There is a growing desire on the part of operators to utilize 2nd and 3rd generation MODUs in deeper water, to take advantage of their wider availability and lower day-rates. Generally speaking, increasing the water-depth capability of an existing rig requires extensive upgrades to several operational areas, including the draw works, mud system, and buoyancy. These upgrades typically require 6-12 months in drydock and 10’s of millions of dollars in capex, particularly for the addition of high-buoyancy sponsons.

Because of the time and cost involved in a traditional drydock upgrade, many drillers and rig owners are exploring other options. Emerging technologies that can extend depth capability include new mud systems, artificial seabeds, and synthetic mooring lines. Many of these upgrades can be used immediately on existing rigs with minimal or no drydocking and relatively low downtime costs.

One such simple upgrade technology is the use of lightweight high-performance-fiber mooring lines as a replacement for much heavier steel wire rope. The use of synthetic fiber lines can greatly reduce the vertical loads on the rig, enable the use of existing winches in greater water depths, and/or increase the amount of available variable deck load. This is particularly important when drilling with older rigs in locations far from an established offshore logistical infrastructure. Environmentally induced offset can also be reduced, in part because of the higher fairlead angles possible with synthetics.

As with many other proposed new drilling technologies, actual field experience specific to MODUs is limited. The principal goals of the present study were to gain experience with one type of high-performance fiber rope, high-modulus polyethylene (HMPE). Specifically the study set out to identify handling issues with these types of lines, to verify their potential for weight savings, and to gauge their ability to withstand typical operational environments.

Abstract
This paper describes the deployment of a high-modulus polyethylene (HMPE) mooring insert line on the Scarabeo III MODU. Several new technologies are now available that can increase the maximum rated water depth of 2nd and 3rd generation drilling rigs. The purpose of this trial was to qualify one such technology, the use of lightweight synthetic fiber rope mooring lines. The desire to deploy and recover the lines on existing boats and equipment led to the selection of HMPE as the trial rope material. HMPE ropes are almost neutrally buoyant, have high abrasion resistance and exhibit a strength-to-diameter ratio similar to that of steel wire rope. The HMPE line used in the present study, a field-repairable Plasma® 12x12-strand braided rope, served without incident for 3 years. After damage was discovered at one of the rope terminations, the rope was returned to the manufacturer for re-termination and residual strength determination. The rope was also inspected and any damaged strands repaired prior to being returned to service. The study demonstrated the durability and ease of handling of these lines, in particular the 12x12-strand braid, for MODU mooring applications. The scope of the paper includes static mooring analysis, deployment procedures, mooring load data and residual strength data. Recommendations are made regarding deployment methods for synthetic ropes.

Introduction
There is a growing desire on the part of operators to utilize 2nd and 3rd generation MODUs in deeper water, to take advantage of their wider availability and lower day-rates. Generally speaking, increasing the water-depth capability of an existing rig requires extensive upgrades to several operational areas, including the draw works, mud system, and buoyancy. These upgrades typically require 6-12 months in drydock and 10’s of
trials with HMPE for anchor handling and installation lines.\textsuperscript{9} This paper discusses a trial of HMPE mooring insert and pendant lines begun in December 1997.

The use of lower-cost polyester (PET) fiber rope is generally preferred over HMPE for use in permanent production systems. In this case, e.g. with FPSs, the larger size (approx. twice the diameter of HMPE or steel) need only be accommodated one time, during the installation of the mooring lines. Concern about long-term (20-25 year life expectancy) creep behavior also generally precludes HMPE from consideration for permanent moorings.

In the case of predeployed MODU moorings, wire-sized HMPE may be a cost-effective alternative to PET. The additional equipment and storage space required for PET lines can only be handled by a small number of boats available today. The higher cost of HMPE ropes may be justified by eliminating the need for these larger, more specialized boats and equipment. In more isolated areas HMPE might be favored outright, as ropes would have to be installed using local boats and equipment designed for use with ropes similar in size to wire rope.

