Research Article

Inspection of Wooden Poles in Electrical Power Distribution Networks in Artvin, Turkey

Engin Derya Gezer,¹ Ali Temiz,¹ and Turan Yüksek²

¹Department of Forest Industry Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey

²Faculty of Architecture, Design and Fine Arts, Rize RTE University, 53100 Rize, Turkey

Correspondence should be addressed to Engin Derya Gezer; engin_gezer@yahoo.com

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According to Trabzon Electricity Distribution Local Directorship's statistical data, there are 208.000 utility poles in Trabzon, 180.000 utility poles in Rize, and 121.000 utility poles in Artvin. Every year, 17.000 new utility poles are placed in these three cities. The average lifetime of a treated-wood utility pole is typically 40 to 50 years. However, the average lifetime of a treated-wood utility pole in the Eastern Black Sea Region is only about 10–15 years. In this study, the suggestions for enhancing the service life of treated-wood utility poles in Artvin vicinity were listed by determining the deteriorations and degradations using both visual inspection and nondestructive test methods. The results showed that the most important factors affecting the service life of utility poles were the decay due to fungi, insects, inadequate impregnation, and the deep cracks and splits.

1. Introduction

Wood poles have been used for many decades to support telephone and electric lines throughout North America and all over the world. Unfortunately, wood is subject to deterioration, which can occur because of the abiotic and biotic factors. The biotic agents are the most important decay factor, and wooden poles can be attacked by bacteria, insects, and white-rot, brown-rot, and soft-rot fungi. American chestnut (*Castanea dentata*) and western redcedar (*Thuja plicata*) were commonly selected species for utility wooden poles in the beginning and those poles were used untreated. Those naturally durable woods provided reasonable service life. However, because of the increase in demand for poles and rapid expansion utility systems, it was inevitable to use alternative species. Although the alternative wood species had good mechanical properties, they generally lacked natural durability. Therefore, those alternative species need to be treated with wood preservatives [1].

Wood pole inspection and maintenance programs are very important because of the enormous value of this wood pole plant and the high cost of replacement [2]. Many detailed researches have been conducted to show the

importance of the need for wood pole inspection [3–11]. A comprehensive and detailed wood pole management program must include more than in-place wood pole inspection. A maintenance program should encompass obtainment of treated poles, selection of the proper dimension and size poles for installation based on expected loadings, monitoring of new attachments and loadings to be certain poles are sufficient to carry the new loadings, cyclic in-place inspection and replacement programs based on new loadings and the results of wood pole inspection, and emergency services. Crosno [7] described Southern California Edison's wood pole quality control program as one which incorporates realistic specifications for new poles and pole treatments, inspection of new poles, proper pole installation, periodic in-place inspection, and in line maintenance.

The tree species most commonly used for poles in Turkey is the Scots pine (*Pinus sylvestris*), but other species such as spruce and fir are also used. Wood is a natural biological material and unfortunately susceptible to fungal and insect attack. Decay in wood decay usually occurs when moisture content of wood materials is above fiber saturation point. The outer surface of a pole, although usually treated with CCA (chromated copper arsenate) or with other wood

preservatives to protect wood against fungi and insects, can be attacked by the fungi ascomycetes and basidiomycetes especially by copper-tolerant fungi. However, the internal parts of the pole can be attacked by basidiomycetes fungi, which may enter the wood through deep checks and splits which usually occur during drying process. Subsequent failure of the wooden poles may be inevitable once the pole loses its structural strength due to decay. The decay in poles is mostly found at or near the groundline zone where the conditions are the most favorable for fungal growth. Unfortunately, this is also the location of the greatest bending moment on the wood pole, which magnifies the effect of the decay [12].

Wood poles are still popular and widely used to carry electric power lines and telephone lines in all over the world because of their high strength per unit weight, low installation and maintenance costs, and excellent durability when they are properly treated with wood preservatives. Reliability of these components depends on some factors: a complex combination of age, usage, component durability, inspection, maintenance actions, and environmental factors influencing decay and failure of components. Breakdown or failure of any one or more of these components can lead to outage and cause a huge loss to any organization. In addition, because of new regulations and the concern about environmental contamination, waste management options for treated wood materials are limited. Therefore, it is extremely important to determine the deterioration and degradation on utility poles and predict the next failure to prevent it or reduce its effect by appropriate maintenance and contingency plans [12].

