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Failure of a Climbing Treestand Due to Corrosion and Selective Leaching of Cable's Galvanic Layer: Failure Analysis and Experimental Study

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Abstract

Both supporting cables of a climbing treestand failed when a user stepped onto the stand's foot platform. Analysis of the failed cables revealed extensive corrosion and selective zinc leaching of the galvanized steel cables due to an electrical connection between the treestand cables and the steel frame. Experimental measurements of corrosion rates were performed through accelerated immersion tests utilizing mass-loss and DC current measurements as well as cyclic voltammetry. Results indicated a ~79% to 300% increase in the rate of corrosion as measured by millimeters of cross-sectional area reduction per year. Flaws in the design that led to the creation of a galvanic cell between the treestand cable and its frame are discussed, and alternative designs are proposed. Finally, the manufacturer's failure to properly account for anticipated use environment of the treestand in its design while being aware of similar prior incidents as well as their over-reliance on warnings are presented.

Keywords

Treestand, design defect, steel cable failure, galvanic corrosion, cyclic voltammetry, forensic engineering

Introduction

Hunters often utilize a variety of equipment to augment their experience. One such piece of equipment is a treestand — a platform affixed to a tree that allows the hunter to take an elevated position (typically between 15 and 30 feet above the ground). Treestands are commonly utilized to allow hunters to ambush their prey at short ranges, making the use of bows and other short-range or less-precise weaponry more viable. According to conducted marketing research, treestands are utilized by around 87% of hunters in North America, making it one of the most-used pieces of hunting equipment[1,2].

A treestand typically consists of a two-by-two-foot platform seat with straps and cords that affix the device to the trunk of the tree. Treestands come in a variety of distinctive styles and configurations. Fixed or hang-on treestands utilize straps, chains, and/or serrated metal teeth to secure the stand to the trunk of a tree. To reach a fixed stand that has been previously set up, hunters use climbing sticks that they insert into the trunk of the tree. Ladder stands, on the other hand, provide the user with a ladder they can use to reach the stand platform. These stands offer greater stability because the load is carried by the ladder and the tree. Another commonly used variant is the climbing treestand. These two-piece stands (consisting of a foot-platform and a seat-platform) allow users to ascend the tree by wrapping the stand's cables around the tree trunk and moving one piece at a time until they reach their desired height.

According to the U.S. Consumer Product Safety Commission (CPSC), between 2005 and 2007, a total of 41 treestand-related deaths were reported, and 19,000 treestand-related injuries were estimated to have occurred[3]. In addition to this high incidence of injury, researchers have found that falls from treestands have become the leading cause of hunting-related injury[4]. For example, over a 10-year period in the state of Ohio, it was reported that around 50% of hunting-related injuries were due to falls (with 93% of these being falls from treestands) while only 29% resulted from gunshot wounds[5]. In 2014, the Indiana Department of Natural Resources reported that in 182

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reported hunting accidents over a five-year period, 55% involved falls from a treestand[6]. A report by the CPSC found that nearly 40% of reported treestand incidents were due to a problem with the treestand[7]. Of those who fell from a treestand, 80% were noted to have required surgery, and 10% experienced permanent neurological disability or death[8]. Based on the above information, it is clear that falls from treestands present a significant hazard to the average hunter.

Treestands are known to experience failure from a variety of mechanisms. For example, the plastic deformation or fracturing of the load-bearing sections of a treestand can result in loss of load-bearing capability, causing the user to fall to the ground. Repeated usage can gradually induce fatigue in the load-bearing components, which can reduce the load-bearing capacity of the treestand to the point where normal operation can result in failure. Treestands that rely upon supporting cables or chains can have these components snap, resulting in the stand and its user falling. A treestand and its load-bearing components can also experience excessive corrosion, which renders the stand unfit for use. The mechanism (whether chains, straps, or serrated metal teeth) engaging the stand to the trunk of a tree may also experience failure, leading to the stand disengaging from the tree.

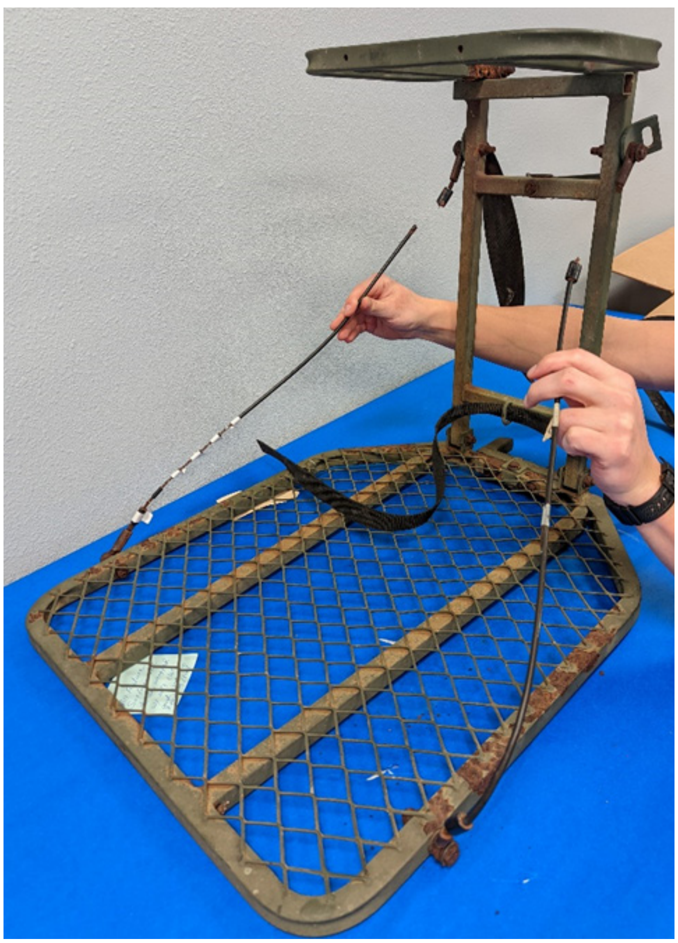

Figure 1
Image of the subject treestand taken by the authors.

Incident Background

The plaintiff of this case was a 5'10" male weighing approximately 225 pounds. Following his initial purchase of the treestand, the plaintiff kept it in its box, and stored it in his garage for two years. Following this two-year period, he unboxed the treestand and affixed it to a tree on a hunting ranch in close proximity to the South Carolina coast — where it was left on the tree for three hunting seasons. Afterward, the treestand was noted to have been taken off the tree and stored in his garage for one year, after which he affixed the treestand on the tree once more. Two weeks before the subject incident, the plaintiff climbed up to the treestand to verify it was fit for use. According to his testimony, he then sat down in the treestand and determined it to be in a reasonably safe condition. During the evening of the incident, the plaintiff used the climbing sticks affixed to the tree to climb up to the treestand. As soon as he put both feet on the foot platform and attempted to attach his safety belt, the supporting cables snapped, sending the plaintiff falling toward the ground and resulting in him becoming paralyzed from the neck down.

Subject Treestand

The subject treestand was a fixed treestand marketed by a U.S.-based manufacturer. Discovery documents, however, revealed that the treestand was actually designed and manufactured in mainland China, and the U.S. manufacturer was a shell company that falsely advertised the stand as being made in the United States. The treestand was comprised of a foot platform and a seat platform that were both connected to a vertical support (**Figures 1** and **2**).

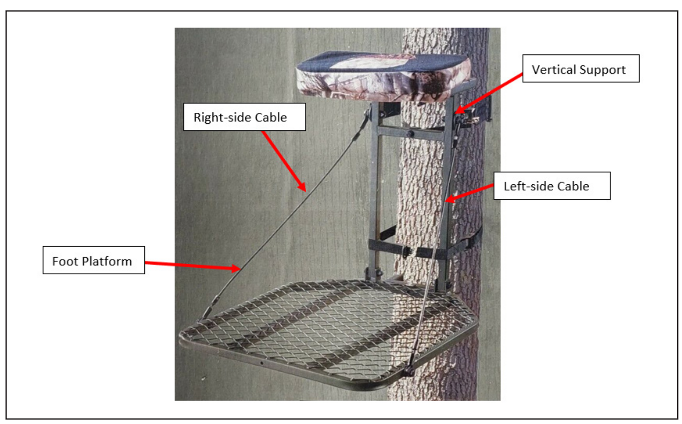

Figure 2
Image of a treestand from the owner's manual, labeled to show the components of the subject treestand.

The vertical support and seat platform are able to fold flat against the foot platform for easy transport. Two galvanized steel cables support the weight of a person standing on the foot section when unfolded.

According to the manufacturer's documentation, the treestand frame was made of Q195 steel with a stated yield strength of 340 MPa, tensile strength of 425 MPa, and "percent elongation" of 39%. A certificate of quality was provided with the raw steel used in manufacturing, verifying that the steel met the above mechanical properties. However, the manufacturer's documents did not state the type, grade, make, or quality of the galvanized steel utilized in the construction of the cables. In addition, a quality certificate for the galvanized steel cable was not provided.

Observations Regarding the Nature and Sequence Of Cable Failures

The two galvanized steel cables that support the foot platform were found to have separated at their connection points to the vertical support (**Figure 1**). Evidence of corrosion was observed on the cables, the cable eyelets, and their attachment bolts.

