



Imperfections in Tree Stand Failures

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Analyses of two climbing tree stand accidents are presented to show that serious imperfections in the chains would not have produced the failures had the tree stands been used within rated capacity. Stress analysis and tests demonstrated that roller chain with cracked links could operate at rated capacity without further crack growth and showed that loads approximately three times rated capacity were required to cause the pullout of an improperly staked pin. Although the chains in the tree stands involved in both accidents had serious imperfections, the imperfections did not produce a failure of the product within the rated capacity of the tree stands. However, operating conditions in excess of the rated capacity exposed the imperfections and led to the failures. Neither imperfection should have been considered a defect because they did not reduce the capacity of the tree stands below the rated capacity.

Keywords: imperfections, intergranular fracture, roller chain, strain gage tests, stress analysis, tree stand

Introduction

Two roller chain failure cases in climbing tree stands are provided as examples of the defect issues raised in a commentary in a recent issue of this journal.^[1] The thrust of the commentary was that the term *defect* is used too loosely. The authors recommended that the term should be used only for cases in which it could be demonstrated quantitatively that the failure occurred because of the defect and would not have occurred in its absence. Failures occurring at loads in excess of design or rated capacity will usually initiate at imperfections, but such imperfections should not be termed *defects* because they do not reduce the performance of the system below design capacity. The two failure cases presented in this article provide examples of failures occurring at loads in excess of rated capacity and associated with glaring imperfections. Testing and stress analysis were used to determine probable loads on the stands at the time of failure.

Tree stands are used for deer hunting because they offer the advantage of surprise by positioning the hunter well above the prey. Climbing tree stands are a special type of tree stand in which the stand itself is used to ascend the tree and then provide a hunting platform. Climbing tree stands are made

as two separate units: a top half with a seat and a bottom half that serves as a foot rest.

The upper half of a climbing tree stand is shown schematically in Fig. 1. The lower half on which the hunter stands is smaller but otherwise is similar. A double pitch A2040 chain encased in heat shrink tubing is used to loop around the tree. The chain

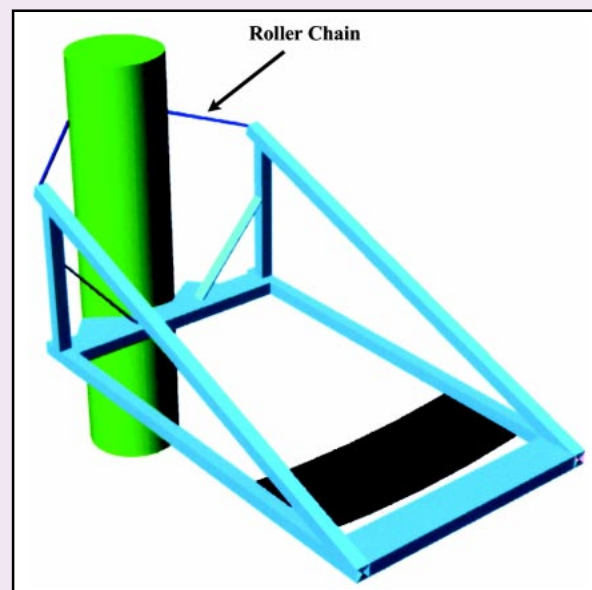


Fig. 1 Schematic drawing of the upper half of a climbing tree stand. A roller chain was used to loop around the tree.

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loop around the tree must be adjustable to keep the frame level for different sized trees. This is accomplished by inserting a steel pin through the side tubes and through the appropriate links in the chain. The heat shrink tubing keeps the chain relatively stiff, prevents kinking, and reduces noise. Noise reduction and stealth are very important for deer hunting. Sudden movement is to be avoided. Dynamic loads caused by rapid movement are therefore not likely.