For MODUs that must carry their mooring package on board, the smaller and lighter HMPE fiber ropes are favored over PET. These ropes are already preferred for many other repetitive heavy marine applications where ease of handling and storage are important issues for the end user. Large HMPE lines are used extensively on ship-assist tugs, tanker moorings, barge transport, aquaculture nets and moorings, trawler nets and lines, heavy lift and specialty moorings. HMPE is favored over more traditional nylon and PET in these applications, even at higher cost, because of its much smaller size (close to steel on a diameter basis), higher abrasion resistance, and near-neutral buoyancy.

### Experimental

For this study and long-term multiple deployment trial, an unjacketed 80 mm diameter Plasma\textsuperscript{®} HMPE 12x12 braided construction was selected. Physical properties for the rope are shown in Table 1 along with 6-strand wire and chain used in the mooring system (PET is also shown for comparison). Braided ropes (12-strand or 8-strand) are preferred in most heavy marine applications because of their flexibility, ease of handling and storage, and simple field splicing of terminations. The 12x12 rope is a braided assembly of 12 smaller 12-strand braided sub-ropes. This construction allows the rope to be field repaired if one of the sub-ropes or strands is damaged.

A jacket was not used because it would greatly impair the operator’s ability to periodically inspect the rope for installation damage. In addition it was felt that damage to the jacket would likely require replacement or re-termination of the rope, so that the jacket in that case was superfluous and added substantial cost. The rope was terminated at each end with a permanently attached protective eared thimble and connecting link. The rope was overwrapped with a heavy-duty protective nylon fabric in the area of the termination.

In the design phase of the trial there was concern that the torque-balanced braided synthetic rope might be damaged by twist induced by the 6-strand wire rope onboard the rig. In order to investigate the magnitude of this effect, an 11.0 m section (6 m clear span) of 80 mm HMPE rope was loaded in series with a 21.3 m section (18 m clear span) of 77 mm 6x36 strand wire rope. Both sections were identical to components that were to be used in the mooring trial. Twist and elongation were measured in the HMPE rope over the center section using gage lengths of 3 m and 1 m, respectively, during cycling to 70, 120 and 180 tonnes. The wire rope section was then removed, and the HMPE rope was pulled to destruction at the same twist as observed at the 180 tonne load level.

### Pre-Trial Experimental Results

Minimum rated break strength of the 80mm HMPE rope is 430 tonnes. Break strength observed during lot testing was 470 tonnes. Table 2 shows the results of the twist testing. During cycling to 180 tonnes, maximum twist observed in the rope was 1.5 complete turns over the 3.0 m gage length. This represents a twist level of 0.5 turns per meter or 1 turn every 25 rope diameters. This twist level was maintained for destructive testing, in which the rope failed at 94% of the untwisted break load. At failure six of the twelve sub-ropes broke first, after which the rope remained intact.

Engineering modulus, \( E \), based on nominal rope diameter of 80 mm was estimated at 22 GPa at the maximum twist level, based on nominal rope diameter and pin-to-pin elongation measurements. This is somewhat lower than the estimated modulus of 25 GPa for the untwisted rope. Interpretation of pin-to-pin stiffness data was complicated by differences in clear span lengths and preloading conditions between the two samples.

### Field Installations

Saipem chose their 2\textsuperscript{nd} generation semi-submersible Scarabeo III as the test bed for the field trial. Scarabeo III was built in 1975, displaces 21,800 tonnes and has a variable deck load of 2500 tonnes while drilling. The rig typically operates in Mediterranean or West African waters and carries its own mooring system, deployed with the help of locally crewed workboats. Scarabeo III currently utilizes a 9-leg (3 legs at each of 3 corners) mooring system, each leg consisting of a recovery buoy, a 100-meter pendant line, a 15-tonne anchor, and 2000 meters of 76 mm diameter 6-strand wire rope. Original rated water depth capability of the rig is 450 meters.\textsuperscript{10} Saipem is working on a variety of technologies to increase the rated water depth to >600 meters.

During the trial period a 700-meter segment of 12x12 HMPE synthetic fiber rope was inserted into one leg of the mooring spread for Scarabeo III. A minimum load was maintained on the line to keep the HMPE line off of the seabed.

The well chosen for the initial deployment was Tuna NE1, one of a series of exploration wells offshore Egypt. Details of the mooring spread are shown in Figure 1. Water depth at the rig was 162 meters. After each of the rig’s 9 mooring legs...
was installed normally, leg #2 was raised for installation of the HMPE insert line. For this well, in order to retain the catenary restoring force for the rig, 250 meters of 3” K4 chain was added between the synthetic insert and the anchor.