The left-side cable also failed adjacent to the eyelet in the segment between the copper crimp and the eyelet (**Figure 3**). The right-side cable failed near where it connects to the frame's vertical support. The right-side cable broke between the copper crimp and the plastic-coated section of the cable (**Figure 4**). Brittle fracture failure of the right-side cable occurred immediately adjacent to the copper crimp near the vertical support (**Figure 4**).

Near the foot platform, the right-side cable eyelet is

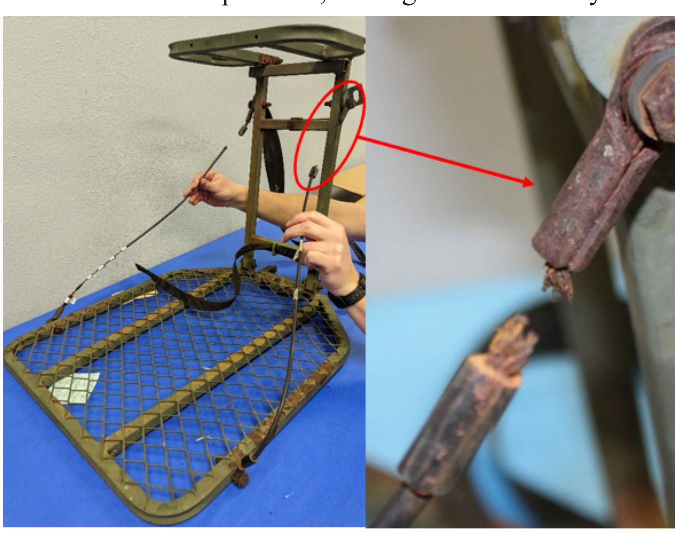

Figure 3
Failure location on the left-side cable.

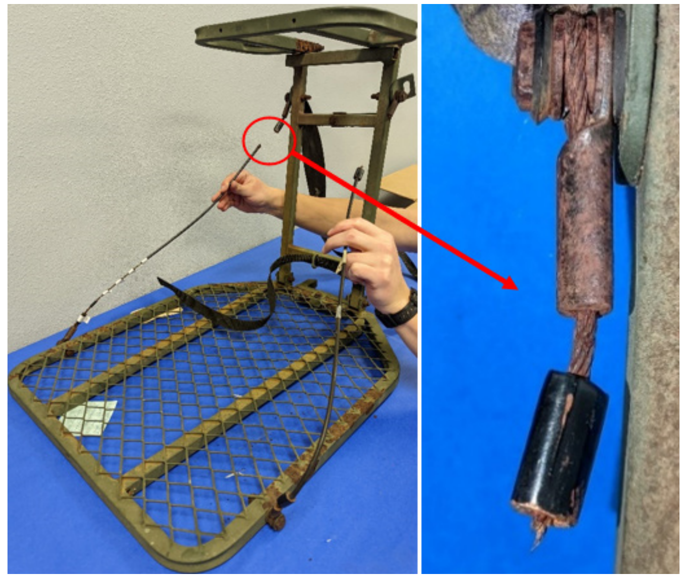

Figure 4
Subject treestand showing failure location of the right- and left-side cables.

attached backward, which likely introduced additional bending stresses on the cable at the area next to the eyelet. This segment of the cable between the eyelet and the copper crimp showed moderate signs of fraying attributable to ductile overload, as evidenced by the elongated fractured tips of the individual wire strands in the frayed area (**Figure 5**). As evidenced by the ductile nature of the individual strand failure, the fraying observed in the segment of the cable between the crimp and eyelet near the foot platform was limited to the loading experienced during the failure event due to overload and not a condition that pre-existed the failure.

Figure 5
Right-side cable foot platform attachment and the frayed segment between the eyelet and crimp with focus on elongated stands, characteristic of ductile failure.

Based on the analysis of the right- and left-side cables, it was determined that the failure of the cables did not occur simultaneously. The failure of the left-side cable likely occurred first due to corrosion degradation and loss of strength in the cable segment between the eyelet and copper crimp, as shown in **Figure 3**. The corrosion degradation and the ensuing loss of strength in the failed segment of the left-side cable are evidenced by the fact that the cable segment adjacent to and below the crimp — having one-half of the cross-sectional area as the failed area and subjected to the same forces — did not fail.

Following the failure of the left-side cable, the right-side cable was subjected to dynamic loading that resulted in brittle failure of the right-side cable at the segment adjacent to and just below the copper crimp due to the small cross-sectional area of the cable combined with stress concentration effect of the copper crimp at this location (**Figure 4**). Additionally, this dynamic loading of the right-side cable, following the failure of the left-side cable, is evidenced by the fraying of some wire stands near the foot platform, as shown in **Figure 5**. Further evidence of dynamic loading of the right-side cable, following the failure of the left-side cable, can be seen in the brittle fracture of the cable coating next to the failed cable segment as well as outward bending of the cable segment between the copper crimp and the eyelet (**Figure 6**).

Mechanisms of Corrosion

Corrosion is the degradation of a material due to chemical reactions on its surface. A common example is the exposure of iron to an electrolyte (such as water), resulting in chemical reactions that reduce the iron to iron-oxide (common rust)[9]. While coatings such as paint or powder coating can reduce the corrosive effect of a medium on steel components, more effective methods include galvanization and alloying with more noble materials (stainless steel)[10].

It is well known that corrosion significantly reduces a steel component's cross-sectional area and reduces mechanical properties, such as fracture toughness and yield strength, which can result in failure of components at or below normal and expected operating loads[11-14].

Figure 6
Signs overload on the left-cable eyelet attached to the foot platform and signs of brittle failure of the polymer coating.

Galvanic corrosion refers to a type of corrosion caused by the coupling of two dissimilar metals. When two metals with different galvanic potentials are connected in a manner that allows for the flow of electrons from one material to the other, a galvanic cell is created. In this cell, the material with the more negative potential plays the role of the "anode," while the material with the less negative potential plays the role of the "cathode" in the galvanic cell.

The anode liberates electrons from itself, which are then transferred over to the cathode in order to provide these electrons for the chemical reactions that are spontaneously occurring on the cathode's surface. In effect, this arrangement causes the anode of the galvanic cell to corrode preferentially while the cathode is protected[15,16]. The galvanic series (**Figure 7**) illustrates the average galvanic potential of a variety of engineering materials, providing

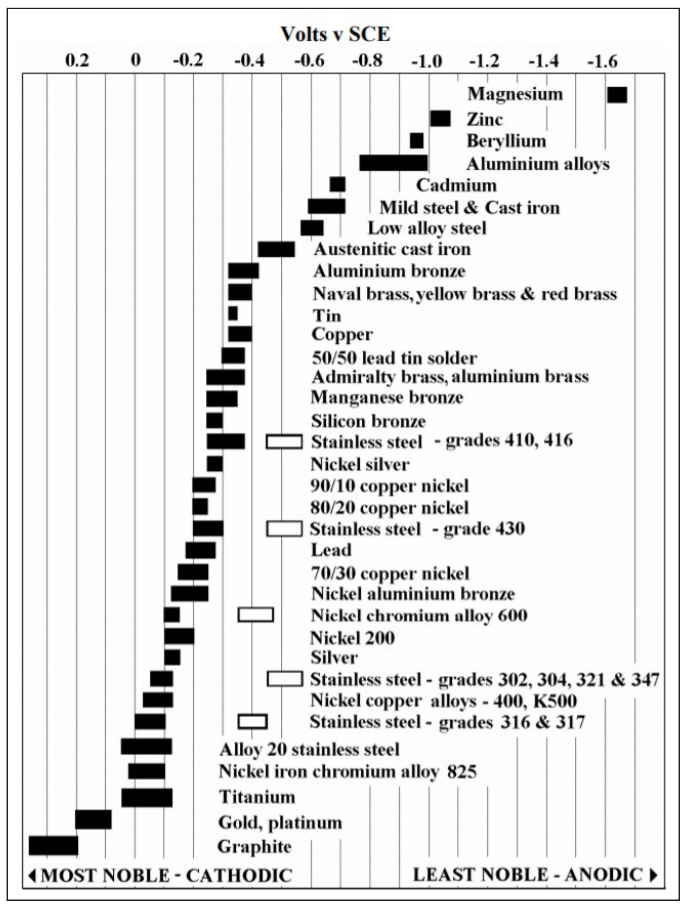

Figure 7
Galvanic series, showing the electrochemical potential of various materials.[17]

insight into which materials in a couple would act as an anode and which would act as a cathode.

Galvanization is the process of coating iron or steel with a layer of zinc in order to provide increased protection against corrosion[18]. Due to its relatively more negative galvanic potential, the zinc will preferentially corrode and protect the nearby or underlying iron or steel from degradation. However, over time, this zinc layer will be depleted, leaving the underlying steel susceptible to corrosion. An illustration of the galvanic connection between zinc and steel is shown in **Figure 8**.

Should a galvanized component be connected to more cathodic material, selective leaching of the zinc coating will occur. The zinc coating will liberate electrons and suffer from degradation to provide the driving voltage for the corrosion reactions that occur at the site of the cathodic material. In addition, the more corrosion-active sites on materials like steel greatly increase the electron drawn from the anodic material. Not only is it now having it protect this new material, but it is also having to do so at a greatly accelerated rate — far beyond what was intended in its design.