The hunter stands on the base or lower half and raises the upper frame on the tree. He then sits on the upper frame, and his weight forces the frame into the tree and seats it. The lower frame or base is then pulled up by toe straps and seated on the tree. This process is repeated until the hunter and tree stand reach the desired position. The hunter then has the choice of remaining seated facing the tree or moving a web seat and sitting with his or her back to the tree. The tree stand designs in these cases were tested to a series of industry standards that were later made into ASTM standards F2120, 2125, 2126, 2127, and 2128. These standards provide for a static safety factor of 2.0 in addition to fatigue and stability requirements.

In two separate climbing tree stand failure incidents, roller chains separated on the upper half of the tree stand and the hunters fell out of the stands. Serious imperfections were readily apparent at the failure location in both chains. However, stress analysis and full-scale testing provided results that indicated that both failures occurred at loads in excess of rated capacity. These are cases in which the failures exposed imperfections but where the imperfections should not be termed *defects* in the chains.



Fig. 2 Both links had old cracks at 65° to the link axis (arrows).

Case 1

Cracked Links

The first case involved a fatal hunting accident in which a pair of links were found broken. These broken links were located just outside of the side tube on the upper stand. Low-power microscopic inspection revealed that both links had old cracks through the same side of the hole wall. Both cracks were oriented approximately 65° from the link axis. Figure 2 shows the two cracked links together. The two old cracks are the top two broken hole wall ligaments. (Chain was black oxide coated.)

The old fracture surface on the straight link (first link to fail) was covered with corrosion (Fig. 3). Cleaning of the fracture was not permitted. However, small areas of fracture clear of corrosion could be found. Intergranular fracture was observed in all such areas. An example of the intergranular fracture is provided in Fig. 4.

Heavy deformation was observed in the hole wall ligament opposite the old cracked ligament (Fig. 5). Substantial necking at the hole wall and heavy shear lips can be seen. Crack propagation from the hole wall was initially by shear and/or ductile tearing and finally intergranular fracture. A transition was observed from ductile tearing to predominantly intergranular fracture at approximately 50% of the width of the wall ligament. An example of the intergranular fracture is provided in Fig. 6.

Fracture faces in the second link were more damaged and more corroded. However, they had a

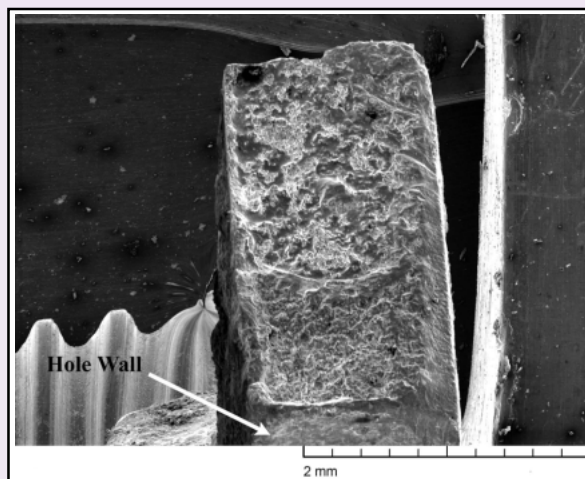


Fig. 3 The old crack in the first link to fail was corroded heavily.

similar overall morphology to the first link. Deformation in the link indicated that it broke after the first link.

Inspection of the rest of the chain from the upper stand revealed a cracked link at the tail end of the chain. The design of the stand and the location at the link are such that this cracked link (Fig. 7) could never have been loaded. The chain was unusually rusty both at this location and at the fractured links. Chains come from the factory with a light coating of oil and are covered with heat shrink tubing. Traces of chlorine were found in some of the rusty areas. Little history was available on how the tree stand had been stored before the accident. Field corrosion tests on similar chain in a seacoast environment failed to produce the degree of corrosion

observed on the chain that was on the tree stand involved in the accident.

No destructive tests were permitted on the actual chain, but tests on a similar black oxide coated chain revealed 48-50 HRC in the links. The specified minimum strength level is 1418 to 1600 kg (1420 kg in ASME B-29.3) for chains made in the country of origin. Exemplar chains from other manufacturers yielded lower hardness (40-43 HRC) for such chains. However, either the specified or the measured hardness levels would render the chain susceptible to hydrogen-assisted cracking from the black oxide coating process or from subsequent corrosion in service or storage.

