Assessment of Reuse Potential of Maritime Pine Utility Poles for Structural Applications after Removal from Service

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There has been a strong recent effort to develop procedures that prevent the unnecessary replacement of timber utility poles. Even when assessments show that the utility pole needs to be replaced, there are many cases in which the removed utility poles can be reused. The aim of this study was to determine the mechanical properties of Maritime Pine (*Pinus pinaster* (Ait.)) utility poles removed from service (UPRFS) in order to assess their ability to be reused in structural applications. A sample of 51 UPRFS in Portugal was selected, and visual and mechanical properties were evaluated through non-destructive and destructive tests. Dynamic modulus of elasticity (MOE_{dyn}) was correlated with bending strength (MOR) (r = 0.43) and modulus of elasticity (MOE) (r = 0.71). UPRFS showed a decrease of 14% and 6% in the mean values of MOR and MOE, respectively, when compared with new utility poles. A high variability and low values were obtained for MOR. These results highlight the reuse potential of the maritime pine utility poles for structural applications. Furthermore, the determined properties of UPRFS could be improved with a more stringent selection process that discards utility poles showing severe damage or by removing damaged areas in the utility poles.

Keywords: Timber utility poles; Maritime pine; Structural reuse; Mechanical properties; Bending test

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INTRODUCTION

Maritime pine (*Pinus pinaster* (Ait.)) utility poles have been used in Portugal since the second half of the 19^{th} century, and currently it is the main species used for this purpose. Globally, telecommunication and power companies make use of timber utility poles for overhead lines. The companies responsible for the maintenance of these lines usually perform simple *in situ* tests to evaluate the conservation state and the ability of the utility poles to remain in service. *In situ* evaluation results are very important because they are used to decide if the utility pole needs to be replaced. However, if the test results are misinterpreted or are inaccurate, the replaced utility poles may still be in good condition. In these cases, the unnecessary replacement wastes resources. In Australia, up to 80% of the removed utility poles are still in serviceable conditions (Nguyen *et al*. 2004).

Non-destructive techniques have been recently developed to assess the structural integrity of utility poles *in situ* and, consequently, their ability to be kept in service for longer periods (Tsang and Chan 2008; Hron and Yazdani 2011; Tsang and Chan 2011; Gezer *et al.* 2015; Reinprecht and Šupina 2015). Despite these efforts, many utility poles in good condition are being removed from service, but this large amount of waste could be reduced by reusing the utility poles in other applications (Cooper *et al.* 1996; Leichti *et al.* 2005).

Several studies have evaluated the structural capability and mechanical properties of new timber poles, including maritime pine poles and roundwood, for structural applications (Vries and Gard 1998; Cerda and Wolfe 2003; Torran *et al.* 2009; Morgado *et al.* 2009; Martins and Dias 2012). To encourage and enhance the use of maritime pine roundwood, Martins *et al.* (2016) used small diameter poles in the fabrication of timber-concrete composite floors for residential buildings, and Morgado *et al.* (2013) developed connection systems for the structural applications of small diameter poles. Because there are many applications for timber poles and roundwood, utility poles removed from overhead lines are good alternatives for some of these situations; however during their service time, they are exposed to extreme conditions and potential damage. Accordingly, to assess their potential for reuse, their mechanical properties must be assessed carefully.

This study assessed the mechanical properties of Portuguese maritime pine utility poles removed from service (UPRFS). For this purpose non-destructive and destructive methodologies were used to evaluate the specimens (Green *et al.* 2006; Morgado *et al.* 2008; Morgado *et al.* 2012), including the following: (i) visual characterization; (ii) determination of the dynamic modulus of elasticity (MOE_{dyn}) through the longitudinal vibration method; (iii) determination of modulus of elasticity (MOE) and bending strength (MOR) using destructive tests according to the CEN/EN 14229 standard (2010); and (iv) correlation of the results. These results were compared with those obtained by Martins and Dias (2012) for new maritime pine utility poles with similar dimensions.

EXPERIMENTAL

Visual Characterization

A total of 51 specimens were selected by simple visual inspection; utility poles with serious damage were rejected. Some selected utility poles showed signs of damage such as attainment of maximum bending moment near the ground-line (Fig. 1), rot in the previously buried length (Fig. 2), and woodpecker holes in the upper part of the utility pole (Fig. 3).

In the specimens that showed signs of a previous failure at the ground-line the failure section was cut, resulting in a reduction of length. Thus, the initial sample was divided into 2 groups. The first group contained 45 specimens with an average length of 8.0 m, and the second group contained 6 specimens with an average length of 7.3 m.

Concerning the other damages mentioned and found in UPRFS, they can be detected through a careful visual inspection. However, these damages were not removed. Therefore, utility poles were tested in the same condition in which they were removed from service. In 41% of the specimens the previously buried length was not cut and some biological damage was found. The buried areas were not distinguishable in some specimens. In 20% of the utility poles other types of damage (woodpecker holes and minor mechanical damages) were visible.

After the removal from service, utility poles were kept outdoors exposed to climatic variations. Also they were tested during a long period of time – approximately 6 months. For these reasons, moisture content of tested UPRFS presented some variations.

The selected utility poles showed two types of preservative treatments: creosote and chromated copper arsenate (CCA), however an assessment of the number of utility poles corresponding to each treatment was not made.

Some utility poles (19.61%) had the year of production marked according to the distribution showed in Table 1.