Another potentially more damaging form of corrosion is crevice corrosion. In general, crevice corrosion refers to corrosion of a material due to stagnant electrolyte (such as water) in a restricted environment or "crevice." The corrosion reactions, which occur over time, gradually alter the chemistry of the entrapped electrolyte. This can take the form of the depletion of oxygen, acidification of the electrolyte due to corrosion byproducts, destruction of protective layers, or the buildup of aggressive ions.

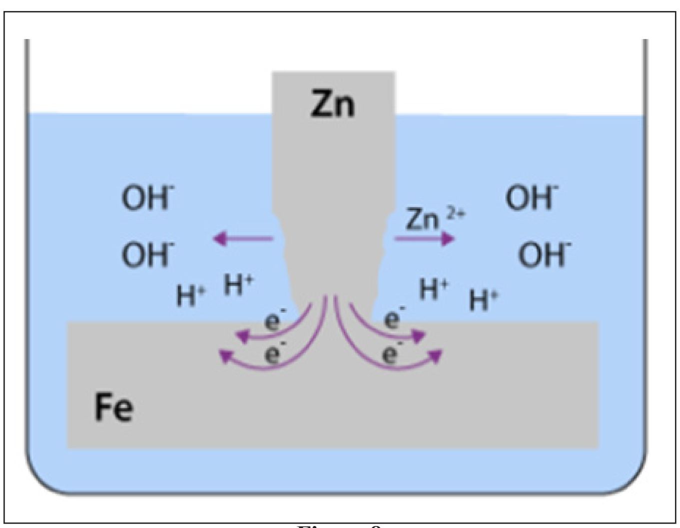

Figure 8
Galvanic corrosion of zinc and steel.[19]

The most common form of crevice corrosion is a differential oxygen corrosion cell — where the oxygen in the crevice is depleted over time, causing the crevice to become an anode in a galvanic cell with parts of the material not subjected to this crevice environment[20]. The other most commonly recognized form of crevice corrosion is the acidification of the crevice environment. This typically works alongside differential oxygen corrosion and results in the reduction in the pH of the local environment, causing corrosion to occur more rapidly due to the abundance of corrosive ions.

Cable Analysis

The subject cable was made from $^{1}/_{8}$th-inch 7-7 galvanized steel cable. Due to its lower electrical potential and zinc's passive oxide layer's lower inherent susceptibility to corrosion, this zinc coating protects the underlying steel from corrosion.

Minimal sectioning of the subject cable's black polymer coating revealed iron oxide (rust) underneath the plastic-coated section (**Figure 9**). The galvanized zinc coating was noted to be depleted as such corrosion could only have occurred after a substantial portion of the zinc coating was depleted.

In order to determine the amount of zinc depletion at various locations along the subject cable, the surface elemental composition was analyzed at six different sections through energy-dispersive x-ray spectroscopy (EDS). Individual wire samples were carefully extracted from these locations and subject to the EDS analysis. The results from the EDS are shown in **Figure 9**.

As seen in **Figures 10** and **11**, the average percent composition of zinc decreased as samples were taken closer to the foot platform. This phenomenon is consistent with the zinc being selectively leached by the cable eyelet, copper crimp, uncoated wire, and foot platform.

The cables on the subject treestand were bolted onto the foot platform through the cable eyelets (**Figure 12**). Although three plastic washers were used to separate the bolt, eyelet, and foot platform, an electrical connection was still present between the bolt threads and edge of the

Figure 9
Iron oxide (rust) present underneath the subject cable's plastic coating.

frame's square tubing. This configuration allowed the galvanized cable to be electrically connected to the eyelet, screw, and to the frame of the treestand itself. This connection allowed for the creation of a galvanic cell, which then caused selective depletion of the zinc from the galvanized steel wire near its connection to the vertical support.

	# of EDS Readings	Average % Zinc	Maximum % Zinc
WS1	13	0.26%	1.10%
WS2	15	11.93	29.20%
WS3	9	12.28%	32.20%
WS4	7	15.29%	44.10%
WS5	12	27.38%	64.10%
WS6	9	33.88%	72.40%

Figure 10
Variation of zinc content on the subject cable as a function of distance from the frame (WS1 closest to frame; WS6 farthest from the frame).

Figure 11
Limited sectioning of the subject cable's black polymer coating to expose wire stands and to measure zinc content in the cable.

Figure 12
Connection between the foot platform and left-cable eyelet on the subject treestand.

The bolts connecting the cable eyelets the to the vertical support of the treestand have 55 mm of thread — around 10 mm longer than the bolts used on the foot platform, which provides more surface area for corrosion to occur on and accelerate the depletion of the cable's zinc coating. It can also be seen that a bracket intended for use with the tree strap is affixed to these bolts. While washers are present at this connection as well, there is no washer separating the bolt nut and vertical support (**Figure 13**). This results in an enhanced electrical connection between the treestand and galvanized cable, further accelerating zinc depletion. It is likely that the increased corrosion of these nearby components caused more rapid dealloying of the galvanized steel cables, which resulted in the cables failing near their attachments to the vertical support where the cable's degradation and loss of nominal strength was greatest.

According to the owner's manual, one is intended to use washers as shown in **Figure 14**. However, there are no warnings in the owner's manual (or on the treestand itself) that warn a user of the danger associated with not placing the washers on correctly. Even if a user installed

Figure 13
Connection between the vertical support and left-cable eyelet on the subject treestand, displaying the direct coupling of the nut and frame.

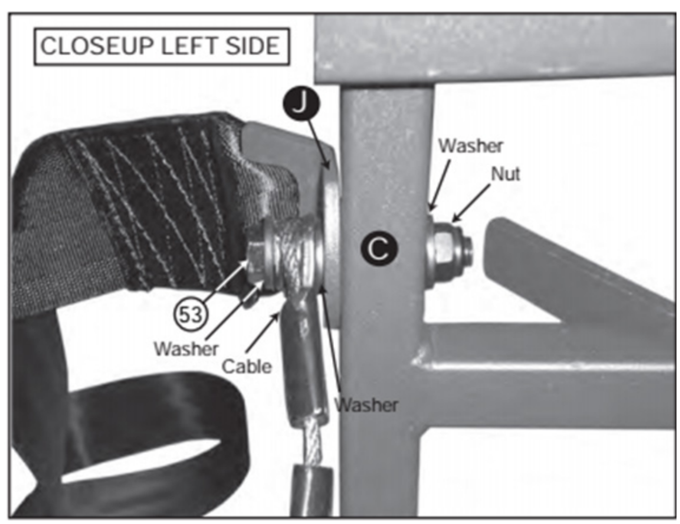

Figure 14
Diagram from the owner's manual showing how to assemble the vertical support connection.

the washers exactly as shown in the owner's manual, the lack of an additional washer behind the bracket allows yet another large piece of metal to be electrically connected to the galvanized cable and provide an even larger surface for contact with the vertical support, enhancing the strength of the electrical connection and thus the rate of corrosion[21].

It is well known that relatively small anode-to-cathode area ratios will corrode significantly faster at the anode than relatively large anode-to-cathode area ratios[21]. For the subject cable, the relative surface area of the exposed galvanized steel was significantly smaller when compared to the large surface area of the exposed surface on the bolt, eyelet, and treestand frame. As a result, the protective zinc coating of the galvanized cable depleted at a significantly higher rate in order to protect all the components it was connected to.

Both the right- and left-side cables were fitted with copper crimps that secured the cable around each eyelet. As shown in **Figure 15**, copper has a less negative electrical potential than both steel and zinc, meaning that both of these metals (when in contact with copper) will preferentially corrode to protect the copper piece.

The American Galvanizers Association (AGA) states that rapid corrosion of zinc may occur if there is contact between galvanized materials and copper with the two metals being considered incompatible in a marine atmosphere environment — much like the one present in the subject incident due to its close proximity to the shore[23]. The AGA states that precautions should be taken to prevent electrical contact between the two metals.

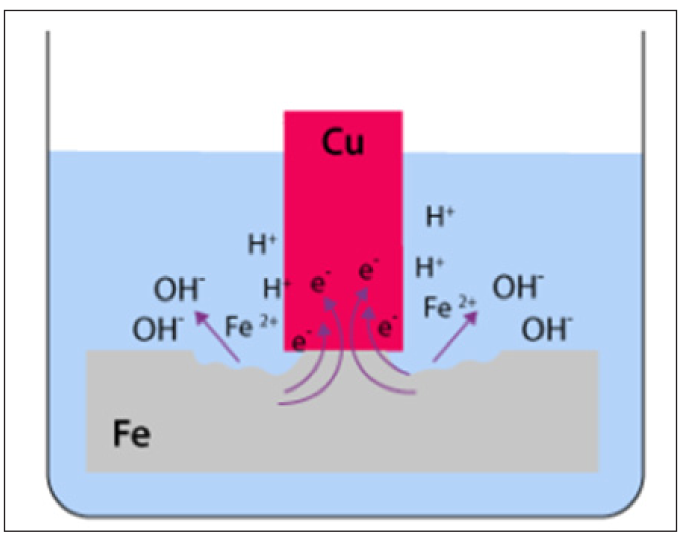

Figure 15
Galvanic reaction resulting from the coupling of copper and iron.[22]

By using copper as their crimping material, the manufacturer introduced yet another galvanic coupling of the cable material to a dissimilar metal, which caused the zinc layer on the subject cables to corrode faster than it would have due to its connection to the steel alone. After the zinc layer was sufficiently depleted, this would then accelerate the corrosion of nearby steel wire stands and significantly increase the likelihood of cable failure.