There are many methods of determining the strength characteristics of wood components, which are categorized into two groups, traditional destructive testing that can be performed in the laboratory and nondestructive evaluation. Visual inspection, sounding, excavation, and boring techniques fall into the first category while information from these types of techniques is inevitably limited and can produce misleading results, because of their inability to quantify the defect. Their ability to detect defects relies only on the experience and judgment of the inspector. Nondestructive evaluation or NDE devices are commercially successful techniques capable of predicting pole strength more accurately without disturbing its service. With the introduction of NDE [11], it is possible to locate problem areas and fix them before they become hazardous. Various devices for the detection of decay and defects are available, but they all have limitations to some degrees.

Hayes [8] estimated the number of wood poles in the United States in active use on utility systems ranged from 110 million to 132 million. In Australia, more than 5.3 million wooden poles are in use. According to Turkey Electricity Distribution Company's statistical data [13], there were about 10 million wooden utility poles in use in Turkey. This data does not include the number of poles used for telephone transmission line. According to Trabzon Electricity Distribution Local Directorship's statistical data [14], there were 208.000 utility poles in Trabzon, 180.000 utility poles in Rize, and 121.000 utility poles in Artvin which is northeastern part of Turkey, along the Black Sea. Every year, around 17.000

new utility poles are placed in these three cities. The average lifetime of a treated-wood utility pole is typically 40 to 50 years. However, the average lifetime of a treated-wood utility pole at the Eastern Black Sea Region is only about 10–15 years.

Unfortunately, a few studies have been conducted about wood pole inspection and maintenance programs in Turkey. Because of short service life of wood utility poles in the Eastern Black Sea Region, waste of raw wood materials, the concern about environmental contamination, and limited waste management options for treated-wood materials, it is very important to determine the factors affecting service life of wooden utility poles and determine the deterioration and degradation on utility poles.

The objectives of this study were as follows:

- (i) to inspect and determine the deterioration and degradation on utility poles using both visual inspection and nondestructive test methods in Artvin;
- (ii) to determine the factors/reasons for the short service life of the wooden utility poles in the study areas.

2. Materials and Methods

In this study, the wood utility poles in service located in four different regions of Artvin vicinity (Figure 1) were inspected visually according to AWPMA M13-01 [15], a guideline for the physical inspection of poles in service standard method. For each study area, around 150 utility poles were visually inspected and 30 of them were also inspected by semi- or nondestructive test methods.

2.1. Deterioration and Degradation on Utility Poles. The utility poles were visually inspected according to AWPMA M13-01 [15], a guideline for the physical inspection of poles in service standard method, and the following information was recorded:

(A) wood species:

chemical treatment,
age of pole,

(B) type of defect and location:

(1) external defects:

- (a) maximum depth of defect,
- (b) location of defect,
- (c) residual circumference,

(2) internal defects:

- (a) location of defect,
- (b) residual shell thickness.

2.2. Interior Deterioration and Degradation on Utility Poles. The traditional method of testing poles for decay usually does not give accurate results. Researches showed that a large number of poles are replaced unnecessarily and a significant number of poles continue to fail unexpectedly in service [12].

FIGURE 1: Four different study areas where utility poles were inspected in Artvin vicinity.

FIGURE 2: (a) The determination of interior defects and decay by IML-RESI F-300. (b) 45°-adaptor allows determining defects and decay below the ground level.

Therefore, along with the visual inspection, semi- and/or nondestructive methods were also used to determine the internal defects of utility poles. Semi- and nondestructive methods used in this study were explained below.