The tree stand was known to have been used successfully several times prior to the accident. Each use would have probably produced at least 30 or more load cycles on the chain. Low-cycle fatigue crack growth in the uncracked ligaments does not appear likely because rupture of these ligaments occurred with substantial necking at the hole wall.

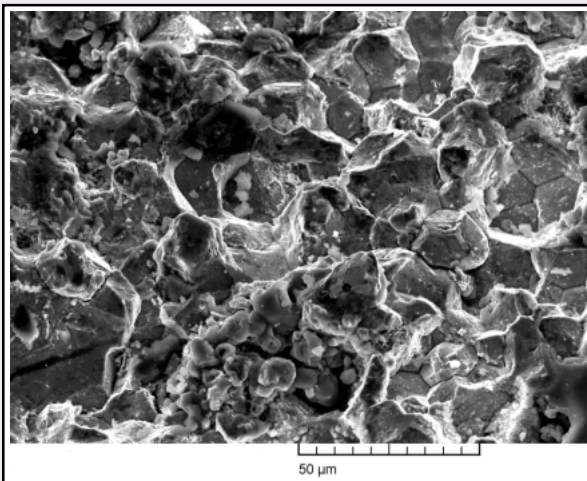


Fig. 4 Intergranular fracture in the old crack

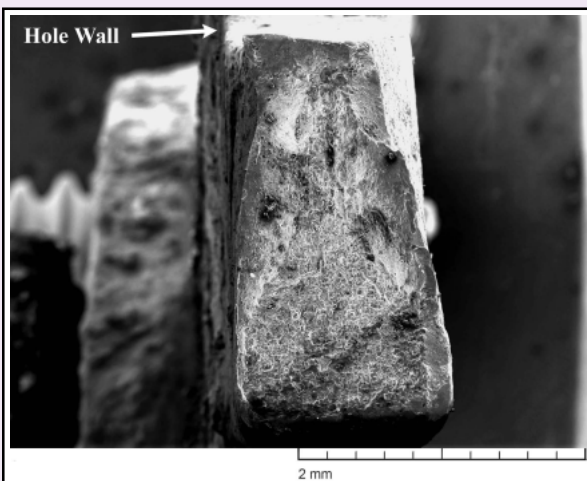


Fig. 5 Heavy necking at the hole wall surface and shear lips on the rupture surface

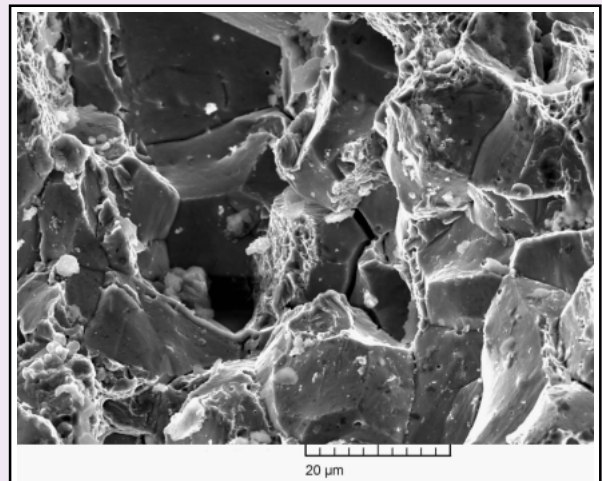


Fig. 6 The flat fracture seen in Fig. 5 was mostly intergranular.

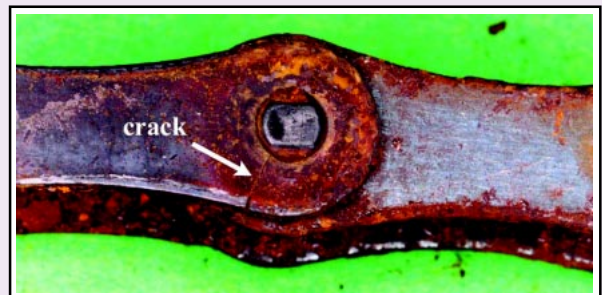


Fig. 7 This cracked link was found in the end of the chain where no operating loads could have been placed on it.