Stagnant water, which accumulated in the cable wire ropes (due to the ends of the cables being exposed), was the electrolyte through which corrosion was facilitated. It is likely that crevice corrosion within the coated sections of the wire ropes played a role in their degradation. Even so, a greater degree of zinc depletion noted closer to the eyelet — with the greatest depletion occurring on an exposed section of the wire as well as the wire rope failure occurring at these exposed sections as well. These facts indicate that, more likely than not, crevice corrosion was not the driving factor in the observed corrosion and that a galvanic cell was responsible for the initial depletion of the zinc layer, allowing for severe corrosion to occur on the exposed wire ropes and ultimately resulting in the failure of the supporting cables.

Accelerated Corrosion Testing

In order to quantify the degree to which the coupling of the galvanized steel cable with the treestand increased corrosion, accelerated corrosion testing was performed on an exemplar treestand from the manufacturer (**Figure 16**),

Figure 16
Exemplar treestand utilized in accelerated corrosion testing.[22]

and in accordance with ASTM G31 “Standard Guide for Laboratory Immersion Corrosion Testing of Metals” and ASTM G71 “Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes.”

Multiple 1.25-inch-long samples of $^{1}/_{8}$th-inch 7-7 galvanized steel cable were cut to size and weighed (**Figure 17**). In order to maintain a similar ratio of exposed wire-to-treestand surface area as that used in the full-scale treestand, the foot platform of the exemplar treestand was sectioned into 5"x5" square samples, with the bolt hole at the middle of the frame side (**Figure 18**). Where there was no bolt hole along the frame’s edge, additional 5"x5" square samples were cut from the remaining part of the frame, and a $^{5}/_{16}$th-inch hole was drilled into the frame to emulate the bolt hole present on the first two samples. The defense refused to (or was not able to) provide information regarding the OEM hardware for the drilling of these holes. As such, these holes were drilled utilizing an industrial drill press in the possession of the Texas Tech Department of Mechanical Engineering. Each 5"x5" square treestand section used in the authors’ corrosion tests consisted of a portion of the foot platform, a 5" portion of the frame, with one of the 45 mm bolts and three provided washers (**Figure 19**). The weight of each sample comprised of the above components was recorded.

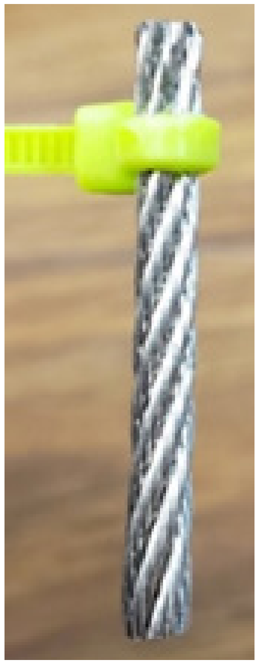

Figure 17
Cable samples used in corrosion testing.

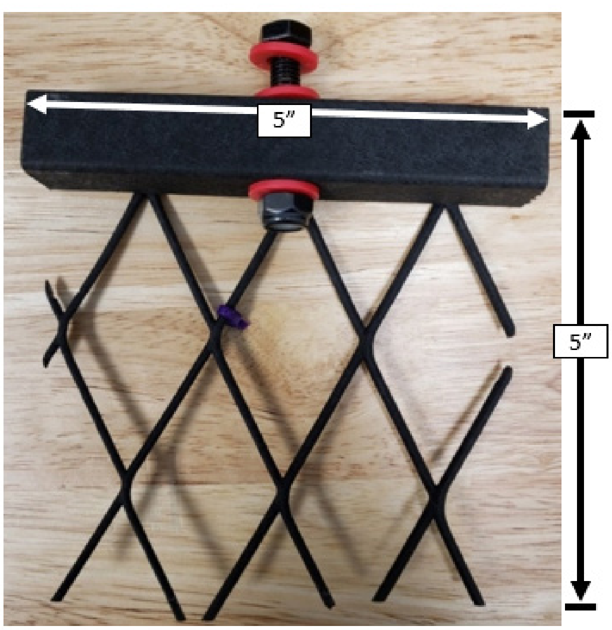

Figure 18
5"x5" square samples utilized in corrosion tests.

Two separate baths of 1.025 specific gravity saltwater (typical of seawater salinity) were prepared for the immersion of the coupled cable and treestand samples. The cable and treestand immersed in each bath were then galvanically connected via Rodeostat potentiostats, which were programmed to monitor the current flowing between the samples. In addition, two cable samples and two treestand samples were each suspended in separate baths of 1.025 saltwater in order to measure their corrosion rate in the absence of a galvanic connection between the wire and treestand.

After 10 days (240 hours) of continuous immersion in saltwater, both the cable and treestand samples were removed from the test baths. The cable samples were then dried, cleaned via an ultrasonic bath, and weighed in order to quantify the amount of their corrosion based on their mass-loss. Based on mass-loss measurements for each sample, the corrosion rate of the samples and the effect of the galvanic coupling on increasing the corrosion rate were determined. As shown in **Figure 19**, the galvanic coupling between the wire and treestand frame was shown to increase the rate of corrosion by around 300%.

In order to verify the result of the galvanic immersion testing, accelerated corrosion testing utilizing direct physical connection between the wire and treestand frame was performed (**Figure 20**). Four treestand samples and four cable samples were prepared. Two treestand samples had a cable sample affixed to the bolt threads via zip ties in order to simulate a connection between the bolt and cable eyelet. The remaining two treestand samples and two cable samples were left separate to determine the effect of coupled vs. uncoupled wire and frame samples.

	Average Corrosion Rate		
	Total Mass Loss grams / 240 hours	**Equivalent radius reduction mm per year**	**Coupled vs. Uncoupled % Increase**
Coupled Treestand and Galvanized cable	0.0509	3.0085	300%
Uncoupled Galvanized cable	0.0127	0.75065	

Figure 19
Mass-loss based corrosion rates for coupled vs. uncoupled cable/treestand samples utilizing accelerated immersion testing with connections made via potentiostats. Radius reduction per year was calculated via equations provided in ASTM G1.

Figure 20
Sample of treestand and wire physically connected via zip ties.

The samples were then immersed in separate baths and left immersed for 10 days, after which they were removed, dried off, cleaned, and weighed for mass loss. The average corrosion rates of the cable for the coupled wire and frame as well as the uncoupled sample are shown in **Figure 21**.

Based on these results, the direct-connection test result showed that the galvanic connection increased the corrosion of the cable by ~79%. This lower percent increase in corrosion rate of 79% for the direct-connection samples as compared to the 300% increase in corrosion rate obtained from potentiostat measurements (**Figure 19**) is due to the imperfect and limited connection between the wire and bolt (**Figure 20**). It would be expected that the connection between the bolt and treestand would be better than this, so the overall corrosion rate of the subject treestand would likely lie somewhere between the results shown in **Figure 19** and **21**.

Cyclic Voltammetry Testing

In order to further verify the results of the accelerated corrosion testing, cyclic voltammetry was also utilized as yet another method for evaluating the increase in corrosion rate of the cable as a result of galvanic coupling with the treestand frame.

Cyclic voltammetry is an electrochemical analysis for measurement of corrosion rate between two dissimilar

	Average Corrosion Rate		
	Total Mass loss grams / 240 hours	**Equivalent radius reduction in mm per year**	**Coupled vs. Uncoupled % Increase**
Coupled Treestand and Galvanized cable	0.01395	0.8245	79%
Galvanized cable alone	0.007795	0.4607	

Figure 21
Direct connection corrosion rates.

metals. A potentiostat was used to alter the natural difference in potential (measured in volts) between the coupled cable and treestand (as well as uncoupled) while measuring the resulting current response to voltage alterations, which was then used to arrive at the corrosion rate of the coupled and uncoupled cable and treestand frame specimens.

To describe the cyclic voltammetry technique in general, a potentiostat is connected to three electrodes. These electrodes (working, counter, and reference) are used in order to provide data to the potentiostat. The working electrode is attached to the material whose properties one wishes to determine while the counter electrode is attached to a platinum rod or sheet to provide an electrically neutral material for the working electrode (cable or treestand segment in this case) to be coupled to, and the reference electrode is attached to an Ag/AgCl reference cell that will correct for any potential variation. The potentiostat then cycles the potential (voltage) from low to high while measuring the produced current response. Then the measured current vs. applied potential are plotted (**Figure 22**) to determine various electrical properties of the working electrode material. By transforming this plot into a "Tafel"

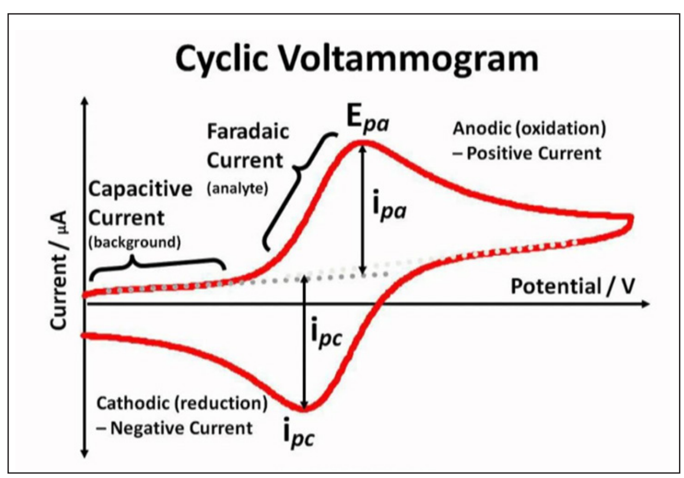

Figure 22
Graph of a cyclic voltammetry scan.[24]

plot (**Figure 23**), one can then extract the Tafel constants, corrosion current, and galvanic potential for each tested material. After these values have been determined for both materials, one can use the Mixed Potential Theory to find the coupled corrosion current and potential. Overlaying the two Tafel plots (**Figure 23**) allows one to find their intersection and extract the corrosion current and potential for the coupled configuration.