To install the HMPE insert, the recovery buoy and pendant line were first used to bring the #2 anchor on board. The workboat then moved toward the rig as the rig wire was partially recovered. During this time the HMPE line was readied for deployment. The original installation plan called for a special chain link (supplied with the rope) to attach to the workwire on the workboat. For that reason the rope was shipped with the required connector at the top of the rope box for ease of access. Unfortunately because of a last-minute change in installation method the other end of the rope was needed. This required all of the rope (all 700 meters) to be paid out onto the deck of the boat prior to loading onto the working winch. (Although an awkward procedure, this would have been impossible with other types of rope.)

After getting to the appropriate connector, the rope was connected to the working wire on the main winch (see Figure 2) using a conventional square-end screw-pin shackle. The winch was then reversed and the soft rope loaded onto the main winch. In this first deployment the rope was wound on top of the working wire and connection hardware with no applied tension. Level winding was guided by hand, as shown in Figure 3. The corners and pin of the square end shackle was observed interacting with the soft rope during winding onto the winch.

Because of the existing wire rope underlay (Figure 2) and the low winding tension, all 700 meters of rope were not able to fit onto the working winch as originally planned. The remaining free end of the synthetic line was then attached to the rig wire (still held in the shark’s jaws). After determining that the shock load would not be detrimental to the rope, the captain released the shark’s jaws and allowed the rig wire (approx. 400 meters of wire) to sink rapidly. The remaining 50 meters of the rope were quickly pulled into the water and immediately the rope was put under load. Because of the rapidly applied load and the low winding tension, the rope momentarily dug into the top rope layer on the winch. [This is not uncommon or particularly harmful to a soft rope and is commonly observed in harbor tug operations. However, every effort should be made to wind ropes onto winches with an applied tension.] The rope was then rapidly paid out from the winch until all 700 meters had been overboarded except for the end termination, which was positioned in the shark’s jaw as shown in Figure 4.

The synthetic line was held in the shark’s jaws while the catenary chain was brought on deck and connected. Although this gripping method apparently caused no damage to the rope, it was a cause for concern. Several chain links could easily be added to each end of the rope for ease in gripping with shark’s jaws or other common deck handling grips. After the chain was connected, the chain, anchor, pendant wire and buoy were overboarded to complete the installation.

Anchors were tested to 100 tonnes. Line tensions were set to maintain position around a nominal working load of 58 tonnes. Data from the tension logs of each anchor leg are shown in Figure 5 for the Tuna NE 1 well.

The synthetic mooring line was also deployed without incident in wells “Kitina SM 4” and “Djambala M 3” off the coast of Congo, as shown in Figures 6 and 8. Water depths for these wells were 324 meters and 113 meters, respectively. Line tension records for the wells are shown in Figures 7 and 9. The Djambala well also saw the first use of HMPE pendant lines as piggyback anchor cables. After completion of the Djambala well, the 80mm HMPE line was moved to other Saipem vessels for trials involving other deepwater applications.

**Post-Trial Examination**

In December 2000, after 3 years of trial use, severe damage was discovered near one of the rope terminations. The rope was then shipped back to the Puget Sound Rope facility for inspection, re-termination and residual strength testing. The damage (cutting across all the strands) appears similar to damage caused by loading the rope across a sharp metal edge. The exact cause of the damage is still under investigation.

Two residual strength test samples were removed, one from each end of the trial rope. Figure 10 is a photograph showing the condition of one of the ropes as received. These ropes showed heavy surface abrasion, contamination by mud/soil, and residual twist – nothing unusual compared to typical used ropes returned from the field. Both samples had seen at least one incident of strand cutting damage (Figure 11) and one example of strand pull-out (Figure 12). Damage in braided ropes does not migrate away from the damage site as in twisted ropes. All the strands and twisted primaries in a braided rope are locked by the radial pressure and contra-helical structure.

New splices were put in the test samples prior to testing. The original termination (soft eye with a protective eared thimble with pear-shape connecting link) in the undamaged end was protected by a heavy wear fabric, and a visual examination showed it to be in better shape than the body of the sample. However, for safety reasons (to eliminate the possibility of flying metal during the strength test) the sample was re-terminated with a soft eye, to remove the thimble and connecting link.

