pilot (simulates man pushing upwards)	2800
Min cyclic load of pilot weight	Half weight of ladder, plus ¼ (weight of pilot + kit)	925
Pilot pushes on far side of ladder to reach next step.	Half weight of ladder, plus ¼ (weight of pilot + kit), plus 0.5 g by man	1113
Ladder put away	Ladder put away	10
Finish	End of test	0

4.3. Discussion of results

Several observations arose during the testing of WP3. These are discussed in turn below:

Small shackle deforms metal fastener: The small shackle arrangement was too small to slide over the fastener and therefore the small shackle contacted the metal clip throughout the testing. After 1500 cycles, the small shackle had caused permanent deformation on the metal fastener regardless of which rope material was used (Figure 62 and Figure 63). No effect was observed on the shackle (Figure 64), hardness testing revealed that this was due to the shackle material being much harder than the metal fastener material (Table 7).

The level of damage was not deemed to be structural to the clip, however:

- The damage could result in sharp edges requiring extra care when handling or climbing. Section 4.6 of BS ISO 799-1 requires *"Each part of a ladder shall be free of splinters, burrs, sharp edges, corners, projections, or other defects that could injure a person using the ladder".*
- If an anti-corrosion coating was present – it would have been ruptured. Section 4.3 of BS ISO 799-1 requires "*Each metal fastener shall be made of material which is inherently corrosion-resistant or treated to be corrosion-resistant. Each ferrous metal part, which is not stainless steel, shall be coated in accordance with ISO 1461."*

Table 7 : The average hardness in Hardness Vickers for the large shackle compared with the average hardness for the metal fastener.

Hardness Testing	Large Shackle	Metal Fastener
Average (HV)	92	47

Small shackle deforms plastic chock: The small shackle was able to pass over the rope seizing fastener and contact the plastic chock directly. The plastic chock tended to get wedged in the small shackle (Figure 65 top left), resulting in a lot of force and manipulation being required to remove the shackle from the plastic chock. An area of wear damage was observed on the plastic chock after removal from the small shackle (Figure 65 top right and bottom right). Due to the wedging effect, the plastic chock was forced to separate from the wooden step during the unloading step (when the ladder was put away) (Figure 65 bottom left). Potentially this could be an issue as Annex A of BS ISO 799-2 requires an inspection to ensure *"Step fixtures are secure and tight" and "Seizings/step securing are in good condition."*

<u>Large shackle contacts wooden step</u>: The large shackle was large enough to pass over both the metal fastener and the rope seizing. This resulted in the large shackle contacting the wooden step. Due to the difference in the heights between the fixed and floating shackle contact points, the wooden step was forced to tilt. This caused separation at one end of the plastic chock from the wooden step (Figure 66). The floating large shackle also contacted the edge of the wooden step, resulting in a small depression about 4-8 mm diameter (Figure 67). Potentially this could be an issue as Annex A of BS ISO 799-2 requires an inspection to ensure *"Step fixtures are secure and tight" and "Seizings/step securing are in good condition."*

<u>Metal fastener slips by a negligible amount</u>: No slippage was observed for any scenario tested involving polypropylene rope material (Figure 68) when the metal clip was used. A relatively minimal amount of slippage (2 - 3 mm) was observed from the top metal fastener in contact with the small shackle for manilla rope material (Figure 68). The bottom (below the step) metal fasteners did not slip when subjected to any test scenario.

The observations on the slippage of metal fasteners, including performance relative to the rope seizing, are specific to the "H" design clips supplied by PTR Holland for the Study (Figure 55). Other designs of metal fasteners/clips were not tested, and the performance of other designs should not be assumed to be equivalent to those used in WP3.

<u>Rope seizing allows a large amount of slip</u>: In all scenarios, where rope seizing was used, a large amount of slippage occurred. The first laboratory test run where a rope seizing was tested resulted in slippage down the entire length of the sample rope until the rope seizing came to a clamping point to prevent further slippage (Figure 69 and Figure 70). The difference between the metal fastener and the rope seizing method can be seen in Figure 71. In this graph the extension (movement in mm) has been plotted against cycle run number. There are two issues with this slippage:

- the step has moved – changing the spacing between steps. Figure 1A of BS ISO 799-1 shows that the steps must have a spacing of 330 mm ± 20 mm.
- The seizing is no longer directly above the chock – allowing the chock to be lost. Annex A of BS ISO 799-2 requires an inspection to ensure *"Step fixtures are secure and tight" and "Seizings/step securing are in good condition."*

There may be several reasons why this may not occur to this extent in-service. The ropes tested were dry ropes (see Figure 72), however, in-service it is likely the ropes will be saturated with sea water. The sea water may cause rope swelling which may increase the effectiveness of the rope seizing. Additionally, the fixed angle of the shackle results in a constant perpendicular angle with the axis of the rope. This is a worst-case scenario, in-service the shackle will likely be able to twist at an angle reducing the load in the slippage direction.

The shackle caused rope wear: Both the small and large floating shackles wedged in between the inside faces of the chock and the rope during testing. With the addition of a release step (applied release force to simulate removing the shackles), some level of rope wear occurred to both rope materials. A black deposit can clearly be seen on the surface of the ropes (Figure 73). This black deposit is most likely due to the shackle coating rubbing on the rope surface (fretting). A more prominent black deposit can be seen on the manilla rope due to the rougher surface of the manilla rope material (Figure 73 and Figure 74). The individual strands from the polypropylene and manilla rope were observed under a macroscope after testing had been carried out. The strand with the most amount of wear for both the manilla and polypropylene rope material are shown in Figure 75. The strands remained predominantly intact with less than 10 % of the fibres, in the strand examined, becoming broken. Clearly broken fibres and obvious wear would not pass any regular inspection of the pilot ladders in-service.

The rope wear was observed within the first 100 cycles: Within 5 cycles, black deposit from the shackle material coating was observed on the rope. The black deposit built up and became more prominent over a 100-cycle period. Comparing the 100th cycle to the 1300th cycle showed that the majority of the black deposit and the rope wear tended to occur in a short period of time, typically by 100 cycles (Figure 76).

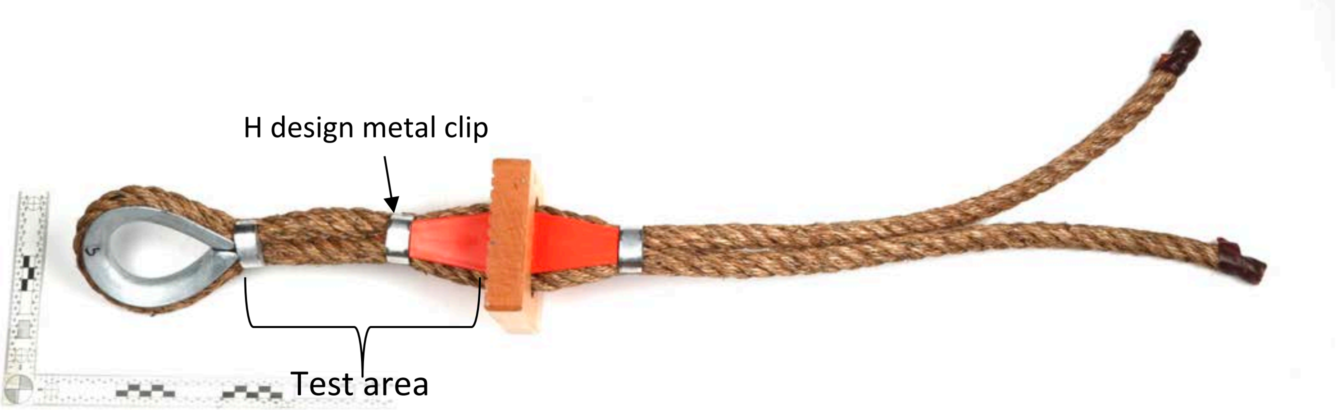
4.4. Summary

From the samples tested:

