NORTH AMERICAN WOOD POLE COUNCIL

TECHNICAL BULLETIN

The Performance of Distribution Utility Poles in Wildland Fire Hazard Areas -

What We Know and Don't Know

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Abstract

This paper addresses the question; How well do galvanized steel distribution poles resist wildfire exposures compared to preserved wood poles? Most utility poles are of preserved wood, so utilities have little experience or documentation about how galvanized steel poles perform in wildfires. The factors of topography, wind and fuel density that lead to more serious wildfires apply equally to wood and steel poles. Utility poles are likely to be exposed to wildfire temperatures of 500°C (932°F) to over 1,200°C (2,192°F). Wood poles, especially those with oil-borne preservatives, tend to develop outer char that insulates interior wood and self-extinguish, thus limiting damage in some fire exposures. Steel poles do not burn, but will not support design loads if the steel reaches temperatures of 500°C (932°F) or more. Damage to galvanizing is also possible due to the heat of wildfires, making eventual corrosion damage more likely. Utilities should minimize fire risk by use of vegetation management, locating pole lines where accessible, using redundant loop systems and having capacity to replace many poles promptly following fires. Available data does not support a conclusion that distribution poles of galvanized steel will resist wildfires any better than those of preserved wood.

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Introduction

Wooden utility poles treated with preservatives provide the backbone of the U.S. electric and telecommunications systems. Wood poles are chosen because they are strong, light-weight, plentiful, economic and long lived with average service life of approximately 70 years[1].

USWAG reported that there are approximately 130-135 million preserved wood utility poles in the U.S. and that approximately 99% of new poles purchased each year are preserved wood[2]. Compared to preserved wood poles in the typical distribution size range, galvanized steel poles cost approximately 70% more and concrete and fiberglass poles cost approximately 100% more[3].

While the suppliers of non-wood poles claim longer service lives for their products than for wood, experience does not support such claims. Thus, preserved wood utility poles offer the lowest life-cycle cost option for typical distribution uses.

Regarding wildfires, utilities wonder if spending more for poles made of other materials would be worthwhile in fire hazard areas. There is no clear answer, but the issues of this question are considered below.

[1] *Morrell, J. J. Estimated Service Life of Wood Poles. Technical Bulletin. North American Wood Pole Council, 2008. http://www.woodpoles.org/documents/TechBulletin_EstimatedServiceLifeofWoodPole_12-08.pdf.*

[2] *Roewer. Comments on Pentachlorophenol Revised Risk Assessments: Notice of Availability and Solicitation on Risk Reduction Options – Docket ID No. EPA-HQ-OPP-2004-0402. Letter to USEPA from Utility Solid Waste Activities Group (USWAG). June 16, 2008.*

[3] *Smith, S. Managing Treated Wood in Aquatic Environments, Chapter 4 Economics of Treated Wood in Aquatic Environments. Edited by J. Morrell, K. Brooks, and C. Davis. Forest Products Society, USA. 2011.*

Discussion

What factors affect wildfire severity?

In recent years, there has been considerable focus on the Wildland Urban Interface (WUI) in relation to potential damage from wildfires. The potential exposures of buildings and other improvements within the WUI can help to understand the exposures of utility poles. The National Institute of Standards and Technology (NIST) has proposed a Hazard Scale for evaluation of fire exposure potentials within the WUI[4]. This report provides an excellent discussion of the variable factors that affect the severity of fire exposures, both from direct flame and from embers. Three dimensions affecting fire intensity are fuels, topography, and weather. These are illustrated in Figure 1, which is copied from the report.

Figure 1 – Dimensions of Fire Intensity

Fire exposures are categorized by potential heat flux likely to result from fires. These are summarized as follows:

F1: No significant heat flux expected. No real hazard.

F2: Low hazard. Generally the interior of a community. Heat flux up to 0.8 watts per square centimeter (W/cm^2).

F3: Moderate hazard. Combustible material is distant enough to prevent direct contact by flames. Heat flux expected to be 0.8 to 2 W/cm^2.