No evidence was found for low-cycle fatigue, which should have resulted in incremental crack growth with little necking or reduction in area. Conventional stress calculations based on the hunter's weight for hooks^[2] (a chain link with a crack such as shown in Fig. 7) showed elastic stresses approximately twice the tensile stress in the opposite hole wall. However, these stresses are primarily bending stresses, and plastic redistribution of the stresses will occur. Hole wall stresses of this magnitude indicate that the hook was at or near proof load conditions.^[2] A reconstruction test using saw cut links was run to verify the predictions from the calculations.

Saw cuts were put into exemplar links from another chain source that had a hardness of 40 HRC and was thus softer and had a lower yield strength than the accident links. Both cuts were made at the same location and orientation as the old cracks seen on the failed chains. The stand was loaded to the equipped weight of the hunter, 1070N (which was close to rated capacity 1220N), under conditions duplicating the tree diameter at the time of the accident. No deformation was observed in either link after two tests (Fig. 8).

This test validated the hook stress calculations and demonstrated that higher forces than would be expected in normal use were required to break the already cracked links. The tests also confirm that the stand could have been used successfully with cracked links. Thus, while the old cracks were glaring imperfections created some time before the accident, they were not the proximate cause of the accident. There had to have been an additional source of loading.

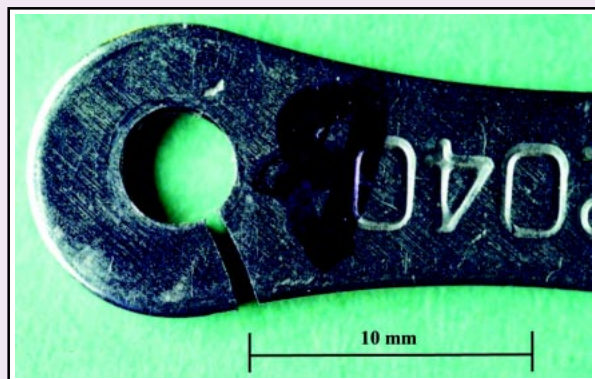


Fig. 8 One of the exemplar links after testing shows no deformation or opening of the saw cut.

Not enough data exists to recreate the accident, but one unusual feature of the accident is worth considering. The hunter had recently been diagnosed to have a heart condition and was found dead at the scene with a severe head wound and little blood on his clothing or on the ground. No autopsy was performed. A massive heart attack could produce a strong reaction in the hunter and result in dynamic loads on the stand. The dynamic load would have increased the stresses on the link and could have been sufficient to break the chain. Additionally, a heart attack or other such event could greatly reduce the flow of blood from the head wound and result in the observed severe wound with little blood.

Case 2

Pin Pullout

The second case involved a slightly different design for a climbing stand but the use of the double pitch roller chain was the same. A separated chain was found at the accident site. Close examination revealed that a pin had pulled out (Fig. 9). Pins are normally "staked" or upset with two opposing flats on each pin end. The end that pulled out did not show obvious evidence for any stake, while the opposite end had one heavy stake (Fig. 10). The end that pulled out was partially hidden and could not be examined directly because destructive testing was prohibited.

A transverse strut strengthening the two side arms was observed to be bent. This bending is illustrated in Fig. 11, which has the bend exaggerated for clarity. The nature of the sharp bend, stand design, and location of the strut made it unlikely that

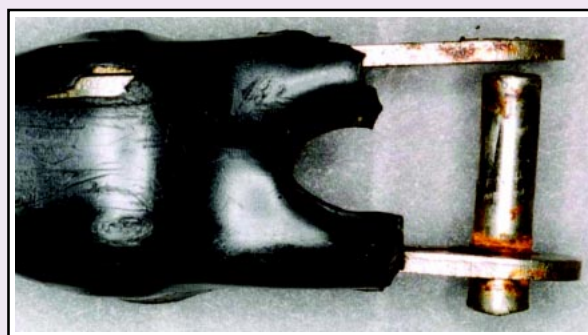


Fig. 9 The pin pulled out of an outer link plate in this failure. The bottom end of the pin was clearly upset while the top was not.