2.2.1. Resistograph. In order to determine the internal decay and/or damaged zones in utility poles, 30 utility poles for each study area were inspected by using an IML Resistograph. Inspection by resistograph for each pole was conducted at breast height and below ground using 45-degree adapter. The IML-RESI F-300 instrument has been designed for use on wooden utility poles. Often, possible defects are located in the interior of the poles and cannot be identified from the outside. The IML-RESI System is based on a drilling resistance measuring method. The variation in resistance results in increases and decreases in the amount of torque applied to the drill shaft (Figure 2(a)). A drilling needle with a diameter of 2.54 mm penetrates into the wooden poles with a regular advance speed, and the drilling resistance was measured. The data for each pole was recorded on a wax paper strip at a scale of 1:1 and also transferred to computer for further evaluation. The poles were only insignificantly injured because the drilling hole closes itself due to a special drilling angle that was customized for the drill bit. In addition, with 45-degree adapter it is possible to examine the utility pole below ground level (Figure 2(b)). In general, about 90% of all the timber pole defects or damages are located below the groundline level; therefore, it is necessary to carry out complex investigations or excavations to detect them.

2.2.2. Micro Hammer. The utility poles were also inspected using an IML Micro Hammer in order to display the interior conditions of the utility poles. For this purpose, 30 utility poles from each study area were tested and the velocity was measured for each pole by repeating the measurements at three numbers of locations around the pole circumference. The IML Micro Hammer measures the time it takes an impulse to travel through the wood utility poles. Due to the characteristic sound velocity of each wood species, the measurement values clearly display the interior conditions of a utility pole.

The time for the pulse to travel across the pole was measured. The waves of ultrasound travel at speeds of approximately 2000 m/s in sound wood, slow down to speeds in the range 1200–1500 m/s when passing through around early stage decayed sections, and slow down to speed of less than 1200 m/s in decayed or damaged wood. The time of flight gives an indication of the presence of decayed material [12].

2.2.3. Wood Preservative's Penetration Depth and Retention Levels. In order to determine the penetration depths of wood preservatives inside the utility poles, increment core samples were collected from 30 utility poles from each study area. Penetration depth was measured (nearest mm) using stains as described in the standard and [16]. In addition, increment core samples were ground and analyzed by X-ray fluorescence (XRF) spectroscopy using a Phoenix Spectro II spectrometer to determine the Cr, Cu, and As contents in the utility poles [17]. Retention was expressed on kg/m³ basis using

FIGURE 3: White- and brown-rot fungi observed on utility poles in Artvin vicinity.

an assumed density value of 442 kg/m^3 for southern pine as per American Wood Protection Association Standard A12 [18]. Since actual initial retention levels of the poles were not known, the calculated retention data must be viewed as advisory only.

3. Results and Discussion

3.1. Visual Inspections and Observations

3.1.1. Deterioration and Degradation on Utility Poles. The utility poles in four different areas of Artvin vicinity were inspected visually according to AWP A M13-01 [15], a guideline for the physical inspection of poles in service standard method, and were also inspected to determine internal defects using increment core, IML Resistograph, and IML Micro Hammer. According to visual inspection as well as semi- or nondestructive tests results, white-, brown-, and soft-rot fungi were determined (Figure 3).

Wang and Zabel [19] proposed and illustrated the common locations and 6 different patterns of decay seen in the groundline zone of utility poles in the eastern United States. Similarly, based on our observations in this study, 4 different decay patterns might be proposed.

(1) *Surface Rot.* It was usually seen (especially in study area I) at the beginning of the decay or when the utility poles were exposed to extremely high moisture: outer zone of utility poles becomes softer (Figure 4(a)).

(2) *Small Decay Pockets.* These kinds of decay patterns usually developed due to fungi mycelium entering inner untreated zones through cracks and checks (Figure 4(b)).

(3) *A Large Decay Pocket.* This was the advance form of small decay pockets (Figure 4(c)).

(4) *The “Hollow” Decay.* This decay pattern may result from an advancement of the in-between type or a decay fungus that has escaped the preservative treatment. In this type of decay, fungi mycelium usually enters center of the pole before preservative treatment. In addition, because top of a utility pole is usually exposed to extreme sunlight and rain

repeatedly, this type of decay pattern was seen on the top of utility poles (Figure 4(d)).

According to visual observations, the highest decay damage was found as 55% of the utility poles inspected in study area I, while the lowest decay damage was found as 10% of the utility poles inspected in study area IV (Table 1).

Based on visual and nondestructive inspections, the following remarks about deterioration and degradation of utility poles were made.