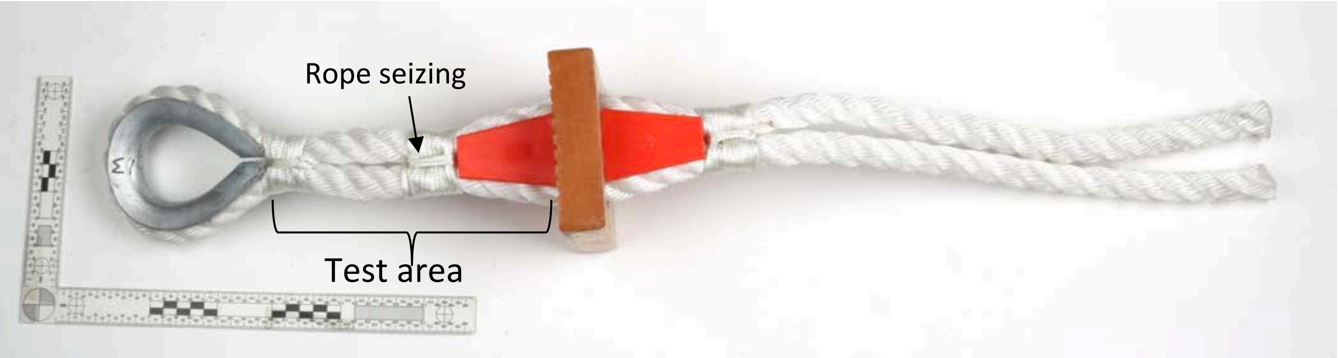
- Large shackles pass over fixings and contact the wooden chock causing deformation to the chock and wooden step.
- The rope seizing allows a large amount of slippage to occur to the wooden step and chock assembly (in dry conditions).

- Metal fasteners do not allow any movement of the wooden step and chock assembly along the pilot ladder.
- Small shackles rest/impact the metal fasteners (clips).

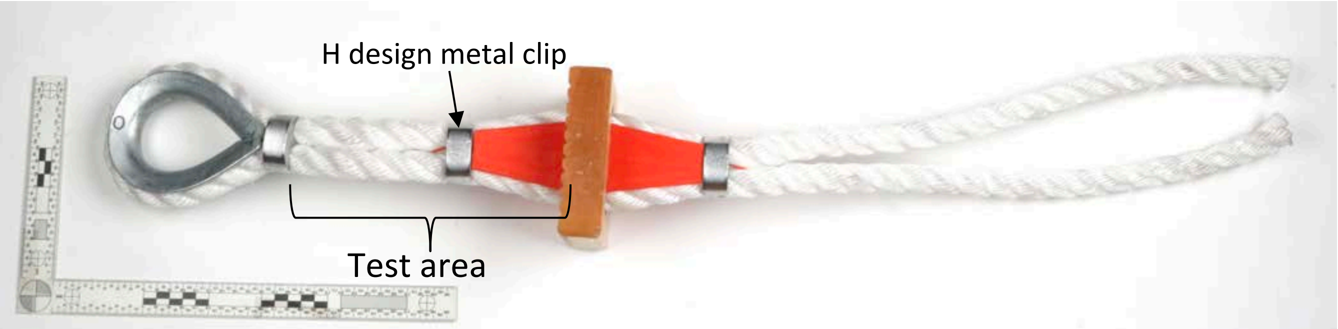
E: 20 mm manila rope, with step and manila rope seizing (sample F the same)



G: 20 mm manila rope, with step and metal clip seizing (sample H the same)



M: 20 mm polypropylene rope, with step and polypropylene rope seizing (sample N the same)



O: 20 mm polypropylene rope, with step and metal clip seizing (sample P the same)

Figure 55: As received condition of samples (with step) for WP3, note unlike WP1 these samples have no lower thimble (eye end). Area under test highlighted in each case.

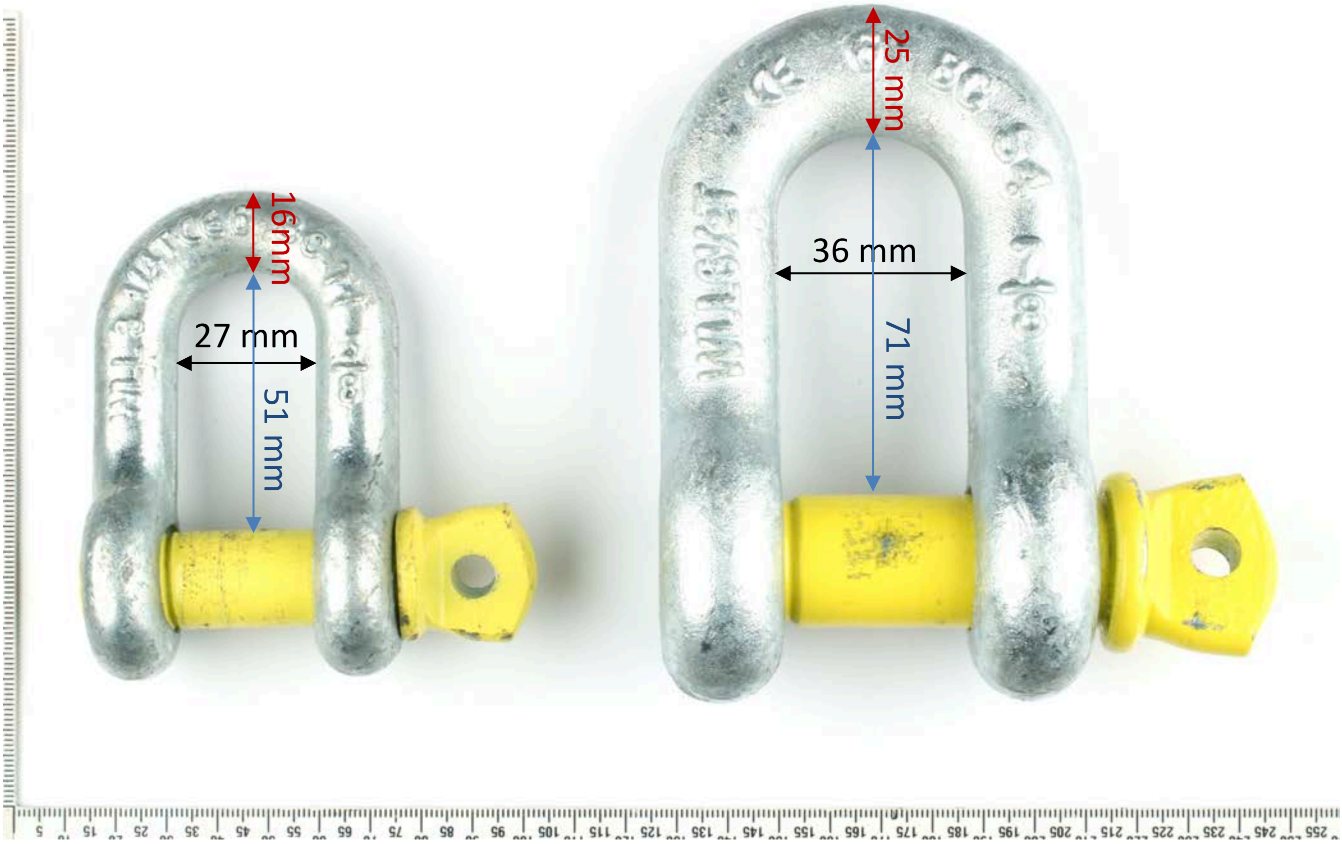


Figure 56: Two sizes of D-shackle were provided.