Imperfections in Tree Stand Failures (continued)

the bend was produced by the hunter falling on the strut.

There had been criticism of the use of roller chain in climbing tree stands, because roller chain was never intended for applications involving bending forces that obviously are present when in use on a tree climbing stand. Calculation of bending forces was not attempted because of the complexity of the problem. However, strain gages were used to directly measure bending stresses and tensile forces in the chain links located where they emerged from the side arms. This was the location where the greatest bending and nonuniform stresses were expected. A small tree diameter was also expected to exacerbate the problem, because the takeoff angle of the chain from the side tubes would be greater.

Individual links were strain gaged in the waist or mid-section for force and bending stress. Each force link was gaged for a full 350 ohm bridge with a 1.57 mm gage length strain gage. Bending stresses in each link were measured with a standard half bridge at 350 ohms and 1.57 mm gage length gages. Data was acquired with a data acquisition system. Threaded rods with nuts were used in place of pins in order to be able to interchange link placement. The threaded rods were close fit and nut tightness effects were tested. Each link was tested for proper performance before assembling the chain.

Strain gage tests revealed that tensile and bending stresses depended on distance from the end of the

side tubes and whether the link was on the top or bottom. Bending stress links just exiting the side tube yielded the highest bending stresses (120 MPa). The direction or the sign of the bending stress was opposite in the two links, with the lower link having a higher and positive value. Tensile stresses of 269 MPa were measured in the top tension link just exiting the side tube. The bottom tension link produced less than half this value. Tension stresses dropped much faster than bending stresses as the gages were moved away from the side tube exit hole. The maximum combined stress at 1250N load (rated capacity was 1220N) was 338 MPa. These stresses are in the waist or middle of the link. Stresses in the hole wall ligaments are slightly higher because the area is slightly less. Using an elastic stress concentration factor of 3.4 (finite width plate) produces hole wall stress estimates near yield at the corners of the hole walls. (Bending stresses are only present on the surfaces.) Thus little deformation of the hole wall would be expected.

Actual tests were run with a similar but larger seat frame because no exemplars for this particular model were available. This larger frame should have increased forces on the links on this stand because the leverage and angles were larger. Figure 12 shows the setup and data from the tests with the highest bending stresses.



Fig. 10 A view of the bottom head in Fig. 9 shows a large, single indentation in the head.

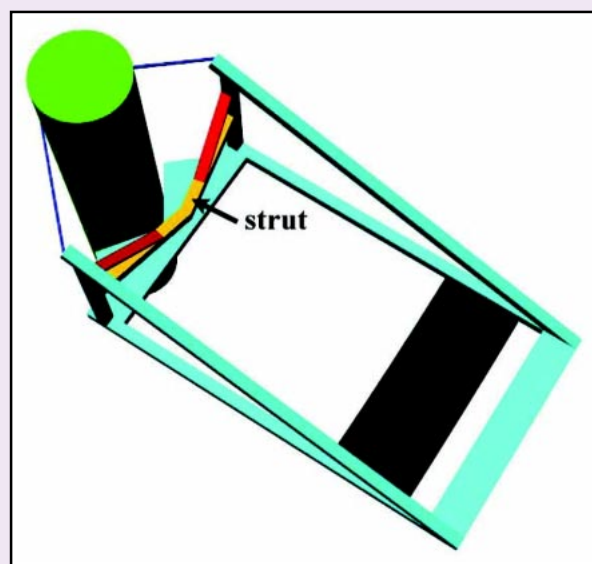


Fig. 11 The arrangement of the tree stand with the bent strut

A second concern for bending in the roller would be widening of the holes in the link plates. These chains do become loose with use. However, inspection of chains used on tree stands never revealed significant opening of the hole diameters that could allow the pins to work out.