Results show that for two similarly sized pieces of galvanized steel cable and treestand steel, a galvanic couple increases the corrosion rate of the cable by around 175% (**Figure 26**). The cyclic voltammetry analysis displayed a slightly lower corrosion rate than the initial mass-loss analysis given in **Figure 19** (313%) but a higher corrosion rate than direct connection test results in **Figure 21** (79%). This lower rate (when compared to mass-loss results of

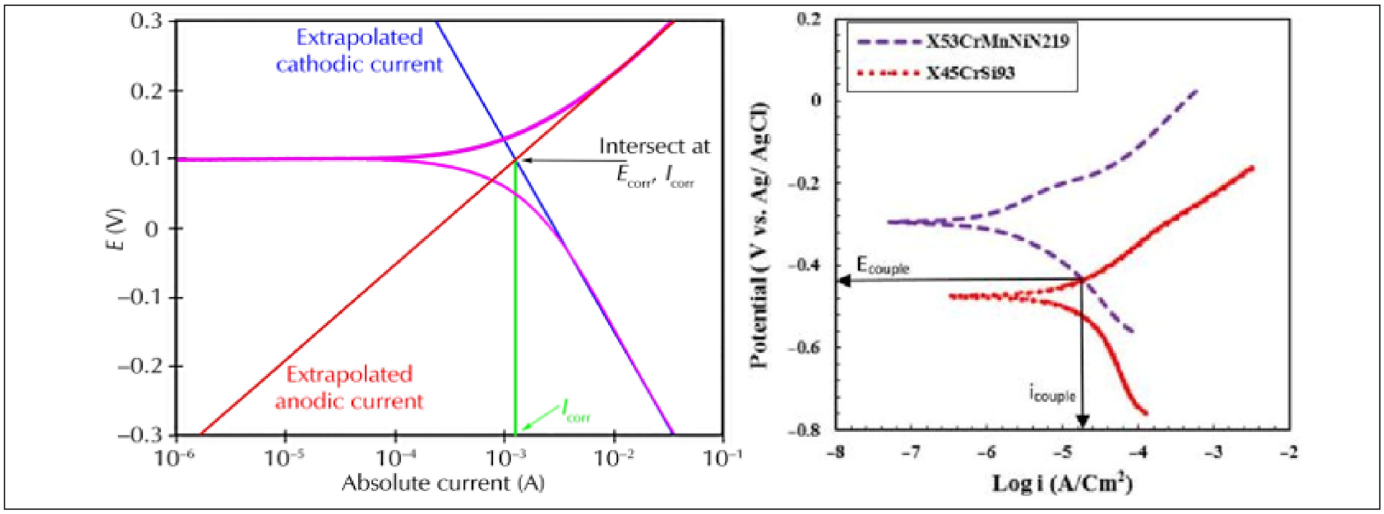

Figure 23
Tafel plot and data that can be extracted from it (left) and combination of Tafel plots to determine the effect of a galvanic connection (right)[25,26].

Following the above-stated procedure for cyclic voltammetry, a platinum counter electrode and an Ag/AgCl reference electrode were placed in a bath of reverse osmosis water containing 0.008 moles of iron(III) chloride ($FeCl_3$). Since the Ag/AgCl electrode and platinum electrode used in this study were small, a strand of cable material and a smaller segment of treestand frame (**Figure 24**) had to be used in relation to the size of electrode. The cable and treestand samples were individually connected to the working electrode and subjected to a voltage sweep while recording the corresponding current response.

The potential and corresponding current were plotted and converted to a Tafel plot from which the galvanic potential, corrosion current, and Tafel constants were extracted (**Figure 25**). The corrosion currents for the galvanized steel cable by itself and the cable galvanically connected to the treestand were then converted to corrosion rates via Faraday's Law, as given in ASTM G102.

$$\text{Corrosion Rate} = K_1 \frac{I_{corr}}{\rho} EW$$

Where: K1 = 3.27 x 10−3 in mm g/µA cm year

Icorr = corrosion current density in µA/cm2

ρ = density in g/cm3

$$EW = \frac{\text{Atomic weight}}{\text{number of electrons required to oxidize an atom of the element}}$$

Figure 24
Treestand frame material (left) and cable strand (right) used in CV testing.

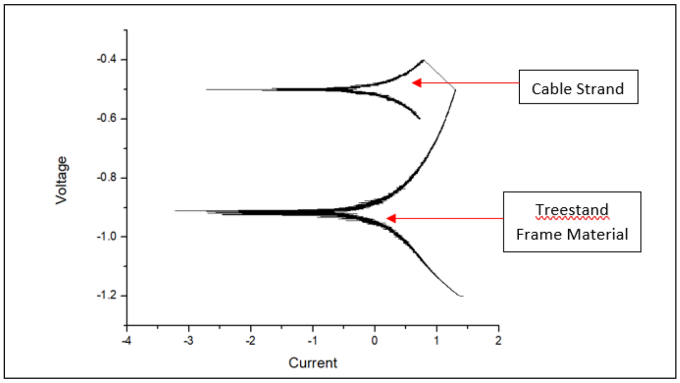

Figure 25
Tafel plots extracts for treestand frame material and cable strand.

	Cyclic Volt Corrosion Rate		
	Corrosion Current ($\mu A/cm^2$)	Equivalent radius reduction in mm per year	Coupled vs. Uncoupled % Increase
Coupled Treestand and Galvanized cable	105.4	1.5789	175%
Uncoupled Galvanized cable	38.34	0.5744	

Figure 26
Corrosion rate of coupled and uncoupled cable and treestand frame, utilizing cyclic voltammetry.

Figures 19 and **21**) is due to the fact that our CV analysis was conducted with cable strand samples that had the same surface area as the treestand material as opposed to being proportionally smaller — as was the case in the direct connection tests and mass-loss analysis utilizing potentiostats.

In summary, the percent increase in corrosion rates of coupled cable/treestand frame samples was determined utilizing three different approaches, namely: 1) the accelerated immersion testing utilizing a potentiostat; 2) direct connection mass-loss based analysis; and 3) cyclic voltammetry. As shown in **Figure 27**, these percent increases were determined to be 300%, 79%, and 175%, respectively.

As previously stated, the subject treestand was in use for approximately four years prior to the incident at issue. Given the fact that direct coupling of the cable to the treestand frame resulted in a significant increase in corrosion rate of the support cable as shown earlier, **Figure 28** shows the additional time (in years) that would have been necessary for the cable to reach the degree of corrosion that caused its eventual failure, had it not been directly coupled with the treestand's frame.

Similar Previous Incidents

Discovery documentation revealed a number of previous incidents similar to the one that occurred in the subject incident (i.e., involving failure of the company's treestands due to cable corrosion). In the first of these similar incidents, failure was observed in the segment between the right-cable eyelet and copper crimp near the vertical support. However, in the case being investigated here, the left-cable and right-cable both failed in the segment between the crimp and cable eyelet (**Figure 29**).

As in the previously reviewed incident, the second similar incident the authors reviewed showed that both

Test Method	% Increase in Corrosion Rate of Coupled Cable/Treestand Samples
Accelerated immersion Testing with Potentiostat Connection	300%
Accelerated immersion Testing with Direct Connection	79%
Cyclic Voltammetry	175%

Figure 27
Percent increase in corrosion rate of coupled cable/treestand frame samples as compared to uncoupled samples.

Test Method	Additional Time Before Cable Would Have Recached Failure
Accelerated immersion Testing with Potentiostat Connection	12 Years
Accelerated immersion Testing with Direct Connection	3.16 Years
Cyclic Voltammetry	7 Years

Figure 28
Additional time (years) before cable would have reached failure as determined by the various test methods conducted.

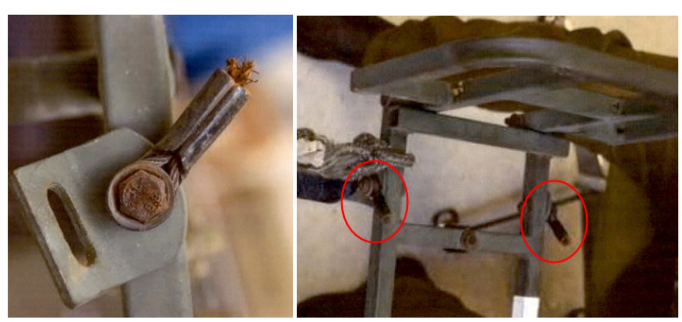

Figure 29
Failures observed on the treestand of the first similar incident with both failures occurring between the eyelet and crimp.

cables failed at the segments between the eyelet and crimp near the vertical support (**Figure 30**). The fracture surface of the right-side cable showed clear signs of ductile failure. Fraying of the right-side cable was observed in the segment between the cable eyelet and the crimp due to dynamic loading experience when the other cable failed suddenly, shifting the force to this side — similar to what happened in the subject incident.