F4: Severe hazard. High heat flux and direct flame contact is expected. Heat flux to be greater than 2 W/cm^2.

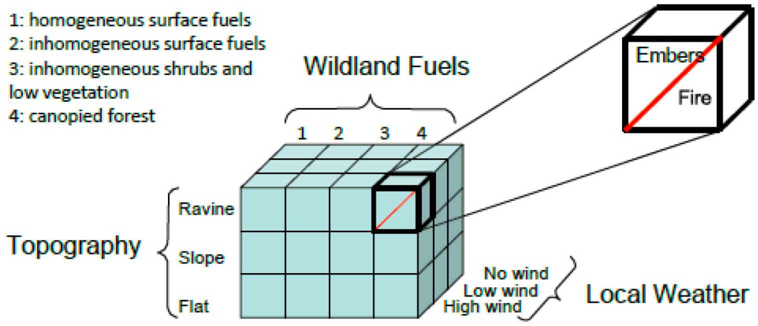

Figure 1 — Dimensions of Fire Intensity
NIST defines the severity of fire exposure based on three factors: wildland fuels, topography and local weather. Each spot in this matrix determine the assignment for a Fire Exposure Zone (F1, F2, F3, F4) to indicate the increasing susceptibility of structures to radiative ignition from fire flames.

This report also discusses the importance of embers in spreading fires. In the case of utility poles, it is likely that the same conditions that increase fire hazard would also apply at the base of poles, increasing the duration of elevated temperature exposure.

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[4] *A. Maranghides and W. Mell Mell, "Framework for Addressing the National Wildland Urban Interface Fire Problem — Determining Fire and Ember Exposure Zones using a WUI Hazard Scale," National Institute of Standards and Technology, Washington, D.C., Technical Note 1748, 2013. [Online]. http://dx.doi.org/10.6028/NIST.TN.1748*

What are likely exposures to poles from wildfires?

The conditions of most importance regarding utility poles are temperature and length of time at temperatures. Wildfire Today, in its Frequently Asked Questions area, states: *"An average surface fire on the forest floor might have flames reaching 1 meter in height and can reach temperatures of 800°C (1,472° F) or more. Under extreme conditions a fire can give off 10,000 kilowatts or more per meter of fire front. This would mean flame heights of 50 meters or more and flame temperatures exceeding 1,200°C (2,192°F)"*.[5] While this is overly general, it provides a range of temperatures that should be considered.

An article on laboratory research by NIST[6] on burning individual Douglas fir trees provides perspective on the heat release, time frame and potential exposure temperatures. Individual Douglas fir trees of various heights and moisture contents were set on fire under monitored laboratory conditions. The timing of mass loss to fire, heat release rates and temperatures of monitors at various distances and heights were monitored. Trees were completely burned within one minute and the maximum rate of mass combustion occurred within approximately 10 to 20 seconds of the start of combustion. Within the fire center, gas phase temperatures were monitored to peak at approximately 700°C (1292°F). Heat flux from 5-meter tall trees measured two meters from the tree centerline was 40 to 60 kW/m^2. (This equates to 4 to 6 W/cm^2 and is clearly in the F4 Severe Hazard category as discussed above.) Note that this data reflects only one single tree burning alone. Clearly, multiple adjacent trees in a wildfire would produce higher temperatures and flux rates.

In a chapter addressing issues of remote sensing of fire characteristics for use in fire mapping[7], the authors discuss the temperatures at the leading edges of fires that need to be measured. They note that typical fire front temperatures are in the range of approximately 800°C (1,472°F) and may often exceed 1,000°C (1,832°F).

Another paper[8] discussing issues of remotely monitoring fire temperatures noted that for a wildfire in California, temperatures in the advancing fire front were often approximately 827°C (1,521°F) and ranged as high as 1,227°C (2,241°F). Temperatures behind the front generally ranged from 527°C (981°F) to 727°C (1,341°F).

While the above sources and many others not cited are helpful in estimating the temperatures to which utility poles may be exposed, studies actually measuring the temperatures attained by the pole surfaces could not be located.