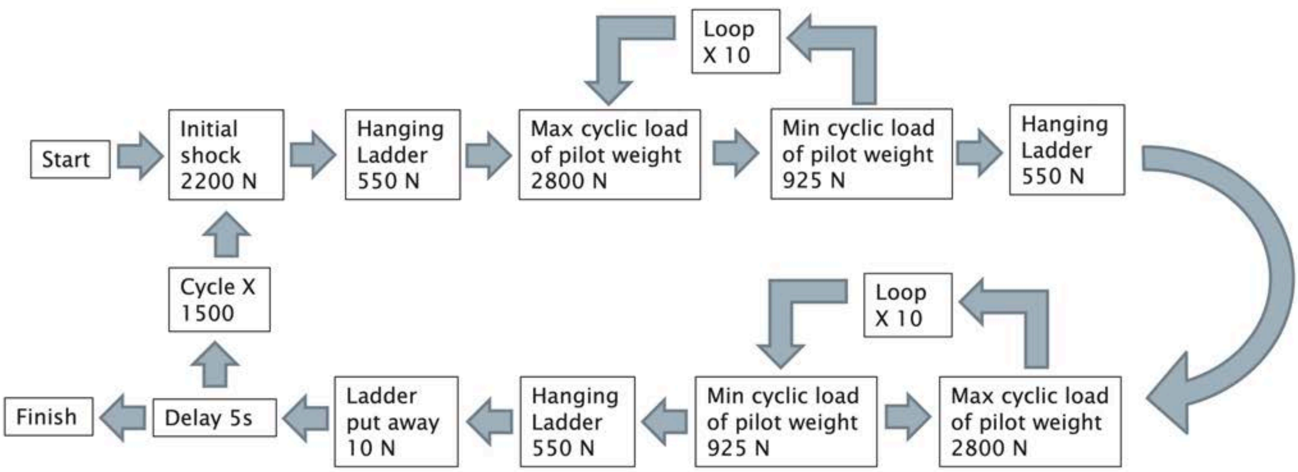


Figure 57 : Schematic showing the loading sequence.

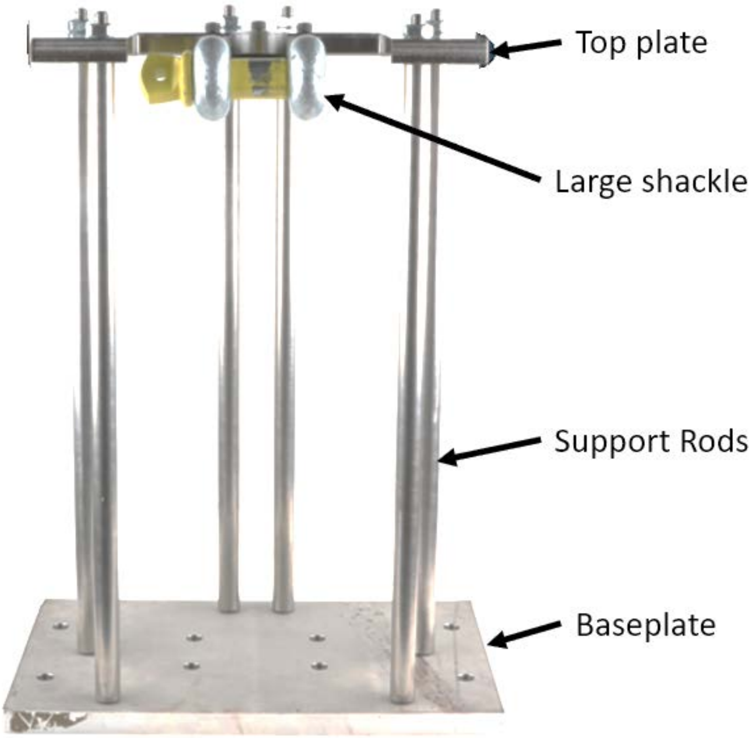


Figure 58: The rig for WP3 D shackle testing with the large shackle arrangement.

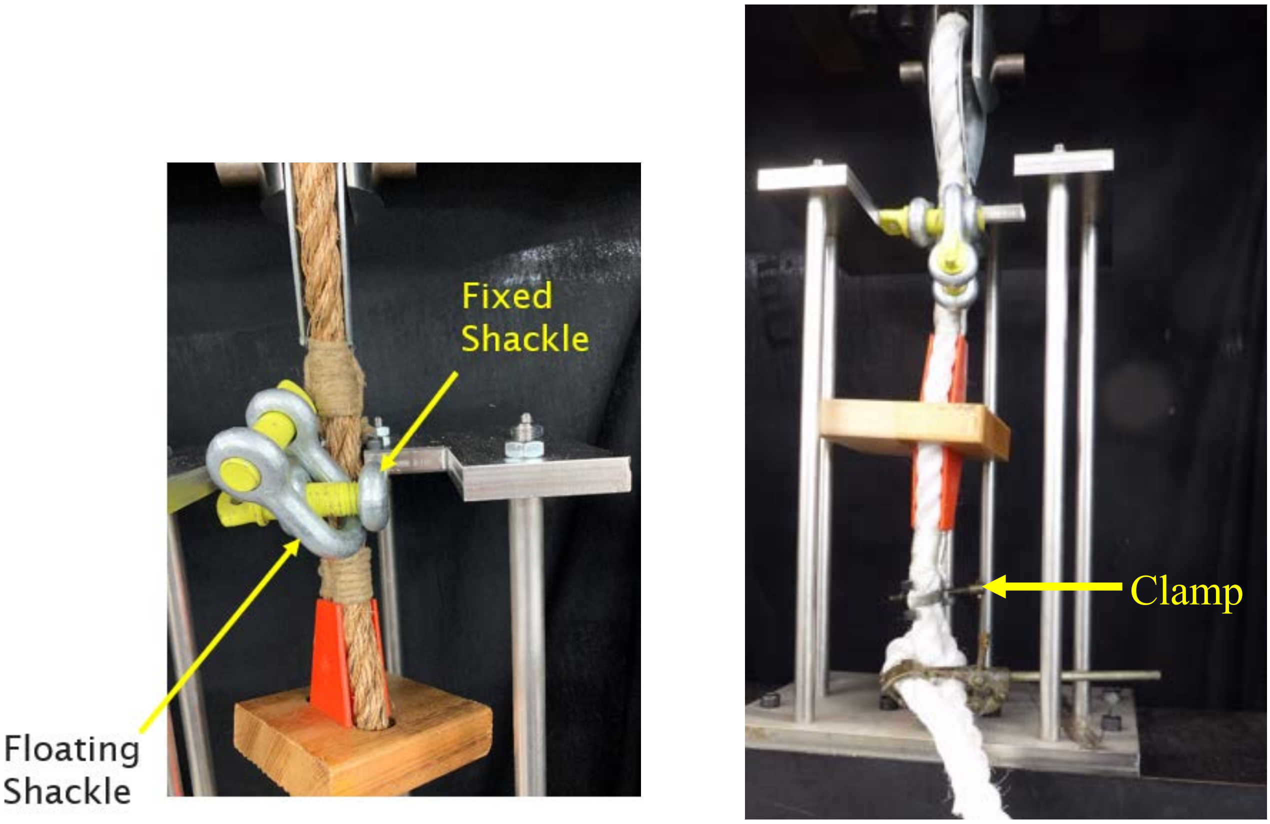
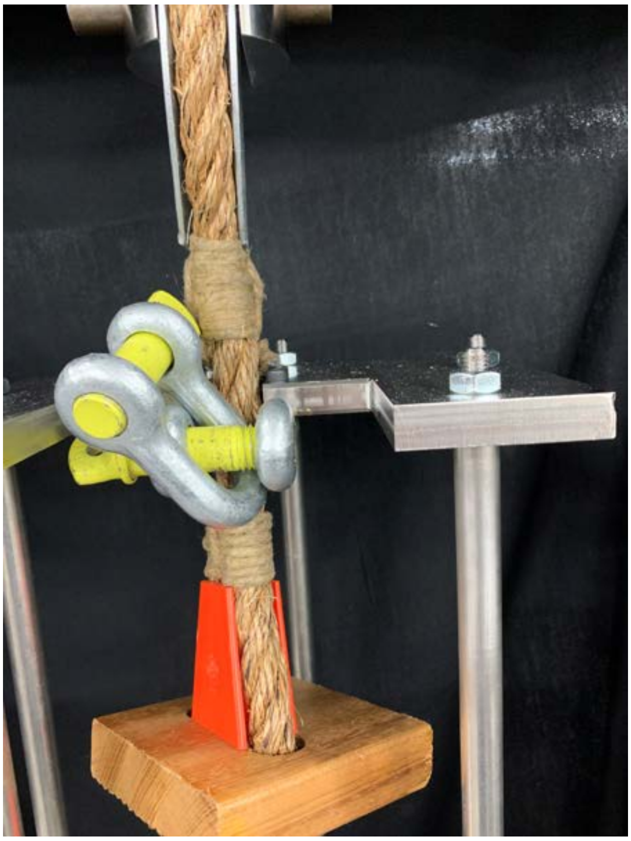