(1) *Insect Infestation.* In this study, insects' attacks were observed on treated-wood utility poles in all four different study areas. While the most insect-attacked wood poles were observed in the study area I, the least insect-attacked wood poles were found in the study area IV (Table 1). Insect attacks were usually seen on the utility poles whose cambium and outer bark sections were not properly removed before impregnation. In addition, intense insect attack was also observed on the utility poles which were already degraded by decay fungi (Figure 5). The outer and inner bark, which need to be peeled away from softwoods after being cut, protect the tree from fungi and insects and from drying. Bark must be removed from poles during processing because it attracts many wood-boring insects, retards drying, and prevents preservative treatment. Peeling wooden utility poles is necessary to enable the wood to dry quickly enough to avoid decay and insect damage and to permit the preservative to penetrate satisfactorily. Even strips of the thin inner bark may prevent penetration. Patches of bark left on during treatment usually fall off in time and expose untreated wood, thus permitting decay to reach the interior of the member [20].

(2) *Burning.* Interestingly, a few fire-damaged poles were also observed in the study areas. In particular, poles located out of city centers suffered from this damage. It was thought that shepherds and/or some people made fire at the bottom of the utility poles in order to warm up or for barbecue purposes. Because of the fire at the bottom of the utility poles, outer zones of utility poles near groundline which were more sensitive for fungi and insects attack were damaged and this led to shorter service life of utility poles than expected.

Fire damage can make poles useless. Extreme care should be taken in burning rubbish or brush along rights-of-way

FIGURE 4: Decay patterns observed on utility poles. (a) Surface decay. (b) Small decay pockets associated with checks. (c) A large decay pocket associated with a check. (d) Hollow-type decay.

TABLE 1: Visual inspection of the utility poles in four different study areas in Artvin vicinity.

Location	Number of poles inspected	Penetration depth (cm)	Deep cracks (%)	Insect attack (%)	Decay (%)
Area I	150	1-6	95	50	55
Area II	150	1-6	85	25	20
Area III	150	1-6	85	30	30
Area IV	150	1-6	75	15	10

FIGURE 5: Insect attacks on the utility poles.

where treated poles are spotted. After poles are set in the ground, the immediate area should be cleared of weeds and grasses. Fire-retardant coatings may also be used to protect poles from fire. When a chemical weed killer is to be used, a soil-sterilant, water-soluble type that will keep weeds down for a 3-year period is recommended [21].

(3) *Deep Cracks and Checks.* One of the defects observed on utility poles in the study areas was the deep cracks and checks (Figure 6). In this study, it was found that around 85% of the inspected utility poles had deep cracks and checks in all 4 study areas (Table 1). It was reported that checks may extend into the pole beyond the shell of treated wood. Fungi, termites, and carpenter ants enter the poles through the exposed untreated wood and may cause extensive internal deterioration within 10 years after installation [22].

The deep cracks, splits, and checks thereafter cause the internal deterioration of treated poles because the untreated center portion of the pole is exposed to fungi and insects. Although internal decay may occur above ground as a result of checks or holes drilled after treatment, the critical groundline zone of poles is most subject to such deterioration because moisture conditions near and below groundline are most favorable to growth of wood-destroying organisms [21].

In addition to deep cracks and checks, damage by people and wood peckers may also affect the service life of utility poles. According to visual inspections in this study, damages on utility poles due to people and wood peckers were observed (Figure 7).

(4) *Preboring Holes before Impregnation.* Preboring all holes used for attachments such as guy wires or cross-arms should be made before impregnation because it helps to protect the preservative-treated shell from damage. Drilling in the field after impregnation exposes untreated wood, creating the potential for aboveground decay. However, based on our investigations, it was found that preboring holes were made after impregnation (Figure 8). In addition, poles were cut in length after impregnation which causes untreated cross sections of utility poles exposed to fungi and insects. Therefore, service life of treated poles may become shorter than it should be.

(5) *Penetration of Wood Preservative.* The depth of preservative (CCA) penetration was measured (nearest mm) from the

increment core samples taken from CCA-treated utility poles in both service (in 4 study areas) and storage area. The results showed that penetration depths of wood preservative (CCA) in utility poles ranged from 1 to 6 cm. (Figure 9 and Table 1).