How do wood poles perform in fires?

Wood poles will burn. However, the extent of damage to wood utility poles and their load-bearing capabilities varies greatly with conditions. Duration of exposure is important. The longer poles are exposed to elevated temperatures, the more likely they are to be damaged or destroyed. Older, more weathered poles are more likely to burn than newer ones.

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[5] *Bill Gabbert. (2013, April) Wildfire Today. [Online]. http://wildfiretoday.com/faq-wildland-fire/*

[6] *A. Maranghides, R. McDermott, and S. Manzello W. Mell, "Numerical simulation and experiments of burning douglas fir trees," Combustion and Flame, vol. 156, pp. 2023-2041, July 2009.*

[7] *P. Riggan and R. Tissell, "Airborne Remote Sensing of Wildland Fires," in Developments in Environmental Science, M. Arbaugh, A. Riebau and C. Andersen A. Bytnerowicz, Ed.: Elsevier, 2009, vol. 8, ch. 6, pp. 139-168. [Online]. http://www.fs.fed.us/psw/publications/4451/psw_2009_4451-001_139-168.pdf*

[8] *K. Charoensiri, D. Roberts, S. Peterson, and R. Green P. Dennison. (undated) Utah.edu. [Online]. http://content.csbs.utah.edu/~p-dennison/pubs/rse_dennison2006_preprint.pdf*

An important aspect of wood pole performance in fires is that wood poles may be very substantially burned in a fire, yet still be able to support the attached wires. As wood is exposed to heat, the surface develops a layer of char. The char layer insulates the deeper wood, slowing the rate of decomposition[9]. Following a relatively brief fire, most treated wood poles will self-extinguish with minimal char development, although copper treated poles may continue to smolder.

Wood at 2 and 3 cm below the exposed surface is much cooler than the surface due to the natural insulating ability of wood and wood char. Under fire exposure, the depth of char in wood will progress at approximately 0.65 mm per minute. After 30 minutes of exposure, wood 2 cm below the surface had gained only approximately 100°C (212°F) of nearly 500°C (932°F) at the surface. A 10 minute fire exposure (probably long for wildfires given NIST data shows that individual trees were consumed in less than one minute), would cause charring to a depth of 6.5 mm (less than 1/16th inch)[10]. See Figure 2 from same source. Thus, while the surface may char when poles are exposed to fire, most of the pole cross-section may not be damaged or lose strength. Such poles may continue to support their loads after the fire and may or may not require replacement, as determined by scheduled evaluations. Actual burning characteristics of poles will vary greatly depending on factors previously discussed.

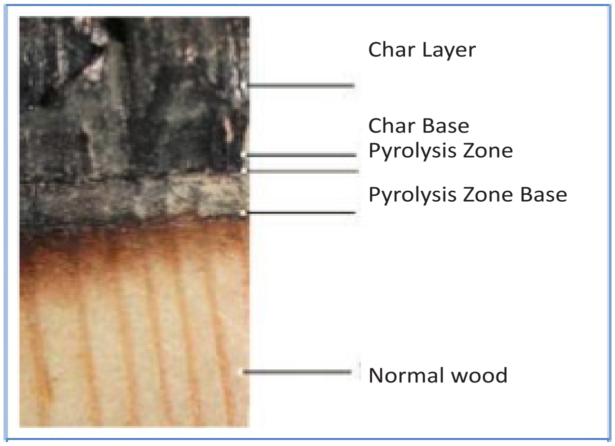

Figure 2. Degradation zones in wood by fire

The structural impact to a wood pole would be based on the depth of charring, since this reduces the effective pole diameter, but the inner wood strength would remain unchanged. Thus, for a 45-foot Class 2 Douglas fir pole of 13-inch ground-line diameter with ¼-inch loss to fire damage, the maximum allowable moment would be reduced by approximately 11% and the tip deflection at design load would increase approximately 17%. Importantly, the allowable load of the damaged wood pole would still be approximately 150% the design load.

Does the type of preservative or species of wood matter?