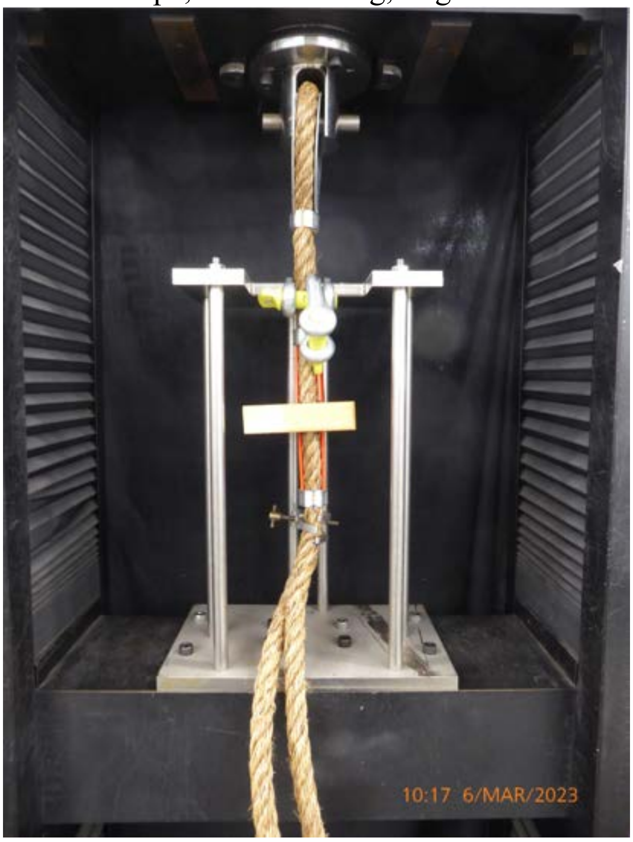
Figure 59: Images showing the 'D' shackle testing arrangement in the test jig with the fixed shackle, floating shackle and clamp labelled.



E: Manila rope, manila seizing, small shackles

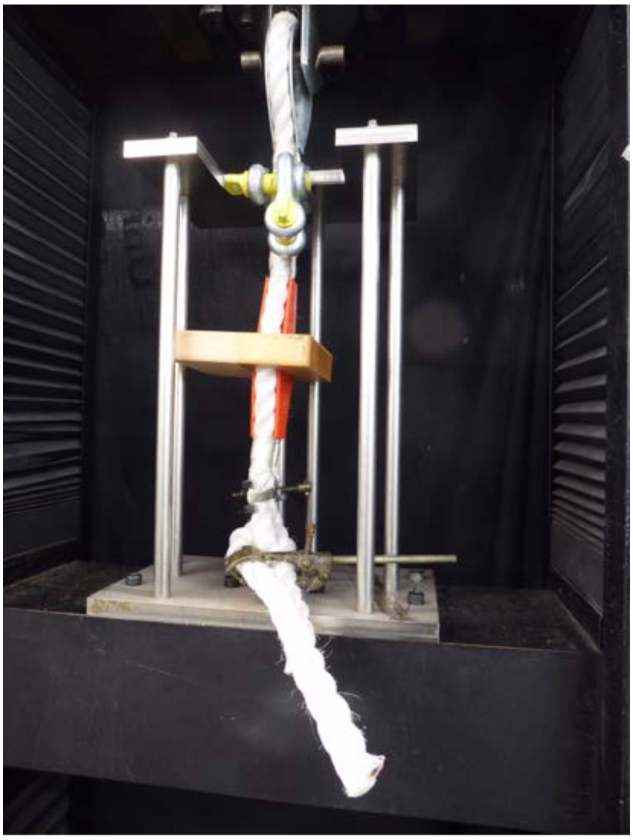
F: Manila rope, manila seizing, large shackles

G: Manila rope, metal clip, large shackles

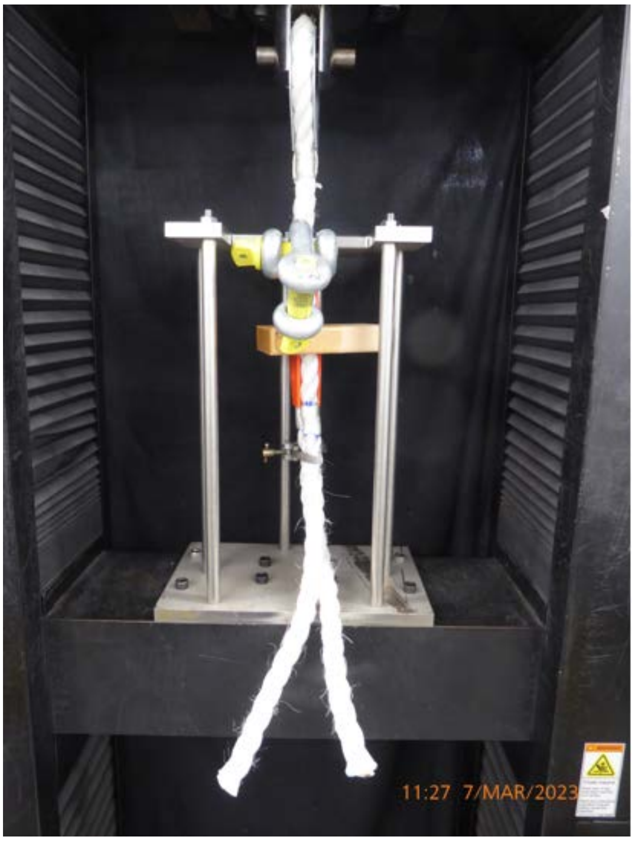


H: Manila rope, metal clip, small shackles

Figure 60 : The specimens as set up in the Instron H machine for Specimens E, F, G, H, from top left to bottom right.



M: Polyprop rope, polyprop seizing, small shackles



N: Polyprop rope, polyprop seizing, large shackles

O: Polyprop rope, metal clip, large shackles

P: Polyprop rope, metal clip, small shackles

Figure 61 : The specimens as set up in the Instron H machine for Specimens M, N, O, and P from top left to bottom right.

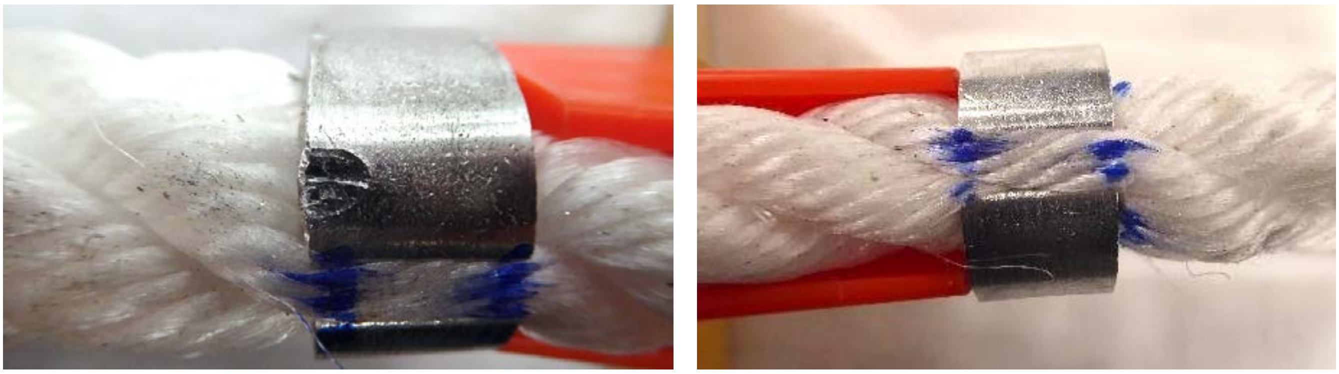


Figure 62 : Specimen O after 1500 cycles showing (Left) permanent damage to the top metal fastener from contact with the small shackle. The metal fastener did not slip during the test. (Right) No slippage was observed on the metal fastener underneath the wooden assembly.