Tests were run to determine the effect of a pin with no upset or staking on one end. One pin end was ground flush to duplicate lack of staking. Using this pin on a tree stand produced no pullout. A test was then run with the pin driven out of the two bottom links at 4000N load. Figure 13 shows the pin clear of the link and stable at 4000N. The bottom link location was chosen because of higher bending stresses. This stand (test stand design shown in Fig. 1) was bent as a result of the force component in the tubes toward the centerline of the stand. Bending of the strut on the accident stand was similar in nature. While the stand in this case had two transverse members, the overall stiffness was similar.

The pin pullout tests were repeated with the similar results. The pin could have worked loose during prior use before the accident, but these tests demonstrate that a chain in the condition

found could still support loads adequate to deform the stand, 4000N. Normal load for this stand and hunter was approximately 750N.

Stress calculations were performed on the bending of the transverse strut. Forces in the chain pro-

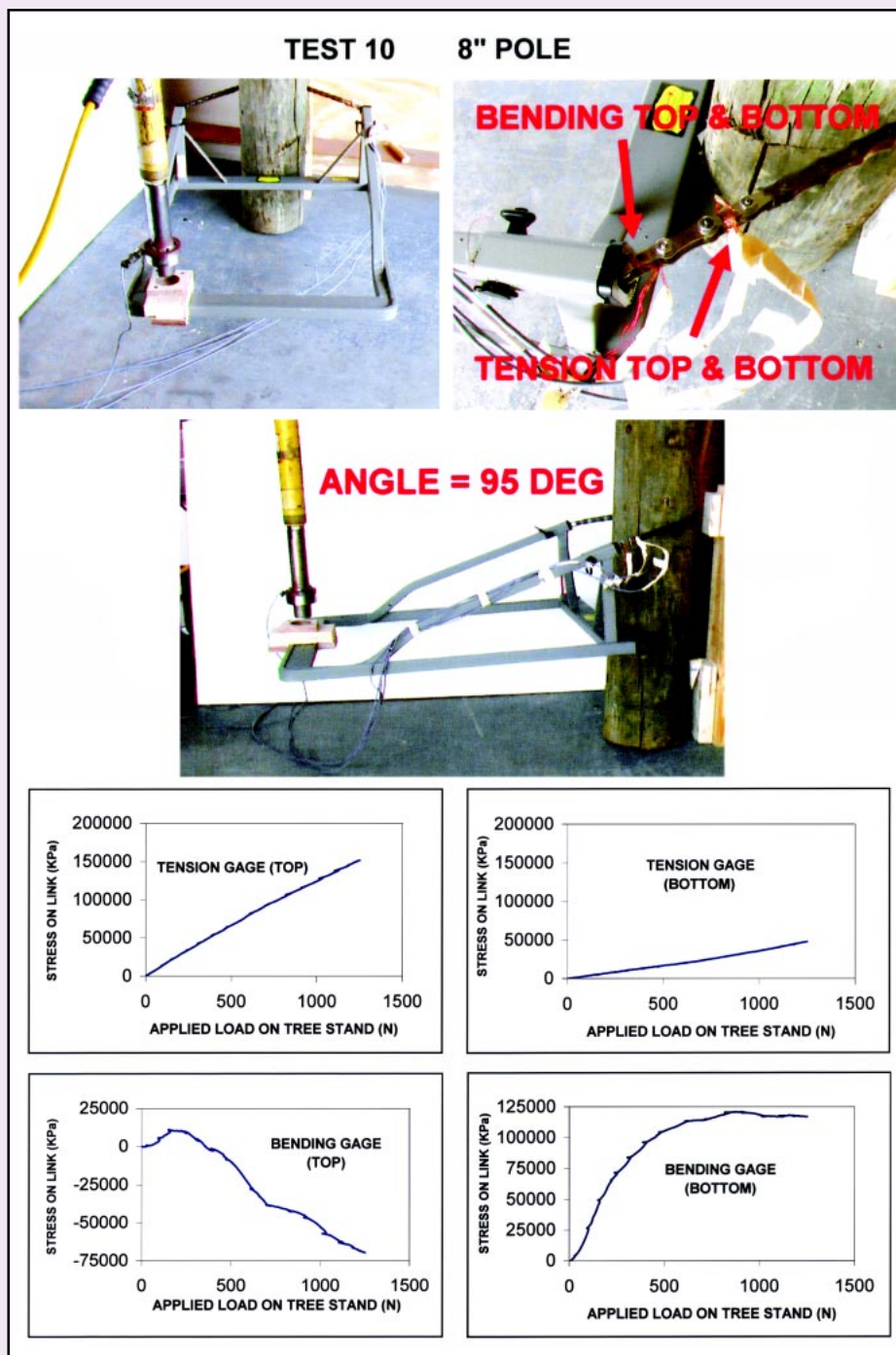


Fig. 12 Sample data from the tree stand show that forces and stresses depend on location. Bending stresses were never linear with applied load.



Imperfections in Tree Stand Failures (continued)

duce both bending and compression in the strut. This condition was analyzed using the secant formula for columns.^[3] Actual plastic collapse is not well defined for this situation, but using elastic stresses 50% over the yield stress as a starting point for plastic collapse yielded a stand load of at least 3560N. This is in reasonable agreement with the tests on a similar stand. The hunter's weight was approximately 750N.