The type of wood preservative does seem to have some impact on fire survivability. Generally, the oil-borne preservatives of penta, creosote and copper napthenate are less likely to be destroyed by fire than the water-borne copper containing preservatives. In one laboratory test using Australian hardwood, CCA treated poles were "seriously damaged" while creosote treated ones "survived with minimal damage." Following 10 minutes of severe heat exposure, creosote treated samples self-extinguished, but CCA treated onescontinued to smolder until the samples were consumed[11]. Oil-borne penta- and copper napthenate-treated poles are generally reported to survive fires similarly to creosote treated ones.

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[9] *White, R. and Dietenberger, M. Fire Safety of Wood Construction [Book Section] // Wood Handbook - Wood as an Engineering Material. - Madison, WI : Forest Products Laboratory, 2010.*

[10] *Fonseca, E. and Barreira, L. Charring rate determination of wood pine profiles submitted to high temperatures. Polytechnic Institute of Braganca, Portugal. Undated. Webpage: https://bibliotecadigital.ipb.pt/bitstream/10198/1569/1/ACI15.pdf.*

[11] *Gardner W. D. and White, J. A. Jr. [Online] // Forest and Wood Products Australia. - Apr 2009. - Oct 12, 2011. - http://www.fwpa.com.au/sites/default/files/PNA014-0708%20Fire%20Retardant.pdf.*

In particular, chromated copper arsenate (CCA) preservative treated wood tends to continue smoldering, called “afterglow,” after the initial flames have been put out[12]. Thus, water-borne copper-based preservative treated poles may survive the initial brief fire exposure, but fail as the internal smoldering fire consumes the remaining pole cross section.

Western red cedar poles may not perform as well as Douglas fir due to having more checking and heartwood, according to a report by Southern California Edison[13]. Water-borne copper napthenate is reported to not support afterglow due to the lack of oxygen in the formulation[14].

Can wood pole performance be improved?

Additives have been developed that improve the fire performance of both oil-borne and water-borne copper containing preservatives. However, communications with preservative manufacturers indicates that utilities have so far not been willing to pay the increased cost associated with the improved fire performance.

Coatings are available that can be applied at the treating plant or, most commonly, in the field to poles in place. Most coatings are intumescent, meaning that upon exposure to fire, the coating expands to form a low density insulating layer that minimizes heat exposure to the wood[15]. There are various types of coatings available that have proven effective in protecting wood poles from moderate fires, but offer less benefit in extreme fires.

Do steel poles perform better than wood?

While steel may not be likely to “burn” like wood, galvanized steel utility poles may be damaged and fail under wildfire conditions. Data for steel poles relative to wood poles fire performance is lacking. However, the properties of steel relative to fire exposure provide a basis to consider expected pole performance.

There are two very different effects to galvanized steel utility poles that should be considered related to wildfire exposure: loss of strength and loss of galvanizing. Loss of strength due to wildfires is obvious when it occurs, since the poles may bend over under even a small load. Loss of galvanizing without loss of strength may occur at lower temperatures or when not subjected to bending loads and not be obvious, since such a pole would still be standing. It would, however, be subject to accelerated corrosion and weakening over time. These issues are addressed by the following sources.

Steel loses strength as the steel’s actual temperature rises in a predictable pattern. One article[16] summarizing the effects of fire on

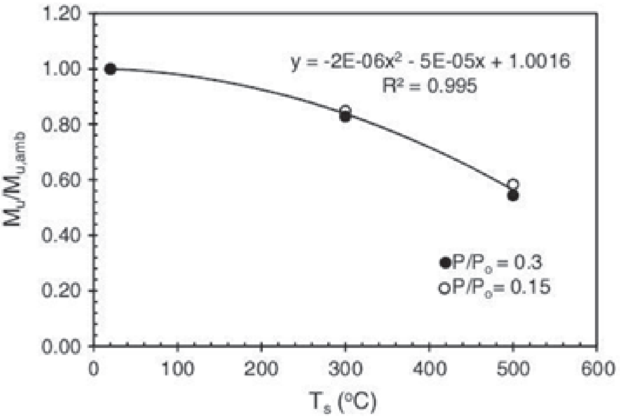

Figure 3. Strength of steel at elevated temperatures

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[12] *Evans P., Beutel, P., Cunningham, R., and Donnelly, C. Fire resistance of preservative treated slash pine fence posts [Journal]. Forest Products Journal, 1994. - 9 : Vol. 44.*