Figure 63 : Specimen H after 1500 cycles showing (Left) permanent plastic deformation to the top of the metal fastener from contact with the small shackle. The top metal fastener slipped 2 – 3 mm from its initial position during the test. (Right) No slippage was observed on the metal fastener underneath the wooden assembly.

Figure 64 : No visible damage was found on the shackle after any of the tests.

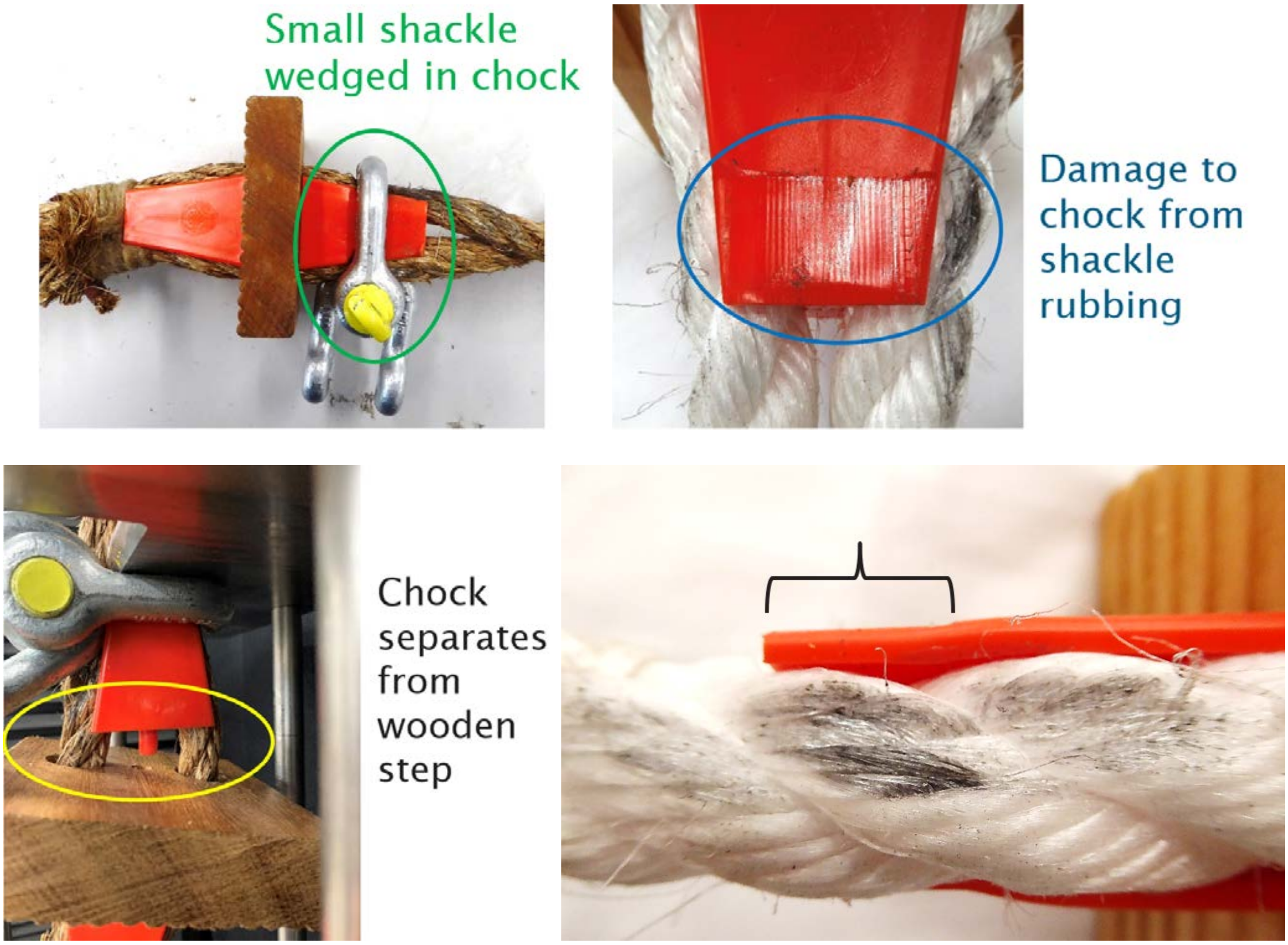


Figure 65 : The small shackle passed over the rope seizing and got wedged in the chock (Top left). When the small shackle was removed after testing, damage to the chock surface was observed (Top Right). The wedging effect resulted in the chock coming away from the wooden step during the 'ladder put away' step (Bottom left). Permanent deformation was observed to the chock (Bottom right).

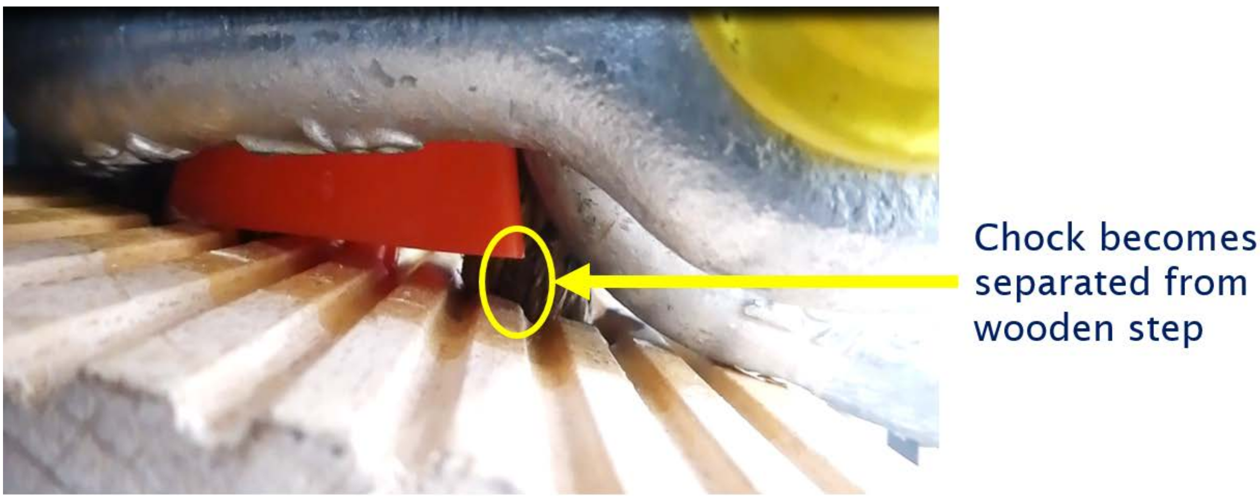


Figure 66 : The large shackle contacts the wooden step in two places at differing height levels, resulting in a tilt effect and one end of the chock becoming separated from the wooden step.

Figure 67 : Specimen N after 1500 cycles showing the damage that the large shackle did to the wooden step.