In the third similar incident, both the right and left cables failed just below the eyelet affixed to the vertical support. The bolts on this section were attached backward with the nut directly adjacent to the eyelets (**Figure 31**). As in other cases, the important factor to note is the fact that the thicker cross-section of the cables failed before the thinner cross-section below the crimp indicates that the segment between the crimp and eyelet experienced severe degradation of its strength due to corrosion as a result of galvanic coupling between the cable, copper crimp, and treestand frame. Fraying of the cables similar to the previous incident was observed (**Figures 32** and **33**). This fraying and the elongated strands suggest the occurrence of ductile overload.

The fourth similar incident involved a newer model of the manufacturer's treestand. As shown in **Figure 34**, newer models of the manufacturer's treestands come with a thermoplastic coating over the cables. This coating, however, is loosely attached and allows water to easily seep and become trapped on the inside, corroding the cable. At the same time, the coating prevents users from observing the degradation state of the cables.

The fifth similar incident involved a hang-on treestand

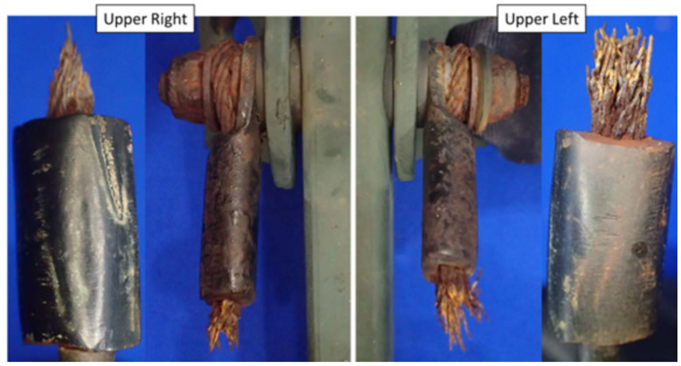

Figure 31
Locations of failure observed on treestand in the third similar incident.

Figure 30
Cable failure in the second similar incident.

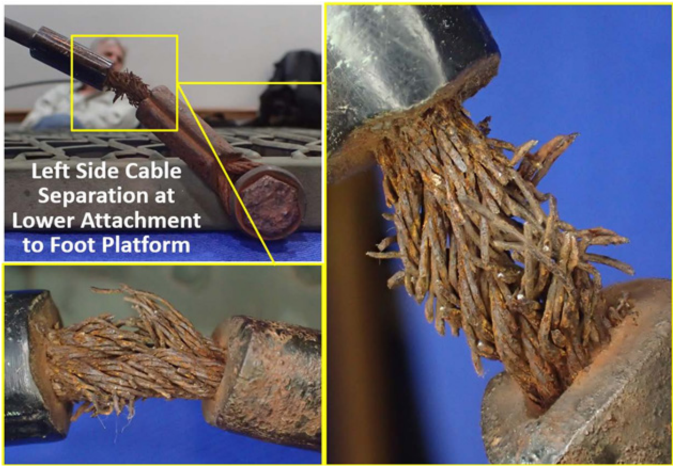

Figure 32
Fraying of wire strands in the segment between the eyelet and crimp that occurred following the initial failure.

Figure 33
Close-up view of cable failure in the third similar incident.

Figure 34
Failed cables the fourth similar incident.

produced by the manufacturer. The documents for this incident included an expert report on behalf of the plaintiff. In this report, the expert explains that even though the treestand was intermittently used, it suddenly failed after five years of use. As shown in **Figure 35**, the support cables fractured between the cable eyelet and copper crimp at the attachment point in the vertical support. Similar to the authors' analysis, the expert determined that the failure was due to accelerated corrosion degradation of the cables due to a galvanic coupling between the copper crimp and galvanized steel cable material.

A report from the CPSC describes an incident involving a similarly constructed treestand[27]. In this incident, the treestand, which had been installed for two hunting seasons and stored in the user's garage during the off-season, failed when the user was attempting to take down the stand at the end of this second hunting season. The failure occurred when one of the corroded cables holding up the foot platform broke (**Figure 36**), which caused the user slip off of the stand, although his fall arrest harness broke his fall. Examination of the treestand and similar stand owned by the user revealed that their cables were also corroded and showing signs of degradation failure.

Despite the large number of previous similar incidents, both to their own products and the products of companies they shared designs with, the manufacturer made

Figure 35
Failed cables from the treestand in the fifth similar incident displaying extensive corrosion.

Figure 36
The failed cable on the climber treestand fractured between the copper crimp and plastic coating, showing the same design as the subject cable in the subject case.

no attempt to release a safety notice or recall the subject treestand. The number of previous incidents should have alerted the manufacturer to the propensity of its treestand cables for corrosion and the danger that they presented. As such, the subject failure was reasonably foreseeable by the manufacturer — yet it made no attempt to fix its design or warn users of the hazard it presented.

Testing Conducted by the Manufacturer

According to testing documentation provided, the manufacturer did not perform environmental testing on the subject treestand in order to determine its suitability for outdoor use.

The current president of the manufacturer asserted that it would have been impossible for them to do environmental testing on the subject treestand due to different environments it could be exposed to. Therefore, the manufacturer decided to not test its design to any of these possible environments instead of performing testing according to the worst foreseeable environment, as is standard practice in engineering design.

A reasonably prudent manufacturer would have considered corrosion as a foreseeable degradation mechanism for a product designed for outdoor use. Had the manufacturer performed accelerated corrosion testing to simulate outdoor environment usage, it would have observed that the subject treestand (in its as-designed condition) was unreasonably susceptible to corrosion and degradation of the cable system, which is the most significant load-bearing component of the treestand.

CPSC Hierarchy of Controls

The hierarchy of controls represents the necessary steps for elimination or reduction in the probability of exposure to a known hazard[28]. **Figure 37** is a graphic representation of the hierarchy of controls. These well-established and universally utilized controls begin with the most effective measures for hazard reduction and continue to lesser effective measures. These steps, in order of effectiveness, are elimination, substitution, engineering controls, administrative controls, and PPE.

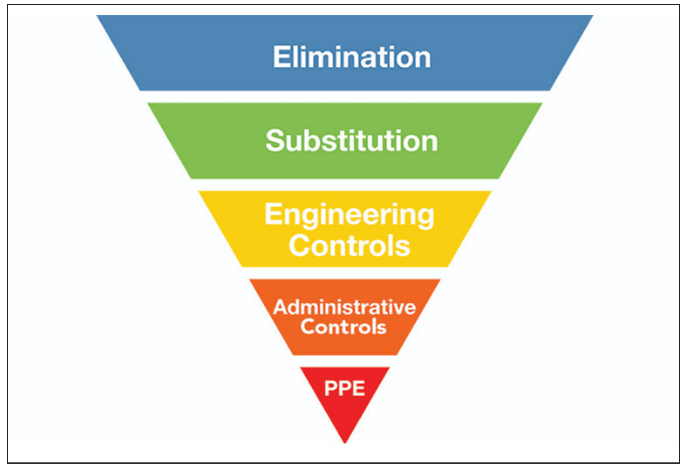

Figure 37
Engineering Hierarchy of Controls.[29]

The engineering hierarchy for reducing/eliminating hazards requires that a known hazard should be eliminated by designing the hazard out of the system when possible. If a hazard cannot be eliminated through design, the next step is to guard against the hazard.

Analysis of Warnings and Non-Compliance with Safety Engineering Principles

As mentioned in the section on the Hierarchy of Controls, one must eliminate a hazard by designing it out of the system when possible. If elimination of a hazard through design is not feasible, one is to utilize the next most effective means of controlling a hazard. Merely warning a user of a hazard when it is economically and technologically feasible to address the said hazard through more effective means of hazard control is in gross violation of this basic safety engineering principle.

Several factors contribute to the low placement of warnings on the hierarchy of controls. As indicated later in this paragraph, the main reason for this low placement is the fact that all warnings partly rely on the user's understanding and executing the warning's instructions in order to be effective — an approach that is highly unreliable, especially when more effective means that do not rely on human interaction exist.

The effectiveness of warnings depends on the user and a variety of psychological factors that can influence how the user reads, understands, and interprets warnings given to them. For example, users might feel they are "educated" and ignore a series of warnings or not read them thoroughly enough out of a feeling that they already know what it's going to say — or that they are already knowledgeable enough about the topic[30,31]. Exposing the user to too many warnings within a small area (or within a short period of time available for the user to digest them) can cause the reader to either become desensitized to the stated hazards or simply ignore the warnings altogether. This is a well-known phenomenon in safety engineering referred to as "overwarning."[32] It should also be reasonably expected that a user could gloss over or forget certain warnings[31]. For this reason, standards state that warnings for critical hazards should be placed on or near the hazard itself or be made in a manner that is too obvious to ignore. By doing so, users are reminded of the hazard each time they are in a situation that has the potential to expose them to it.

The above principles, which, if not considered, would render a warning deficient in design, are internalized in the ANSI Z535 family of standards, which are universally accepted among the safety engineering community. Requirements for the design, wording, and placement of warnings are given in ANSI Z535, all of which combine to form warning labels that effectively communicate the hazard to a user and ensure that, on a more-likely-than-not basis, the user would follow the recommendations of the warning for hazard avoidance.