[13] *Peralta, Art Personal communication (Email-Wildfire experience with utility poles). Southern California Edison, 2011.*

[14] *Freeman, M. Personal communications. March 2014*

[15] *White, R. and Dietenberger, M. Ibid.*

[16] *A. Varma, A. Agarwal, and A. Surovek L. Choe, “Fundamental Behavior of Steel Beam-Columns and Columns under Fire Loading: Experimental Evaluation,” Journal of Structural Engineering, vol. 137, no. 9, pp. 954-966, Septemeber 2011.*

steel structural members produced Figure 3. As shown, steel begins losing strength as soon as it reaches approximately 200°C (392°F). Steel retains 80% of its strength at 300°C (572°F), and retains only approximately 50% of its strength at 500°C (932°F), at which point a pole could no longer support its design loads.

Very similar strength to temperature data is presented in a paper by the American Institute of Steel Construction (AISC)[17]. This report also notes that upon cooling, steel will likely regain all or most of its original strength. However, since hollow utility poles require that the circular cross section be maintained and undamaged for strength, this would likely be of little value after a pole is bent.

The AISC also notes[18] that the elasticity, or stiffness, of steel is also reduced once it attains elevated temperatures. Figure 4, copied from the AISC source, shows that elasticity begins to be reduced at 100°C (212°F) and is nearly lost as the steel reaches 700°C (1,292°F).

Data showing the combined effect of temperature to both allowable stress and deflection are shown in Figure 5. This figure represents the stress ratio as the actual fiber stress divided by the allowable stress, which is assumed to be 55,000 psi for high strength steel. Deflection change is the deflection estimated to occur at the noted temperature with a typical design load of 2,400 pounds applied 2-feet below the top of a 45-foot pole with 6-feet buried divided by the deflection at 100°C (212°F). At 550°C (1,022°F), deflection has approximately doubled and stress is overloaded by three times. Under such load conditions, failure would be likely.

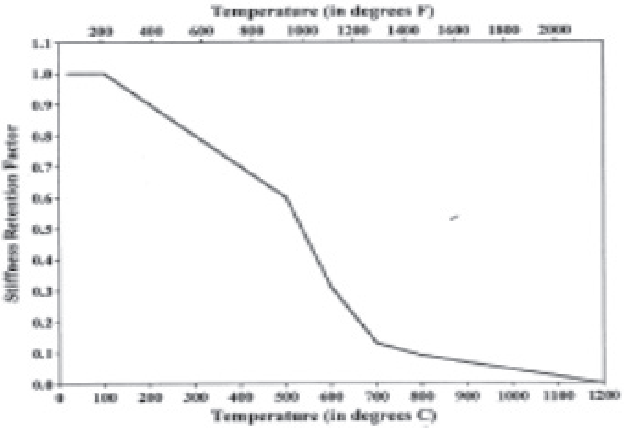

Figure 4. Elasticity at elevated temperatures

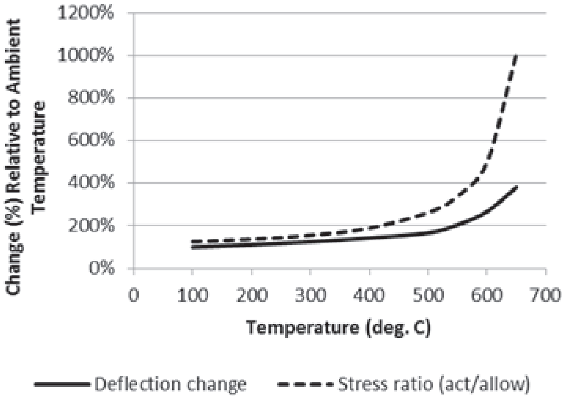

Figure 5. Deflection and stress related to temperature

Thus, data regarding steel strength firmly indicate that if portions of steel utility poles reach temperatures above 500°C (932°F), they will likely be unable to support design loads.