Utility wood poles are usually treated with either oil- or water-based preservatives using empty or full cell pressure treatment process in order to achieve a certain desired depth of penetration at a level or retention that provides biological protection against fungi and insects. The proportion of sapwood varies greatly with wood species, and this becomes an important factor in obtaining adequate penetration. Penetration requirements differ according to the wood species, amount of sapwood present, and the ease with which it can be treated [20, 23].

The proper penetration and retention levels of wood preservative are very important to protect wood poles. The retention and penetration obtained in application determine the effectiveness in protecting wood materials against decay and insects. Preservative effectiveness depends on many factors such as the protective value of the preservative chemical, the method of application, and extent of penetration and retention of the preservative in the treated wood. Even if the wood preservative is very effective, good protection cannot be ensured with poor penetration or substandard retention levels.

Colley and Amadon [24] studied the relation between penetration and decay in utility poles treated with creosote and inspected around 3102 poles in the field ages up to 26 years. They found that 95.16% of the poles which failed in inspection had penetration less than 1.8 inches (4.572 cm) and 60% of the sapwood thickness which was lower than minimum required penetration depth. They reported that in the sections of the lines that were inspected the incidence of decay was definitely correlated with the depth of penetration of the creosote and the percent of sapwood penetrated.

3.1.2. Inspection Results by Resistograph. Some resistograph outputs of the utility poles inspected in four different study areas in Artvin vicinity are given in Figure 10.

As is seen in Figures 10(a) and 10(e), although there was no visible decay or deterioration on the utility poles when they were inspected visually, decay pockets and hollow parts in the interior zone of the utility poles were determined when they were inspected by resistograph. It was assumed that

FIGURE 6: Deep cracks and checks on the utility poles.

FIGURE 7: Damages on the utility poles were caused by people and wood peckers.

FIGURE 8: Preboring holes were not made before the impregnation.

the reason for the decay pockets and hollow parts inside the utility poles was the presence of the deep cracks and splits. Although utility poles were treated with wood preservatives, because of these deep cracks and splits, fungi mycelium and insects might easily get into the interior location of the utility poles where the penetration depth of wood preservative is limited. In addition, these deep cracks and splits could affect mechanical and strength properties of utilities which might cause failure of utility poles. Therefore, it is very important to detect the defects inside the utility poles.

As is seen in Figures 10(c), 10(d), 10(e), 10(f), 10(g), and 10(h), although there was no visible decay or deterioration on the utility poles when they were inspected visually, small decay pockets and hollow parts in the interior zone of the utility poles were determined when they were inspected

by resistograph. Thanks to resistograph inspection, determination of early stage of decay and deteriorations might be possible. The lifetime of utility poles in service could be increased by periodical inspections and determining the decay and deteriorations at early stage using bandage and other remedial treatments. It is important to point out that the durability of the in-service wooden pole is related to several factors, mainly the quality of new wood poles going into service (inherent characteristics of the wood, limited control on white wood, and treatment process); the environmental factors (climate conditions, soil characteristics, and nature of fungal/insect attack); and the effectiveness of the inspection and maintenance programs [25].

While this method shows good results in assessing utility poles, it only provides health assessment at the location of drilling. Even though the hole size produced is relatively small, repeated drilling may weaken the pole locally.

3.1.3. Inspection Results by Micro Hammer. The utility poles in four study areas were inspected by Micro Hammer and the results are given in Table 2.

It was found that average velocity in study areas I, II, III, and IV was 1710, 2050, 1911, and 2230 m/s, respectively. Number of sound, early state, and decayed and/or damaged poles was determined for each study area. For this purpose, if the measured velocity for a given pole is higher than 1500 m/s, the pole was assumed sound while if the velocity is lower than 1500 m/s and higher than 1200 m/s, the pole was assumed to be at early stage decay and/or damaged; if the velocity was lower than 1200 m/s, then the pole was sorted as damaged

FIGURE 9: Penetration of wood preservatives in utility poles.

and/or decayed. The highest number of decayed/damaged poles was found in study area I, while the lowest number of decayed/damaged poles was found in study area IV.

In one study by Robert et al. [26], stress wave testing was examined as a technique for evaluating structural stability of timber bridges and they reported that the presence of decay greatly affected stress wave propagation velocity in wood. The results showed that propagation velocities for nondegraded Douglas-fir were approximately 1250 m/s, whereas severely degraded members exhibit velocity values as low as 310 m/s [26].