In the subject incident, the owner's manual had a number of deficiencies that further reduced the effectiveness of its stated warnings. The owner's manual contained a total of 66 warnings, all of which lacked signal words and appropriate coloration, which were in direct violation of ANSI Z535 requirements. This large number of warnings also induces overwarning, and, when combined with the lack of proper warning designs, makes it highly likely that a reader would zone out and stop paying attention or just not bother to continue reading. Another deficiency of the subject treestand's warnings is the inadequacy of most of the warnings in describing why the warnings are there in the first place or what to look for in order to execute the instructions stated in the warning[31-33].

The manufacturer claimed compliance with the requirements of TMA 02, yet fails to conform with the universal requirements of ANSI Z535, which supersedes the TMA standards. The instructions and warnings provided by the manufacturer, in fact, are in direct violation of many of the safety engineering principles underlying warnings discussed earlier. Specifically, TMA 02 fails to give proper instructions regarding proper signal words, coloration, and warning information as outlined in ANSI Z535. Contrary to the teachings of ANSI Z535, Section 6.5.1.1 of TMA 02 states: "The warning label must contain the signal word 'WARNING' and be preceded with or follow the words 'failure to follow all warnings listed could result in serious injury or death'." These requirements result in "overwarning" and "warning fatigue," which are specifically discouraged when designing an effective warning. In all likelihood, the warnings/instructions accompanying the subject treestand were not written with knowledge of the above principles of effective warning in mind. The fact that the manufacturer's warnings failed to account for these well-known phenomena highlights the deficiencies in TMA standards, which openly ignore the universally recognized ANSI Z535 guidelines.

As stated in Joseph Ryan's *Design of Warning Labels and Instructions*: "Warning labels that cannot be seen, or those that do not adequately describe the hazard, serve the same purpose as no warning label at all." By giving too many warnings and instructions to the user in the owner's manual, the manufacturer's warnings are deemed deficient and in violation of well-accepted principles of effective warning design. Additionally, the manufacturer's failure to rank and differentiate between different levels of risk associated with different hazards encountered in the use of the treestand resulted in the most critical warnings not having proper emphasis to attract the user's attention, further reducing the effectiveness of the stated warnings.

On page 4 of the subject treestand's 2011 owner's manual, under the section entitled "Proper Care and Maintenance," it states: "Inspect for defects (damage, rot, corrosion, cracks, freezing, excessive heat, etc.) before every use is required. Do not use if the damage is detected or suspected." While this section of the owner's manual does talk about the need for inspection of the treestand for signs of corrosion, the discoloration observed on the exposed sections of the subject treestand's cables near the eyelets would not appear to be significant enough to an average user to conclude that the subject cable's mechanical strength was significantly degraded and unsuitable for use.

The plaintiff testified that he did not consider the rust present on the subject treestand to be an issue, as most equipment he worked with experienced similar rusting to some degree due to his proximity to the coastal environment. Furthermore, the above warning is stated only once among a plethora of other warnings about the treestand and placed on the final page containing warnings in the manual. Such an important warning should have been placed on the treestand itself or, at a minimum, earlier in the manual and heavily emphasized in order to ensure readers were not desensitized by the number of warnings in the manual.

If the manufacturer wanted its users to inspect the treestand for corrosion, it should have placed a warning instructing them to do so on the body of the treestand — where it is more likely to be seen and followed on a regular basis. However, the warning label, which was affixed to the subject treestand, did not once mention corrosion as a factor that should be considered during inspections.

In the event that there was a similar treestand with corrosion damage that could have been apparent to the average user, the presence of a proper warning would make the user more likely to inspect the cables and come to the conclusion that they were in a dangerous condition. The plaintiff testified that if such a warning existed on the subject treestand, he would have followed it to the best of his ability.

The 2011 owner's manual for the subject treestand also states "DO NOT leave your treestand outside since weather or animals may cause damage. Tree growth can also cause stress and damage straps and buckles. It must be stored inside when not in use." This warning is once again stated once among a plethora of other warnings. As such, one could reasonably expect a user to gloss over or forget it.

A significant number of hunters are known to leave their treestands up on the tree between use. Since a user needs to hammer in climbing sticks and strap the stand on, some users (especially those advanced in age) might choose to forgo this hassle and simply leave the stand up in order to save time and avoid destroying a good hunting tree. In addition, the very design of a fixed treestand makes it difficult for users to attach and remove it on a regular basis, resulting in some to simply leave it up on the tree. Furthermore, the reference to its name as "fixed" treestand provides a connotation of the device being permanent and may contribute to a decision to leave the stand up on the tree — as one would assume a permanent device would be reasonably capable of withstanding the environment it is to be used in. The prevalence of users leaving up their treestand (and their reasoning to do so) is a foreseeable risk that a prudent designer should consider when constructing this type of product.

Various employees from the manufacturer have provided testimony stating that they know hunters will leave their treestands up for extended periods of time. The former president stated in his deposition that they know hunters will not take the treestand down after each use — and that the stand will be fine if left up for a few weeks (if not months). The current president of the manufacturer expanded upon this and asserted that no matter what environment the treestand is left up in, the cable will be perfectly fine for at least two years. In addition, the original founder of the manufacturer stated that users can leave their treestands up for 11 months out of the year and have the stand still be in safe condition. Though all of these representatives define differing amounts of acceptable exposure, their combined testimony shows a clear understanding that hunters cannot be expected to take down their treestand after each use.

Magazine interviews with the executive director of the Treestand Manufacturers Association (TMA) and testimony from the employees of the manufacturer show that the industry not only knows many hunters leave up their treestands, but, to a degree, they also expect it[34]. If the manufacturer truly wished for users to not leave their treestands outside, they should have put this warning by itself on the treestand in bold, noticeable print so users would see it every time they use the treestand.

The founder of the manufacturer as well as their current president stated in their respective depositions that warnings have limited effectiveness and that they (as manufacturers) have an obligation to design out hazards when possible. They additionally stated that they should take into account known misuses of their product as well as the hazards this would create and design out as much as they can. Despite agreeing with this basic principle of engineering design, the manufacturer repeatedly placed the blame for the previous incidents involving cable failure on the user for not following their warnings. The manufacturer had a duty to go beyond merely warning the users about the hazards they knew about but failed to design out the hazards present in their design.

According to the CSPC, between 2005 and 2007, a total of 41 treestand-related deaths were reported, and a total of 19,000 treestand related injuries were estimated to have occurred[35]. In addition to this high incidence of injury, researchers have found that falls from treestands have become the leading cause of hunting-related injury. For example, over a 10-year period in the state of Ohio, it was reported that around 50% of hunting related injuries were due to falls, with 93% of these falls being falls from treestands, while only 29% resulted from gunshot wounds[36]. In 2014, the Indiana Department of Natural resources reported that in 182 reported hunting accidents over a five-year period, 55% involved falls from treestand[37]. A report by the CPSC found that nearly 40% of reported treestand incidents were due to a problem with the treestand[38]. Although most these studies do not indicate how many of these incidents were the result of user errors or product failures, combined with injury and fall reports from litigation and CPSC recalls, the manufacturer knew, or should have known, that there were unreasonably dangerous hazards present in their products that were not being sufficiently designed, guarded, or warned against.

The Executive Director of the Treestand Manufacturers Association stated in an interview that treestand cables are "notorious for failing[34]."This once again shows a clear understanding within the industry that cable failures are an issue that needs to be addressed, yet nothing has been done to alleviate the potential for failure by utilizing common sense alternative designs.

The founder of the manufacturer stated in their deposition that it is ultimately their duty to design a safe product and that this design should, to the best of its ability, take into account and design out known hazards, as is recommended by the hierarchy of controls. The manufacturer failed to adhere to this duty and instead of designing out the hazard posed by their own cables, they negligently shifted the responsibility to the end user.

Use of Safety Harness

Treestand manufacturers recommend the use of safety harnesses, yet the use of such a device is not without its own risk. An HSC Contract Research report[39], entitled "Harness Suspension: Review and Evaluation of Existing Information," presents a study conducted on the Wright-Patterson Air Force Base in Ohio, in which young, healthy individuals were suspended in four different designs of full-body harnesses. During the study, the tests were terminated when either the test subject voluntarily chose to end the study (due to symptoms including nausea, tingling, and numbness of the extremities) or on-site medical professionals chose to end the test. The average suspension time was 14.38 minutes before the test was terminated. Further, an OSHA Safety and Health Information Bulletin (SHIB) 03-24-2004[40] describes the hazards associated with suspension trauma. It states that a worker using a fall arrest system, if not rescued from the harness, can experience venous pooling, which can result in death in as little as 30 minutes.

The engineering hierarchy for reducing/eliminating hazards requires that a known hazard should be eliminated by designing the hazard out of the system when possible. If a hazard cannot be eliminated through design, the next step is to guard against the hazard. Providing a safety harness/fall arrest system, which is accompanied by its own set of risks and hazards, does not give the designer/manufacturer free rein to produce and introduce into the stream of commerce defective and unreasonably dangerous treestands.

Alternative Designs

Another cable material that is commonly used in corrosive environments is stainless steel — the preferred material for cables in extremely corrosive environments[41,42]. Stainless steel is also known to have increased strength compared to galvanized steel, further increasing the benefits of its use[43].

In order to determine the reduction in corrosion if the cables had been made of stainless-steel, galvanic corrosion testing and cyclic voltammetry was performed using the same experimental test setup as described earlier. The results of corrosion testing using stainless steel cables are shown in **Figure 38**.