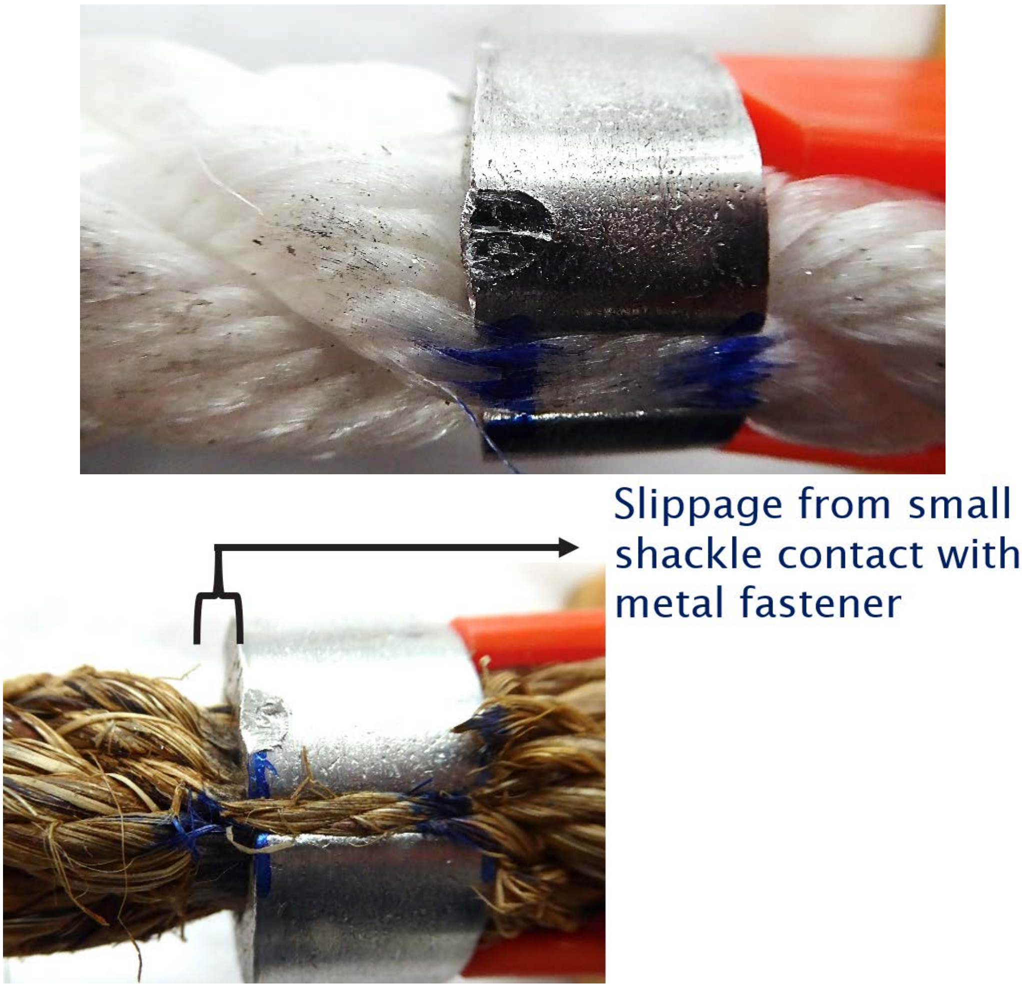


Figure 68 : When the small shackle was used, no slippage was observed for the metal fastener with polypropylene combination. The metal fastener slipped by 2 – 3 mm for the manilla rope.

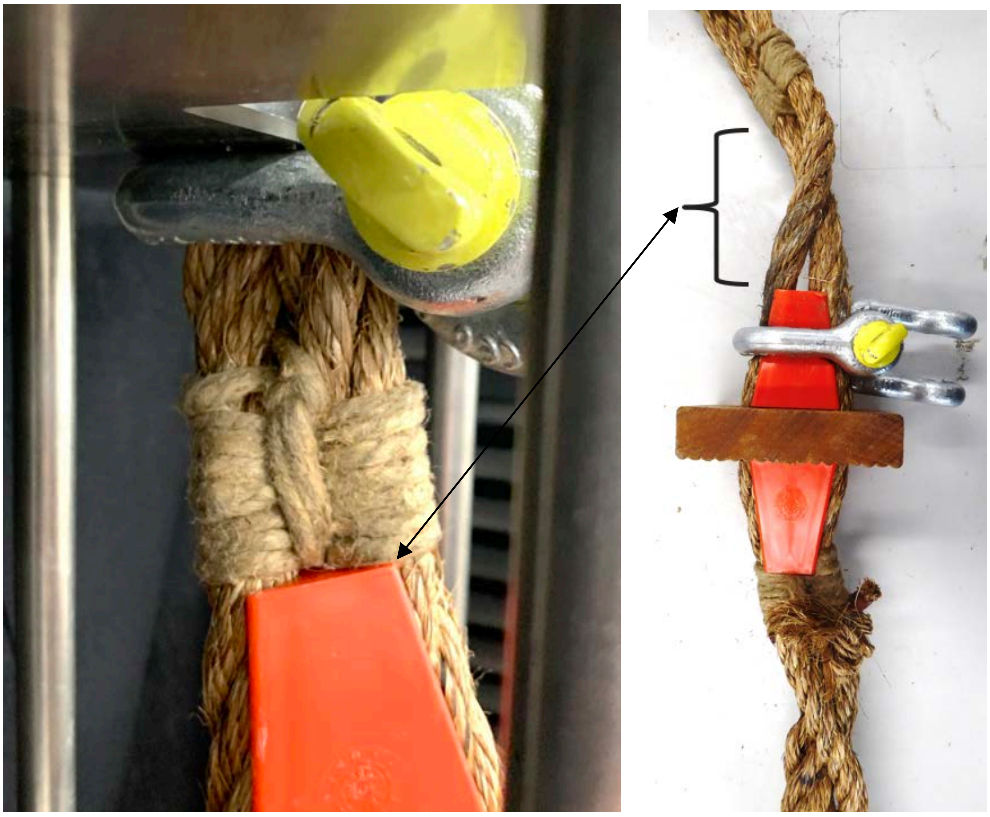


Figure 69 : Left: Specimens E at 0 cycles showing the top chock in contact with the top seizing, and Right: at 1500 cycles showing that the bottom rope seizing slipped down the rope contacting the splicing. Note the distance the chock has travelled and is now over 100 mm away from the top seizing.

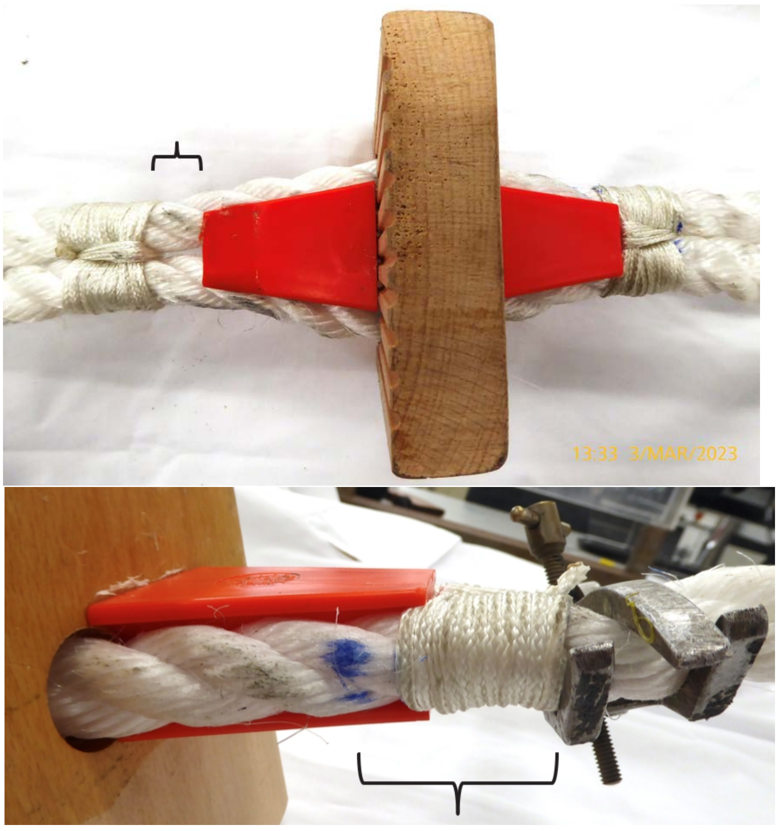


Figure 70 : Specimen M the wooden step assembly slipped downwards (top). The bottom rope seizing slipped approximately 30 mm until it was prevented from slipping due to the clamp (lower).