The two samples were tested at their estimated as-received retained twist levels of 0.3 and 0.5 turns per meter. The break loads for the samples were 466 tonnes and 464 tonnes, respectively, very close to the 470 tonnes original new rope break strength and still well above the 430 tonne rated minimum break strength. Figure 13 shows the load-extension curve for one of the tests.

Modulus of the samples was estimated at 36 GPa based on crosshead extension. As stated previously, crosshead-based modulus data is influenced by splice length and pre-loading conditions, so data can be misleading. Even so, the higher modulus of the used samples is likely a result of the much higher number of “bedding-in” cycles seen by the rope during the field trial.

Note that in both samples at least one area of cut-strand...
damage was located in the clear span of the test sample yet this did not reduce the breaking strength of the rope. These cuts affected only 1 or 2 primary yarn bundles, which would at most reduce the strength by 2/144 or 1.4%. Loop-strands were located close to the ends of the test samples and so were incorporated in the splice region of the reterminated samples. Generally looped strands will be pulled back into the rope during testing to high load levels.

Discussion
As expected, torque from 6-strand wire rope imparted substantial twist to the single braid 12x12 HMPE ropes used in this trial. However, both laboratory testing and field residual strength data indicate that static strength levels in these ropes are not substantially reduced by applied twist, even at relatively high twist levels.

The static modulus of new rope was lowered by applied twist, but the modulus apparently increases again after further bedding-in that helps to relieve the load imbalance. Modulus of single-braid HMPE ropes may be reduced when in series with 6-strand wire ropes at very high loads, as half of the strands will begin to carry more of the system load. Although of minor importance for catenary systems, modulus changes could be significant for taut-leg mooring designs.

The effect of dynamic loading and cyclic twisting on fatigue performance could not be determined from the experimental portion of this trial. Mean loads were low (approx. 10% MBL), the load range was small, and the relative length of wire rope in series with the synthetic was not unfavorable. The ropes performed well during service, and no fatigue related damage was noted in either the synthetic or the 6-strand rig wires.

The distinction between static and dynamic twisting is an important one. While static twist appears to cause little degradation, the current literature describes dramatic fatigue damage in wire rope samples cyclically loaded in series with torque-neutral synthetic fiber ropes (which behave as near-perfect swivels). The damage appears to be the result of high-amplitude cyclic twisting at the connection point, and it is likely that this would also lead to premature failure of any connected synthetic rope. However, what is not clear is what amplitude of twisting would occur at the end of a long (>500 m) section of wire rope. Because of their much longer natural torsional periods, further testing may be necessary to demonstrate conclusively what properties of wire rope mooring lines make them susceptible to similar damage mechanisms.

The technique used in the present trial for inserting the HMPE rope into the catenary mooring was not found to be efficient for the operation. To set the mooring line, pull the anchor and install the insert required 2-3x more time than normal. More efficient methods, such as direct deployment from the rig winches, need to be investigated.

Results of a static mooring analysis of the Tuna NE 1 well are shown in Table 3, which compares observed vessel tension with the equivalent tension required to achieve the same horizontal restoring force. Line tension reductions in the analysis are less than 5% because of the relatively shallow water depths and the position of the line in the mooring leg. In deeper water, or where the synthetic insert begins closer to the fairlead, a significant tension decrease would be expected because of the increased fairlead angle, a second beneficial result of the reduced self-weight of the insert line.

The mooring analysis shows that for all three wells, the HMPE line was largely horizontal and lying close to the seabed during the deployment. Unfortunately the major benefit of synthetic lines comes with their use in more of a vertical direction. Water depths for these deployments were not sufficient to take advantage of the benefits of the synthetic line.

The loads seen by the rope during this trial period were very mild. Only during anchor proof loading did the load on the ropes approach 20% of the breaking load of the rope. Normal service was in the range of 10-15% of the MBL. Thus it was not possible to make observations relative to high-stress phenomena such as creep during the trial period.