Thin-wall steel utility poles are typically protected from corrosion by hot dip galvanizing. Galvanizing involves dipping the whole pole into a bath of molten zinc at approximately 450°C (840°F)[19]. Zinc has a melting point of 420°C (788°F)[20]. This seems to indicate that zinc galvanizing would likely melt off of the pole surface if the surface temperature were to exceed approximately 420°C (788°F).

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[17] *R. Tide, "Integrity of Structural Steel After," American Institute of Steel Construction, Inc., Chicago, IL, Technical report 1998. [Online]. http://www.aisc.org/store/p-946-integrity-of-structural-steel-after-exposure-to-fire.aspx*

[18] *N. Iwankiw, and F. Alfawakhiri R. Gewain, Facts for Steel Buildings - Fire, 1st ed., AISC, Ed. Chicago, IL, USA: AISC, 2003.*

[19] *American Galvanizers Association. (2006) Galvanizeit.org. [Online]. http://www.galvanizeit.org/images/uploads/publication-PDFs/Galvanized_Steel_Specifiers_Guide.pdf.*

[20] *International Zinc Association. (2011) Zinc Properties. [Online]. http://www.zinc.org/basics/zinc_properties.*

However, the chemistry is more complicated. The zinc reacts with the steel to form alloys that contain up to 25% iron, which are actually harder than the steel. Also, zinc near unprotected steel can still inhibit corrosion as the sacrificial anode. The AGA states that the zinc-iron alloy layers will provide continued corrosion protection at temperatures up to 250^{o}C (480^{o}F). Higher temperature exposures are not recommended[21].

Thus, the potential effect of fire on galvanizing is not clear, but the available data lead to a conclusion that expected wildfire temperatures above 500^{o}C (932^{o}F) may heat the galvanized steel enough to damage the galvanizing and lead to increased corrosion.

Temperatures of galvanized steel utility poles exposed to wildfire conditions will vary quite widely, depending on the fire characteristics. The data reviewed does make it clear that under conditions optimal for wildfire propagation, fire temperatures ranging from 500^{o}C (932^{o}F) to over 1,200^{o}C (2,192^{o}F) within the leading fire front and for a while after the front has passed will exist. The actual temperature of steel poles will depend on how close the poles are to the fire and for how long, as well as on other fire conditions, such as described in Figure 1. Actual steel temperatures may be mitigated by steel's heat conducting ability. Heat will be conducted to areas of lower temperature and to the ground. Combustion of ground-level fuel and deposition of hot embers around the pole base would tend to increase actual steel temperatures.

Steel poles are of circular cross section, tapered to narrow towards the top, and made of sheets of steel coiled to the cross section and welded. The sheet thickness will vary depending on the class and height of poles, but will generally be approximately 0.12-inch (11 gauge). The bending strength of poles depends on maintaining the circular cross section. They fail as buckling occurs, much the same way as a plastic straw does when bent. With a wall thickness of only about $^{1}/_{8}$th inch, steel can heat rapidly, lose some strength, deform under stress, and fail by buckling. Since high wind velocity often occurs simultaneous with fire fronts (often, due to the fire), structural loads on utility poles are likely to be relatively high and near to design loads. Even a partial loss of steel strength and elasticity may cause poles in wildfire conditions to buckle and fail.

In one Australian simulated test of wildfire exposure to galvanized steel poles, the poles were not damaged[22]. However, the test did not subject the poles to load during the test (a critical factor), temperature reached by exposed steel was not reported, and those tested were approximately 60% thicker than typical in the U.S.

So, will steel poles survive wildfires better than wood? The available data does not support a conclusion.

What can utilities do to minimize fire risks?