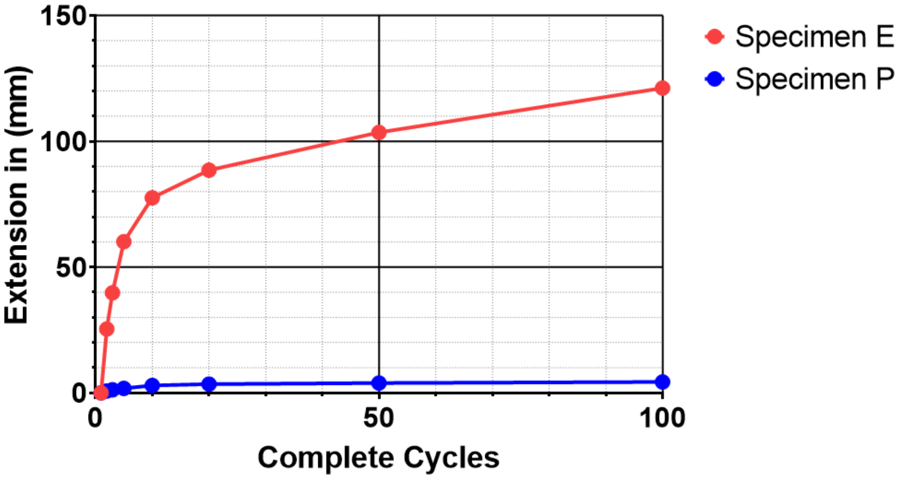


Figure 71 : Specimen E (Small shackle, Manilla, and Rope seizing) extension over 100 cycles with slippage, compared with Specimen P (Small shackle, Polypropylene, and Metal fastener) with no slippage.

Figure 72: Images of the upper rope seizing, note each is in the required figure-of-eight racking and over the required 32 mm length (BS ISO 799).

F: Maninla rope (manila seizing) large shackle. G: Maninla rope (metal clip) large shackle

N: Polyprop rope (polyprop seizing) large shackle. O: Polyprop rope (metal clip) large shackle

Figure 73 : Specimen F, G, N, and O showing damage to the rope from the large shackle.

E: Maninla rope (manila seizing) small shackle.

M: Polyprop rope (polyprop seizing) small shackle.

Figure 74 : Specimen E and M showing the damage to the rope from small shackle rubbing – note that H and P are not shown as the small shackle stopped at the metal clip.

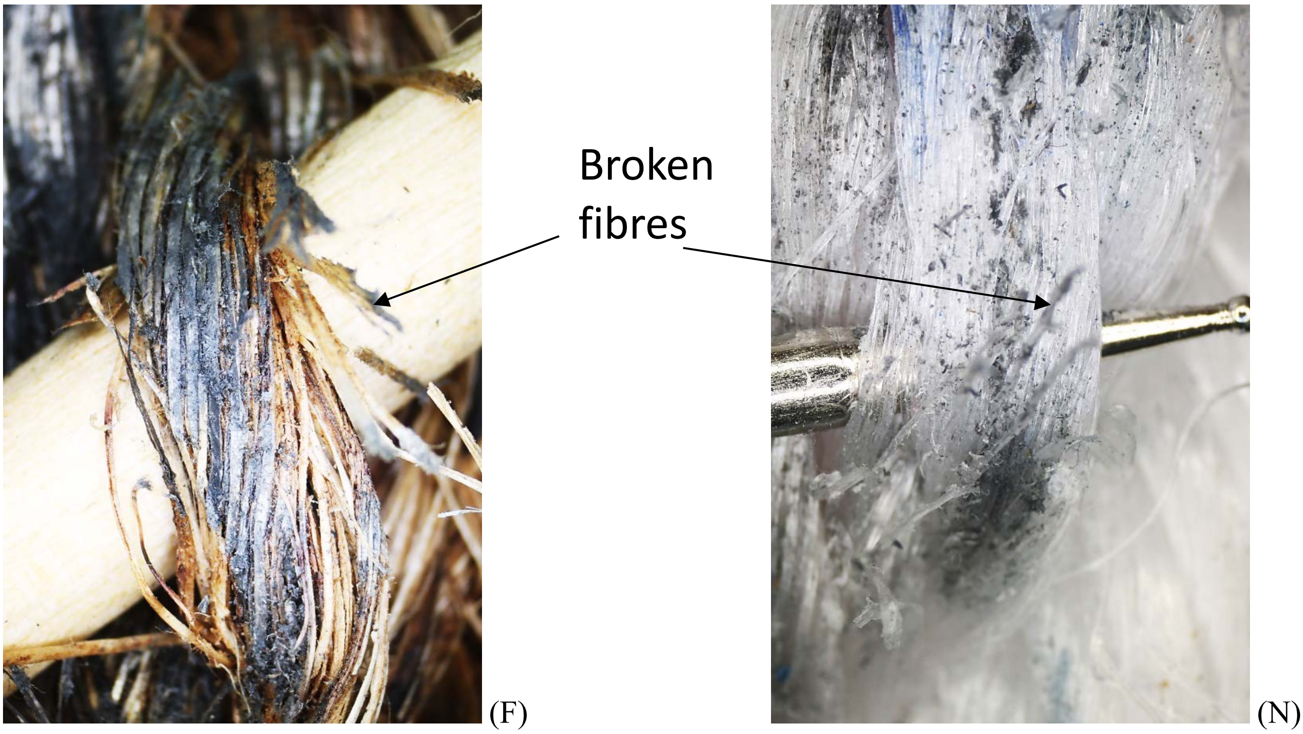
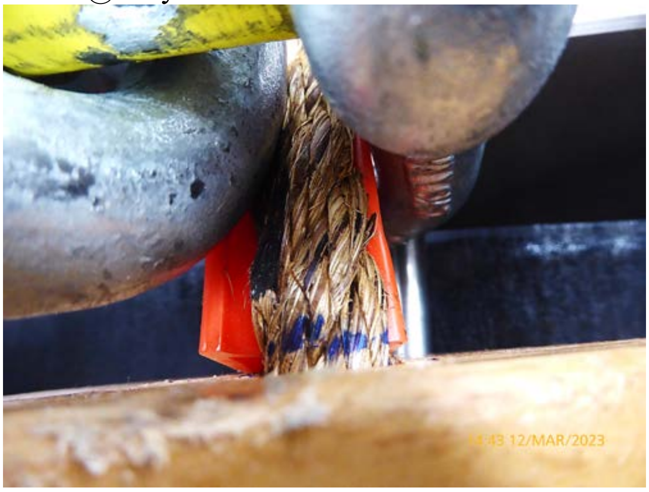


Figure 75 : Macroscope images of the worst worn strands from Manilla and the Polypropylene rope material.


@ 5 cycles


@10 cycles


@100 cycles

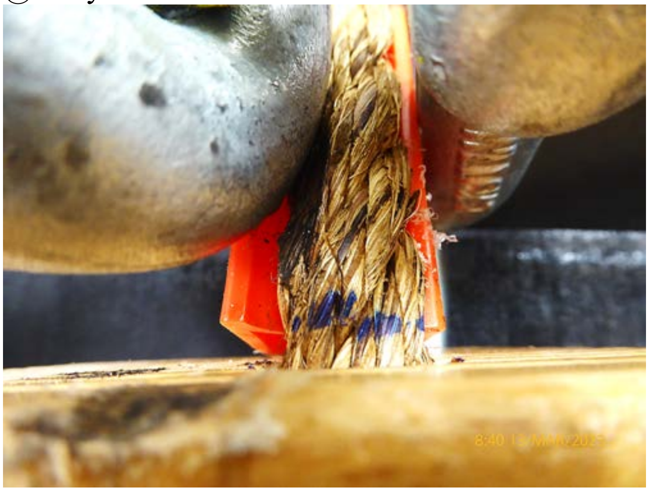

@1300 cycles

Figure 76 : Specimen G showing the progression of the rope wear during testing for 5 cycles (Top left), 10 cycles (Top right), 100 cycles (Bottom left), and 1300 cycles (Bottom right).

5. Discussion

nC² Engineering Consultancy have provided support to the International Maritime Pilots' Association (IMPA) through completion of a laboratory-based project to investigate the impact of various methods of securing of pilot ladders at intermediate lengths.

The work was divided into the following packages:

- WP1 Baseline testing – To determine the baseline response to loading of thimble secured lengths, with a range of materials.
- WP2 Slip/grip testing – To determine the slip/grip of various attachment securing methods to the ladder side rope pair and evaluate any resultant damage.
- WP3 'D'-Shackle testing – To determine the effect of cyclically loading D-shackles on the ladder components.