In tests performed using stainless steel cable material, due to having a galvanic potential near zero, the current response from cyclic voltammetry was too low to discern any valuable data. Likewise, the variation between initial and final mass of the stainless-steel cables after 14 days of immersion in 1.025 specific gravity salt water was so minimal as to be negligible.

In order to determine how economically feasible the use of stainless steel would be, a basic economic analysis was performed. According to various suppliers that were contacted at the time of the authors' initial report, the

	Corrosion Rate (Radius reduction in mm/year)
Coupled Treestand and Stainless-Steel cable	0
Stainless Steel cable alone	0
Uncoupled Stainless Steel cable	The current response was too low to get meaningful data

Figure 38
Corrosion rates for stainless steel.

average cost of galvanized steel cables is around \$0.20 per foot while 304 stainless steel cables cost (on average) \$0.40 per foot. Considering that each cable uses around 28 inches of 7-7 $^{1}/_{8}$-inch galvanized steel; changing the cable to 304 stainless steel would increase the price of the treestand from \$54.99 to \$55.92 or 1.7%.

As such, it is economically and technologically feasible that the manufacturer could have chosen to use stainless steel for its cables yet chose not to do so as a reasonably prudent manufacturer would. The increased corrosion resistance offered by the use of stainless-steel cable would have vastly outweighed the minimal economic cost associated with their usage. A prudent designer/manufacturer would have easily been able to determine, through a basic cost-benefit analysis, that the usage of stainless-steel cables was beneficial to the success of their product and safety of their users. By failing to perform this commonsense design change, the manufacturer at issue designed a product that could not reasonably be expected to withstand the environment it was intended to be subjected to. As such, it was unreasonably dangerous for its intended use.

As previously noted, the usage of a copper crimp on the subject cable increased corrosion by a considerable amount. It was determined that aluminum was an alternative crimping material the manufacturer could have used, as it is relatively easy to form and is already extensively used in crimping applications. In order to determine how the usage of an aluminum crimp would have affected the corrosion rate of the galvanized steel cables, additional accelerated immersion corrosion testing was conducted.

Exemplar cables were cut ~1.5 inches into the plastic coating, providing a total of four samples (**Figure 39**). The copper crimp on two of these samples was removed and replaced with a commonly available aluminum crimp of a similar size. These samples were then weighed and immersed in 1.025 specific gravity salt water (typical seawater) for 14 days. As shown in **Figure 40**, visual observation alone shows that the cables with the copper crimp corroded significantly more.

Figure 39
The copper (right two) and aluminum (left two) crimp samples.

Various competitor treestands displayed an alternative cable attachment method, which allows the cables to be coated in a plastic sheath that prevents contact with air or water, cutting off one of the required conditions for corrosion to occur. While it is possible that this coating could degrade over time, constructing it out of UV-resistant materials would greatly reduce the likelihood of this occurring. The plastic sheath could also be made out of a semitransparent material, which would allow users to see the cable corroding should water find a way in (**Figure 41**).

In order to verify that cables coated in a plastic sheath would not experience significant corrosion, additional accelerated corrosion testing was conducted utilizing cable samples cut from the midsection of the exemplar treestand cable. One of the ends of the cable was sealed in a flexible polymer sealant to prevent the ingress of water on this end (**Figure 42**). These samples were then partially

Figure 40
Corrosion present on the copper (right two) and aluminum (left two) crimp samples after 28 days of immersion.

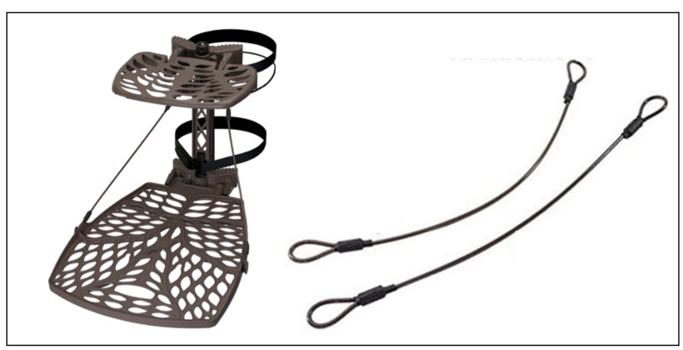

Figure 41
Competitor treestand displaying fully coated cables and an alternative attachment mechanism.

Figure 42
Sample cut from middle of exemplar cable; one end coated in polymer sealant.

submerged in salt water with one of the samples galvanically connected to a treestand sample through the use of potentiostat wires.

Results showed minimal corrosion in both cases with any mass loss or current being so low as to be negligible and within margin for noise and error. Based on the results of these tests, the polymer coating was found to be effective in blocking out the salt water bath and keeping the cable from corroding.

Another method that could be utilized to prevent a galvanic connection between the treestand cable and frame would be to insulate the bolt holes (**Figure 43**).

All of the design alterations discussed above are technologically and economically feasible, and their implementation would have greatly increased the lifespan of the subject cable, preventing the incident from happening at the time it did. Although no projected corrosion time could be determined due to lack of any observed corrosion, it is likely that incident would likely have been postponed by at least bifold the amount of time the plaintiff had been using the treestand — by which time it would be reasonable to assume the plaintiff would have thrown away the treestand due to the degradation elsewhere on its frame.

Summary and Conclusions

Visual analysis of the subject treestand revealed severe corrosion of the galvanized steel cables near their connection points with the frame. The left-side cable failed between the cable eyelet and copper crimp, while

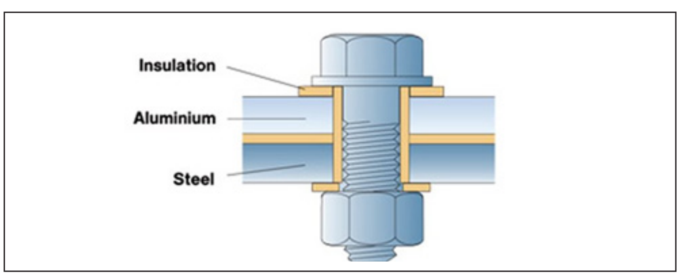

Figure 43
A potential design that could be used to prevent contact between the bolts and treestand.

the right-side cable failed just below the copper crimp. Based on the fracture surface characteristics of the cable strands and location of the failure points at each cable, it was concluded that the left-side cable failed first, leading to sudden overload failure of the right-side cable.

EDS analysis of the galvanized steel cables from the subject treestand revealed lower concentrations of zinc closer to the cable/frame connections, indicating that they experienced substantial depletion of its protective zinc coating, which, in turn, led to severe corrosion-induced degradation at these locations and their ensuing failure under normal and anticipated use.

It is well known that contact between dissimilar metals can result in the formation of a galvanic cell, which, in turn, can cause accelerated corrosion of one of the metals. It was concluded that corrosion of the subject cable connection points was caused by the phenomenon described above, due to improper contact between the cable eyelet, copper crimp, and treestand frame.

The degree to which the improper connection of the cables to the treestand resulted in its degradation under normal and anticipated use was measured through accelerated corrosion testing and electrochemical analysis. Test results indicated that the as-designed and as-assembled cable/frame connection point resulted in ~79% to 300% increase in the rate of corrosion measured in millimeters of cross-sectional area reduction per year, depending on the test method utilized.

It was further concluded that the significant increase in the rate of corrosion caused by improper design of the subject treestand resulted in premature degradation of its cables at the connection points with the frame, which lead to its premature failure under normal and anticipated use. Had the cables on the subject treestand been properly attached to the frame in a manner that would not have resulted in the formation of a galvanic cell, it would have lasted 79% to 300% longer (or four to 16.5 years) before reaching the same degree of degradation that caused its failure on the day of incident.

Susceptibility of the subject cables to corrosion degradation as a result of galvanic cell phenomenon discussed earlier was (or should have been) known to the manufacturer, given the occurrence of similar failures and associated investigations identifying improper design of the cable/frame connections as the root cause of the failure. Given the manufacturer's knowledge of the occurrence of similar incidents in the past, a reasonably prudent manufacturer would have either recalled the subject treestand or issued a product safety notice alerting owners of the susceptibility of the cables to premature failure.

While the owner's manual states that users should keep the treestand indoors when not "in use," no instructions are given regarding the period of time that the treestand can stay outdoors without significant degradation of its cables — nor are any warnings given regarding the susceptibility of the treestand cables to premature degradation should the treestand be left outdoors.

The manufacturer's reliance on warnings and instructions to inform a user of the hazards associated with the use of its product, while prudent in some situations, is not an effective means of protecting users from the hazard when it is possible to design the hazard out of a product or guard against user's exposure to the hazard. As such, the manufacturer did not act as a reasonably prudent manufacturer to address well-known safety issues associated with its product, which directly caused the failure at issue in this case.

Extensive research and testing of various cable connection methods revealed that the failure at issue in this case could have easily been prevented through the implementation of one or more of the following technologically and economically feasible alternatives:

1. Proper insulation of the cable from coming into direct contact with the frame.

2. Use of an aluminum crimp in place of copper crimp to decrease the susceptibility to galvanic corrosion.

3. Use of stainless-steel cables in place of the galvanized steel cables due to their increased resistance to corrosion.

4. Provide a barrier to the elements or coating the exposed portion of the cable to protect from environmental exposure.

The design of the subject treestand was unreasonably dangerous and defective, given the existence of multiple technologically and economically feasible alternative designs that would have prevented the failure of the subject cables under its reasonably foreseeable environmental exposure and use.

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