The rope exhibited good overall resistance to the marine environment and typical handling conditions associated with MODU mooring line deployments. However, the relatively low line loads and shallow water depths seen in much of the trial did not fully test the rope from an operator’s standpoint. The data collected during the trial up to this point is therefore not considered sufficient to completely understand the behavior of the line, particularly under high load conditions. Further trials are planned in other, perhaps more demanding applications after inspection and re-termination of the rope.

Recommendations
The following observations were made during the deployment of the HMPE mooring insert:

Installers should consider what length of line easily fits on the available winches. The 700-m segment used in this trial was found to be slightly too large for most anchor handling tugs when existing work wire volume was considered. Winch volume constraints can be particularly important if methods for line tensioning and level winding during winch loading are not available.

The use of conventional screw-pin shackles should be avoided when such connection hardware is to be wound onto winch drums concurrently with the rope. The sharp edges of the pins were observed on the winch causing abrasion damage and pulled strands, both in steel wire ropes and synthetic ropes. Rounded connectors such as kenter links should be considered in place of screw-pin shackles.

Installers should continue to develop techniques for holding synthetic ropes while connecting to other line segments. Although no damage from shark’s jaws was observed in the present trial, there is sufficient concern given the nature of the gripping method. Synthetic rope terminations should include several permanently attached chain links to allow for holding the rope in shark’s jaws or other deck fittings.

The interaction of HMPE lines and steel surfaces under high stress should be avoided. Even underwater, interaction
can cause heat generation and abrasive damage to the HMPE. For example, a standard J chain chaser should be used only with extreme care when using HMPE mooring lines. In shallow water wells, care must be taken to avoid the possibility of HMPE lines floating on the surface and interfering with workboat thrusters.

Conclusions
The benefits of using HMPE fiber ropes include near-neutral buoyancy, strength comparable to steel, ease of handling and storage, and long storage life (not subject to corrosion or aging). For this reason a trial program was initiated by Saipem to investigate the potential for using these lines in drilling and other applications.

This trial program has verified that HMPE synthetic fiber ropes are a viable technology to help increase the water depth capability for 2nd and 3rd generation MODUs. A 700-meter segment of 12x12 braided HMPE rope was inserted into one catenary mooring leg of the Scarabeo III MODU during several drilling operations over a period of 2 years. The rope demonstrated high tolerance to real world operating conditions, even when deployed repeatedly on the same equipment normally handling wire.

Although the trial was successful, several potential areas of concern have been identified. Contact between steel surfaces and HMPE ropes can damage the lines during deployment, particularly when under tension. Some standard practices, such as gripping in shark’s jaws and the use of J chain chasers, may need to be modified when handling synthetics. The line insertion technique used in this trial increased the anchor-leg mooring time 2-3x and is not considered practical for rapid rig movement. The possibility of floating lines must also be considered when using HMPE. Finally, personnel involved in the deployment and recovery of synthetic lines should be trained in the benefits and limitations inherent in their use.

The reduction in vertical load from reduced self-weight of the mooring line matched predictions, however water depths in which the rig operated and position of the insert line precluded substantial reduction in line tension. Line tensions during the deployments were low compared with the breaking strength of the rope. Because of the low mean tensions and primarily static loading, data collected from this trial were considered insufficient to understand the long-term mechanical behavior of the material. Additional trials with the rope are planned.

Acknowledgements
The authors would like to thank The Cortland Companies and Saipem and its subsidiaries for making this program possible. This trial owes its success to many individuals, but in particular to Dick Ryan of Puget Sound Rope and Carlo Saggini of Saipem.

References

Imperial Unit Conversion Factors

<table>
<thead>
<tr>
<th>Imperial Unit</th>
<th>Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>3.280 840</td>
</tr>
<tr>
<td>mm</td>
<td>3.937 008</td>
</tr>
<tr>
<td>tonne</td>
<td>2.204 623</td>
</tr>
<tr>
<td>GPa</td>
<td>0.145 038</td>
</tr>
<tr>
<td>in</td>
<td>3.937 008</td>
</tr>
<tr>
<td>kips</td>
<td>1.000 000</td>
</tr>
<tr>
<td>Mpsi</td>
<td>1.450 382</td>
</tr>
</tbody>
</table>