Utility poles of any material can have wildfire risk minimized if vegetation (fuel) can be kept a safe distance away from the poles. California's CAL FIRE agency notes state regulations require 10-feet horizontal clearance around certain poles and clearance varying from 4-10 feet from conductors rated from 2,400 to over 110,000 volts, depending on voltage[23]. These are illustrated in Figure 6, which is copied from the California document.

[21] American Galvanizers Association. (2013) In Extreme Temperature. [Online]. http://www.galvanizeit.org/about-hot-dip-galvanizing/how-long-does-hdg-last/in-extreme-temperatures.

[22] Sureline. (2006) CSIRO Bushfire Tests cinfirm rural Advantage for SURELINE. [Online]. http://www.sureline.com.au/go/case-study/csiro-bushfire-tests-confirm-rural-advantage-for-sureline.

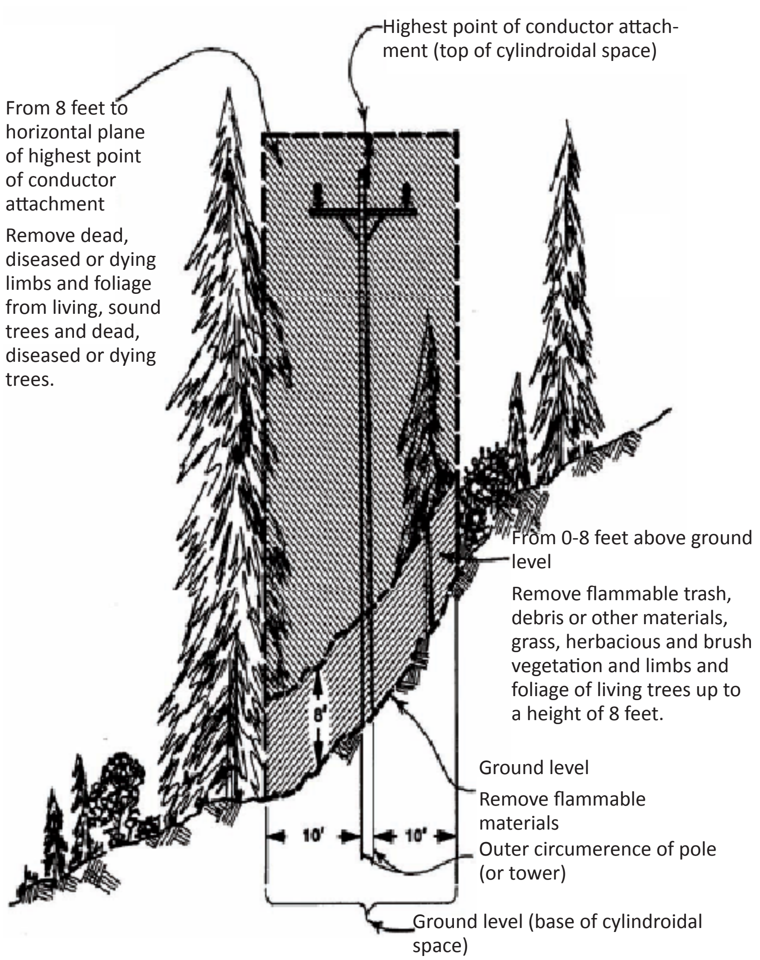
[23] CAL FIRE Engineering Field Guide [Online] // California Department of Forestry and Fire Protection. - 2008. - Sep 26, 2011. Website: http://cdfdata.fire.ca.gov/pub/fireplan/fpupload/fppguidepdf126.pdf.

As every homeowner knows, keeping vegetation under control is a never ending project. Maintaining vegetative clearances requires major commitments of resources by utilities. The effectiveness of vegetation management will depend on how well it is done, as well as factors such as other surrounding vegetative conditions (thick forest growth vs. open grass lands), ground slope, and environmental conditions when fire occurs (humidity, ground moisture, wind, and heat).

Trees outside of the utilities' rights-of-way may be tall enough that they could fall on poles or wires, causing failure. Minimizing such potential, especially for unhealthy or dead trees, requires identifying these and removing them.