Tests and calculations revealed that even with an improperly staked pin, the pullout could not be explained under normal hunting conditions. The hunter had said that he had used the stand to cut down limbs and vines in the tree so he could climb it safely for hunting. These limbs and vines were still present when the scene was inspected. One of the limbs or vines (which were large) could easily have come down on the hunter in the stand, producing a sudden, twisting dynamic force on the stand. This event could easily account for damage observed in the stand and the pullout of the pin that could not be duplicated under static conditions.

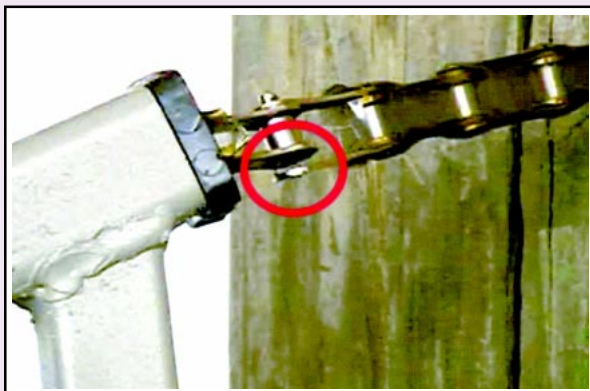


Fig. 13 A link with the pin driven clear of two links is shown to be stable at 4000N load and with little deflection or deformation.

Conclusions

Stress calculations and experimental testing showed that imperfections in these chains would not contribute to a premature failure under normally expected use. Imperfections in both cases (assuming that the chain cracks occurred in manufacturing) were very obvious and totally unacceptable for manufacturing quality for the chain. However, neither imperfection was capable of producing failure under design use conditions. Instead, conditions outside of normal use were the probable cause of both chain failures, even though the failures occurred at imperfections.

Would the chain with the cracked links have failed later after more use? The answer to that question depends on whether the initial cracking occurred in manufacturing or later because of storage in a corrosive area such as where swimming pool chemicals were stored. Additionally, the amount of and nature of future use would also be a factor. No clear answers exist.

Failure of the improperly staked chain with additional service is also difficult to address without conducting fatigue tests on the stand. However, it can be said that because failure most likely occurred at force levels over four times the hunter's weight, it is unlikely that a later failure under normal conditions would occur unless the pin dropped completely out of the chain.

References

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