TABLE 1 - MOORING COMPONENT MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>Mooring Component</th>
<th>Nominal Diameter (mm)</th>
<th>Minimum Break Load (tonne)</th>
<th>Weight In-Air (kg/m)</th>
<th>Weight In-Water (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4 Chain</td>
<td>76</td>
<td>600</td>
<td>128</td>
<td>110</td>
</tr>
<tr>
<td>6-strand wire</td>
<td>77</td>
<td>380</td>
<td>24.7</td>
<td>21.5</td>
</tr>
<tr>
<td>12x12 HMPE</td>
<td>80</td>
<td>430</td>
<td>3.9</td>
<td>-0.2</td>
</tr>
<tr>
<td>PET (ref)</td>
<td>132</td>
<td>500</td>
<td>13.3</td>
<td>3.4</td>
</tr>
</tbody>
</table>

TABLE 2. ROPE-WIRE INTERACTION TEST RESULTS

<table>
<thead>
<tr>
<th>Rope Condition</th>
<th>Static Load, T</th>
<th>Load Ratio (W:S)</th>
<th>Equilibrium Twist, tpm</th>
<th>Twisted Break Load, T</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>470</td>
</tr>
<tr>
<td>New</td>
<td>70</td>
<td>3:1</td>
<td>0.33</td>
<td>n/a</td>
</tr>
<tr>
<td>New</td>
<td>120</td>
<td>3:1</td>
<td>0.42</td>
<td>n/a</td>
</tr>
<tr>
<td>New</td>
<td>180</td>
<td>3:1</td>
<td>0.5</td>
<td>443</td>
</tr>
<tr>
<td>Trial</td>
<td>60 (nom)</td>
<td>approx 1:1</td>
<td>0.3</td>
<td>464</td>
</tr>
<tr>
<td>Trial</td>
<td>60 (nom)</td>
<td>approx 1:1</td>
<td>0.5</td>
<td>466</td>
</tr>
</tbody>
</table>

TABLE 3. MOORING ANALYSIS RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HMPE</th>
<th>Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Load (T)</td>
<td>182</td>
<td>188</td>
</tr>
<tr>
<td>Horizontal Load (T)</td>
<td>411</td>
<td>411</td>
</tr>
<tr>
<td>Vessel Tension (T)</td>
<td>450</td>
<td>452</td>
</tr>
<tr>
<td>Fairlead Angle,°</td>
<td>67</td>
<td>66</td>
</tr>
</tbody>
</table>
Fig. 1 - Mooring Layout for well Tuna NE 1

Fig. 2 - Main working winch for the workboat. Existing wire rope underlay prevented complete loading of the 700-meter 12x12 HMPE synthetic rope.

Fig. 3 - Crewman level-winding the synthetic rope by hand during loading onto the main winch. The rope was wrapped on top of the existing wire and connecting hardware.

Fig. 4 - Capture of the rope termination in the shark's jaws. The addition of several chain links to the termination would provide a more suitable means of gripping the rope.

Fig. 5 - Line Tension Data for well Tuna NE 1

Fig. 6 - Mooring Layout for well Kitina SM-4
Figure 7. Line Tension Data for well Kitina SM-4

Figure 8. Mooring Layout for well Djambala M-3. HMPE pendant lines served as piggyback anchor legs during the deployment.

Figure 9. Line Tension Data for well Djambala M-3. Any reduction in overall line tension because of the synthetic insert was not large compared to weather-induced variation in mean tensions between mooring legs.

Figure 10. 80 mm diameter 12x12 Plasma rope sample as received from Saipem at the end of the trial period. Note the residual twist from connection with the 6-strand wire rope. Note also the general rough appearance and surface abrasion. Two samples were cut from the trial rope and re-terminated for residual strength testing. After 3 years of intermittent oilfield service this rope retained 99% of its original breaking strength.
Figure 11. Example of strand cut damage in the body of one of the residual strength samples. Although the damaged fiber area appears large, only two primary strands (out of 144 total) on the rope were completely severed.

Figure 12. Example of strand pull-out damage in the body of one of the residual strength samples. Pulled strands such as these typically are pulled back into the rope at high loads.

Figure 13. Residual strength test results for one of the 80 mm diameter 12x12 HMPE trial rope samples. Testing was conducted at West Coast Wire Rope & Rigging, Seattle, Washington.