From WP1 it was confirmed that Polypropylene rope, under loading, extended twice the distance of the stiffer manila rope (Figure 18). Interestingly adding the steps to polypropylene ropes reduced the extension under load (Figure 19). It was shown that initial loading, where no pre-stretch has taken place, resulted in twice the expected extension (for both the man made and natural rope choices). There are no requirements (in BS ISO 799) for pilot ladders to be made from pre-stretched rope. An un-stretched rope could extend by 6% (permanent), given normal pilot ladders can be supplied as 1.0 m to 70.0 m in length* this might be an extra 4.2 m on the longest ladder (54 cm on a 9 m ladder).

In WP2 various attachment securing methods were tested. It was shown that the rolling hitch (when pulled tight first) gripped the rope tighter than the cow hitch. Upon repeated knotting and loading of the rolling hitch, in the same test location, the result was that the ladder pair became distorted and compressed (Figure 49 and Figure 50). Note, that if one was to undo a metal clip fixing this too would appear compressed. . Therefore, this compression alone (with no signs of wear) does not equate to a loss of strength or load bearing capacity of the rope.

The max loads reached within the WP2 testing of rolling hitch knots averaged to 2.2 kN (see Figure 44). Note that the static loads on one side of 9 metre ladder would be approx. 2.6 kN/2 = 1.3 kN (Figure 5). In the WP3 tests the max force was 2.8 kN (see Figure 6). In contrast the cow hitch knots failed to grip and instead slipped down the rope at loads less than 200 N. It can

* Marine Safety Suppliers: email to Nick Cutmore 13th Jan 2023

therefore be assumed that in service the cow hitch knot would slide until it reached the fixing, chock or step. No evidence was found to suggest multiple ‘slides’ caused any measurable wear of the ropes. However, the cow hitch knots were not tightened to significant forces within this testing, so the amount of damage to the side rope pair caused through loading of a cow hitch to >2 kN is not known. One can assume that it will depend on the resting position after sliding, the fixing material, and the design of the chock. There will be a combination of tightening of the cow hitch but also significant load transfer to the step assembly.

Interestingly it was noted that the two cargo straps appeared permanently deformed (set) after the 50 repeated tightening – whereas the securing ropes appeared fresh. Note that in WP3 the testing was semi-automated and so the test cycles were set at x1500 (c.f. x50 in WP2). The secondary issue with the cargo strapping was that inspection could only be made of the exterior wear protection layer – not the structural load bearing material within.

WP3 allowed testing of another securing method – the D-shackle. Clearly not intended to tighten on the side rope pair; it would slide along until it caught/wedged/stopped on a part of the ladder step assembly. Two D-shackles were tested (Figure 56) the large shackle was able to clear the fixing and chock and rested on the wooden step. The smaller shackle stopped at one of two locations:

- When a metal clip was present as the fixing – the smaller shackle impacted and stopped here.
- When a standard rope seizing was used the smaller shackle passed over this and wedged on the chock.

In all scenarios involving the D-shackle there was some form of damage to the rope ladder (Figure 62, Figure 65, Figure 67, Figure 69). This suggests that although an easy attachment to make there is some level of risk.

A significant part of the damage witnessed was caused by the D-shackle transferring its loading to the step assembly. Each side of each step assembly is designed to carry the weight of one pilot and their kit, preventing the step sliding down the ladder pair are the fixings (rope seizing or metal clips – see Figure 10). This work has shown that the metal clip is much more effective (under the dry conditions tested) at providing a clamping force to grip the rope pair. When the D-shackle was able to transfer load to a pilot ladder with rope seizing the step assembly migrated under the test loading (see Figure 69 and Figure 71). There is therefore a risk as the same would happen with a cow hitch knot that slid down into contact with the chock or step – it could load the step assembly rather than tighten about the rope pair.

The aims of this work did not include advising on the material used on pilot rope ladder however two (manila and polypropylene) were used as they represented the two most common materials. The work was also not examining the speed or efficiency of workers to create rolling hitch vs cow hitch knots. However, it was noted that cow hitches were 'easier' for the untrained worker to apply. Examining and ranking the options tested herein for securing pilot ladders at intermediate lengths revealed that D-shackles were the worst possible option, in that they created damage to the pilot ladder ropes.

6. Conclusions

Various experiments (not exhaustive) have been performed with an aim to better understand the issues surrounding the impact of various methods of securing of pilot ladders at intermediate lengths. The conclusions from this work are:

- Use of D-shackles under repeated fitting results in damage to the pilot rope ladder.
- The use of a correctly secured rolling hitch will squeeze and compress the ladder side rope pair between the steps. This will be proportional to the length of the ladder. However, without wear the rope should still be structurally sound.
- A cow hitch (rope or cargo strap) knot will slide until it reaches a stop point.
- Under the conditions tested, metal clips were demonstrated to be a more secure method of preventing step migration than rope seizing.
- If loads are transferred to the step assembly where rope seizing are used – there is a risk of step migration. This was demonstrated where D-shackles were present but there is a risk this would also occur when a cow hitch knot slid onto the assembly.
- Under a 10 kN tension of a rope pair:
  - Polyprop extended by 8-9%,
  - Manila extended by 4-5%,
  - Adding steps made them each slightly more ‘stretchy’,
  - No measurable effect of metal or rope/fibre fixing.

7. Recommendations

Following the meeting of the IMPA safety committee (22 May 2023) it was requested that clarity be given as to what practical advice can be drawn from this study to support IMPA recommendations for securing pilot ladders at intermediate length.

A summary of the findings from this work is given in Table 8, included within this is a final column commenting on the recommendation for use. Note that even the ‘best’ ranking solution tested had limitations/conditions of use. Notwithstanding the methods for securing pilot ladders considered in the Study, an alternative method may be the optimal solution for securing a pilot ladder at an intermediate length. A securing clamping or other device or mechanism specifically designed for the purpose and combining the favourable characteristics of the methods tested in the study could be the optimal solution. The favourable characteristics are:

1. The same or better holding performance as a rolling hitch;
2. None of the potential for damage to the structure and critical components of a pilot ladder caused by D-shackles; and
3. A D-shackle's ease of use (unconditional holding performance).

Table 8: Summary of findings from this study.

Method		Force achieved without slippage	Damage	Ease of use	Special considerations	Recommendations
D-shackle	27mm	2.8kN (maximum applied force)	Yes: to critical components of the pilot ladder	Very easy and quick	D-shackles may be considered an attractive securing option for personnel charged with rigging pilot ladders due to their ease of use. However, D-shackle use was demonstrated to transfer loading to the components of the step assembly resulting in damage to the structure and critical components of the pilot ladder.	Not recommended for use due to impact on ladder structure
	36mm					
Cow Hitch	Manilla, Polypropylene securing rope	<0.5kN (average)	No damage to the structure and critical components of the pilot ladder	Simple knot, low skill level	The cow hitch method did not damage the structure and critical components of the pilot ladder. However, the cow hitch method was demonstrated to deliver the worst holding performance of the three securing methods. The cow hitch always slipped, coming to rest on the step assembly – resulting in the undesirable situation where all the forces are concentrated on the step assembly.	Not recommended for use due to poor holding performance
	Lifting strap					
Rolling Hitch	Manilla, Polypropylene securing rope	2.2kN (average)	Signs of squashing and discolouration on side ropes, but no material damage was observed	Complex knot, high skill level. Requires a pre-load before use to ensure superior grip force	The rolling hitch method resulted in signs of squashing and discolouration on side ropes, but no material damage was observed. The rolling hitch demonstrated holding performance which was at least 77% better than a cow hitch. However, the superior performance of the rolling hitch is conditional on the knot being tied correctly and being pre-loaded before use. If either of these pre-conditions is not met, the rolling hitch has the holding performance of a cow hitch. Of the material combinations tested, the least effective holding performance (rolling hitch) occurs when both side ropes and secure ropes are made from polypropylene.	Recommended for use but holding performance is conditional