Figure 6. CALFIRE fire break clearance requirements

Figure 1-10
PRC 4292
14 CCR 1254
Fire Break Clearance Requirements Around Poles and Towers



What strategies should utilities use to minimize risk?

Utilities must practice risk management by weighing reasonably expected fire damage costs against the costs of minimizing fire risk. Not all utility lines are equal, so the impact due to fire loss can vary greatly, even if the same number of poles or miles of line are the same. For example, loss of a line feeding a hospital, factory and large housing subdivision may have high impact to the utility and its customers while one feeding farms and a few houses would not. Thus, higher priority utility lines should be identified and more resources directed to minimizing fire risk than for lower priority lines.

Strategies employed by utilities should recognize that some fires will be so severe that no pole type would likely survive. In fact, in forested or dense shrub areas with wind, high temperatures and low moisture, the heat from crown or other extreme fires may burn or melt wires in place as well as poles. Falling timber may knock down wires and poles, even if they are not destroyed first by fire. Thus, a realistic strategy must include more features than simply trying to minimize fire. In addition to vegetation management, discussed above, there are various strategy tools available to help utilities to minimize the potential for fire exposure and damage and to minimize the economic and social damage following a fire related loss.

These include:

- Lines should be located for ease of firefighting and reconstruction. When utility lines are routed next to roads, it is much easier to fight fires in the area and to replace utility systems rapidly compared to lines that are routed cross-country.
- Redundant options should be incorporated into the design of higher priority electric supply systems. In this way, one leg of a multi-leg system can be lost and power can be quickly routed around the damaged leg, minimizing disruption to customers.
- Utilities should maintain relationships with suppliers that have a capacity to supply large numbers of poles on short notice following a major fire. Wood poles are especially well suited for this, since wood preserving plants typically maintain large inventories of utility poles that are ready to ship. Poles can be shipped from around the country in response to a major disaster. For example, following Hurricane Sandy in 2012 and each of the previous Katrina and Rita storms, approximately 100,000 poles were dispatched as quickly as utilities could use them to make repairs.

Wooden utility distribution poles treated with preservatives remain the preferred choice for most utilities because they offer the lowest life cycle cost compared to alternative materials such as galvanized steel, concrete and fiber-reinforced plastic.

Wood poles tend to develop a char layer when exposed to fire that insulates the interior wood and minimizes further combustion. Thus, wood poles may survive wildfires with only char damage to the outer surface and remain functional.

Conclusions

Oil-borne pentachlorophenol, creosote and copper napthenate preserved poles tend to survive fires better than water-borne copper containing preservative treated poles because they do not tend to smolder in “after glow.”

Additives and coatings are available to improve fire resistance of preserved wood poles.

Data could not be located to compare the fire resistance of preserved wood to alternative materials of galvanized steel, concrete or fiber reinforced plastic utility poles. Formal studies of this subject are recommended.

Lacking direct studies, evaluation of data regarding wildfire characteristics and the properties of galvanized steel does not support a conclusion that galvanized steel poles would perform better than preserved wood. Galvanized steel distribution poles seem approximately equally likely to be damaged by wildfire exposures.

Damage to utility poles of any material can be minimized by effective vegetation management programs.

Utilities should use risk management strategies that reduce the damage to their infrastructure and their customers by:

- Locating utility lines near roads for ease of access.
- Installing redundant electric supply loops to critical or higher value loads.
- Use materials and suppliers that have large inventories and the ability to respond rapidly following disasters with large volumes of poles, as suppliers of preserved wood poles have demonstrated.

Disclaimer

The North American Wood Pole Council and its members believe the information contained herein to be based on up-to-date scientific information. In furnishing this information, the NAWPC and the author make no warranty or representation, either expressed or implied, as to the reliability or accuracy of such information; nor do NAWPC and the author assume any liability resulting from use of or reliance upon the information by any party. This information should not be construed as a recommendation to violate any federal, provincial, state, or municipal law, rule or regulation, and any party using poles should review all such laws, rules, or regulations prior to doing so.

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