Pellerin et al. [27] showed that stress wave speed could be successfully used to monitor the degradation of small, clear wood specimens exposed to brown-rot fungi. They found a strong correlative relationship between stress wave speed and the compressive strength parallel to the grain of exposed wood. Rutherford [28] also showed similar results.

3.2. Amounts of Cu, Cr, and As in Utility Poles in Service. Increment core samples were collected from 30 utility poles for each study area and analyzed for Cu, Cr, and As amounts by X-RF. The results are given in Table 3. According to the AWP Standard U4 [29], the minimum retention of CCA-treated utility poles should be 9.6 kg/m^3 . However, the results showed that amounts of Cu and As in utility poles inspected in service were much lower than required amounts. This

showed that utility poles were not treated properly and the required minimum retention level specified in the standards was not achieved. Another reason for the lower Cu and As amounts could be that the utility poles were installed in service before the fixation of CCA was completed which could result in big losses of Cu and As from utility poles. Therefore, it may be concluded that this might be one of the reasons why the utility poles in this region became out of service in shorter time than expected.

Retention is expressed as the weight of preservative per volume of wood (lb/ft^3 or kg/m^3); achieved retention level depends on wood species and treatment process (i.e., empty or full cell). For example, wood poles used in warmer, wetter climates are exposed to a higher risk of decay and are usually treated to a higher retention than are those exposed to drier, cooler conditions [23].

4. Conclusions

- (1) In this study, the utility poles in four different study areas in Artvin were inspected by using visual and nondestructive test methods. Deteriorations, degradations, and damages in utility poles in the study areas were determined. While IML Resistograph and IML Micro Hammer showed good results in assessing utility poles, they only provide health assessment at

FIGURE 10: Some resistograph outputs for the utility poles inspected in Artvin vicinity.

TABLE 2: Micro Hammer inspection results.

Location	Number of poles inspected	Velocity (m/s) Average	Std.	Number of sound poles*	Number of early stage decayed/damaged poles**	Number of decayed/damaged poles***
Area I	30	1710	360.7	9	15	6
Area II	30	2050	312.8	17	10	3
Area III	30	1911	264.5	13	14	3
Area IV	30	2230	463.3	20	8	2

*Velocity higher than 1500 m/s.

**Velocity lower than 1500 m/s and higher than 1200 m/s.

*** Velocity lower than 1200 m/s.

TABLE 3: Cu, Cr, and As amounts in utility poles inspected in 4 study areas.

Location	Pole age	n^2	Decay hazard classes ³	Cr %		Cu %		As %		Ret. ⁴ kg/m ³
				Avr.	Std.	Avr.	Std.	Avr.	Std.	
Area I	15–20	30	High >70	0.950	0.273	0.211	0.087	0.285	0.092	6.40
Area II	15–22	30	Moderate 35–70	1.091	0.269	0.271	0.010	0.300	0.070	7.35
Area III	12–22	30	Moderate 35–70	1.017	0.274	0.250	0.021	0.290	0.066	6.88
Area IV	18–24	30	Low 35<	1.082	0.255	0.290	0.063	0.368	0.083	7.70
Retention ¹ (control)		10		0.999	0.066	0.413	0.014	0.758	0.082	9.60

¹Min required retention (9.6 kg/m³).

²Number of poles inspected.

³Calculated based on Scheffer's formula.

⁴Calculated value based on the formula given in the AWP Standard.

the location of drilling/testing. Therefore, when poles are inspected, both visual observation and nondestructive test results should be taken into account to evaluate the pole health.

- (2) The results showed that the most important factors/reasons for the short service life of utility poles were

- (a) the decay due to fungi,
- (b) insect infestation,
- (c) inadequate impregnation,
- (d) insufficient preservative penetration depth,
- (e) the deep cracks and splits,
- (f) poor quality control,
- (g) no inspection and lack of remedial treatments.

- (3) It is very important to increase service lifetime of wood poles because of the costs associated with their replacement and environmental concerns, because out of service poles are considered hazardous wastes which must be adequately disposed of or recycled.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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