Fig. 1. Attainment of maximum bending moment near the ground-line

Fig. 2. Rot in the previously buried length

Fig. 3. Woodpecker holes

Table 1. Distribution of the Removed Utility Poles by Year of Production

Years of Production	Number of Poles
1960 – 1964	1
1980 – 1984	3
1985 – 1989	1
1990 – 1994	2
1995 – 1999	1
2000 – 2004	1
2005 – 2009	1

The utility poles were visually characterized according to the CEN/EN 14229 standard (2010) so that they could be easily compared with previously published results. Accordingly, the following properties were evaluated and recorded: length of the utility pole, nominal diameter at the butt, nominal diameter at the ground-line (1.5 m from the butt), nominal diameter at the point of load application, slope of grain, and growth rate either at the butt and tip of the utility pole. The utility poles were also weighed in order to determine their approximate density at time of test. Additionally, the straightness of each utility pole was evaluated and verified if it was within the limits imposed in CEN/EN 14229 (2010).

CEN/EN 14229 (2010) allows for deviations in pole straightness for two situations. Single sweep is permitted as long as the longitudinal axis of the pole remains within a distance of 1% of the pole length from a straight line drawn from the center of the tip to the center of the pole 1.5 m from the butt. Double sweep is permitted if a straight line from the center of the tip to the center of the pole 1.5 m from the butt remains within the limits of the pole.

A total of 16 utility poles (31.37%) presented double sweep within the limits of CEN/EN 14229 (2010), and 34 utility poles (66.67%) showed single sweep, of which 2 did not fulfill CEN/EN 14229 (2010). One utility pole (1.96%) did not show significant sweep.

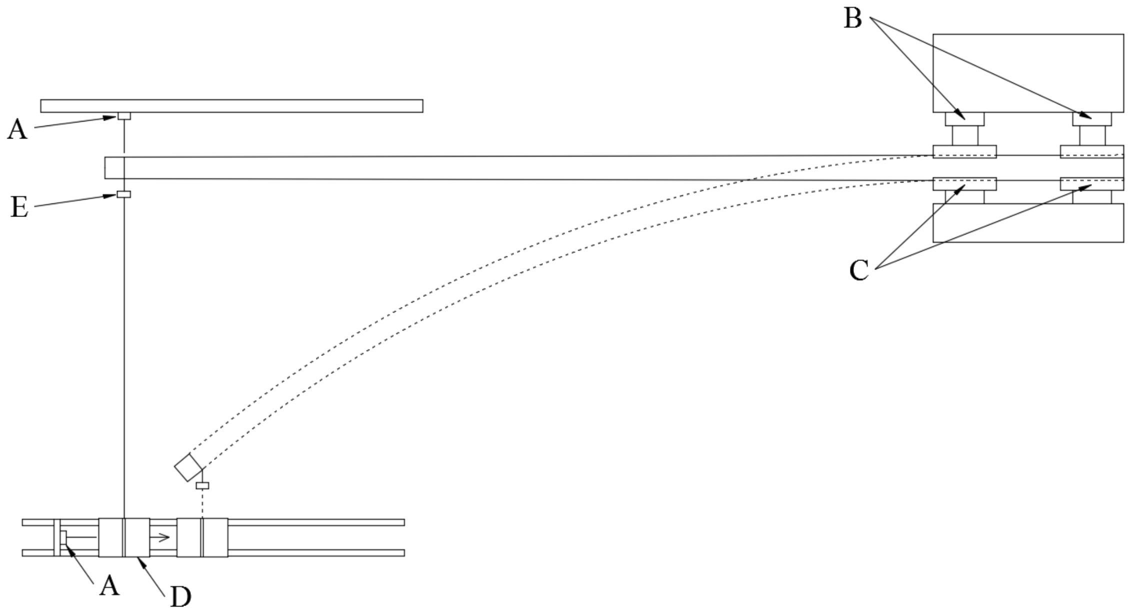
CEN/EN 14229 (2010) also defines the standard length for utility poles of 8 to 10 m, and the standard diameter at 1.5 m from the butt end of 180 to 220 mm. Some utility poles that did not meet these requirements were tested as well.

Non-destructive and Destructive Tests

Non-destructive tests are quick and easy alternatives for estimating mechanical properties without destroying the specimens. Transversal and longitudinal vibration methods are known for the good correlation coefficients achieved between MOE_{dyn}, MOR, and MOE (Vries and Gard 1998; Morgado *et al.* 2008). In a previous study Morgado *et al.* (2008) achieved a correlation coefficient of 0.77 between MOE_{dyn} and MOR using longitudinal vibration method, showing the potential of this methodology to predict the mechanical properties. Therefore, in this study, the utility poles were tested by longitudinal vibration, using a longitudinal impact with a hammer, and acceleration was measured in the same direction. The non-destructive tests were complemented with mechanical (destructive) tests to determine MOE, MOR, and also to calculate the characteristic value of MOR ($MOR_{,k}$).

These tests were performed according to CEN/EN 14229 (2010) using the cantilever bending test method, presented in Fig. 4. In this testing setup the bottom section of the utility pole was rigidly clamped up to the assumed ground-line and the load was applied 150 mm from the tip of the utility pole. Two pairs of hydraulic clamps were used together with timber shoes of 500 mm each and shaped to fit the wood utility pole. The specimens were tested in a position such that the underside of the tested utility pole in its "natural rest" was in tension. The characteristic value of MOR was calculated using the expressions in Annex D of the same standard.

After each destructive test, a sample of the entire cross section with a thickness of approximately 50 mm was cut as close as possible to the failure position to, posteriorly, determine moisture content (w) and density (ρ). The failure location of each utility pole was recorded.



A – Deflection measuring devices
B – Hydraulic clamps
C – Wood shoes (500 mm each)
D – Trolley mounted winch
E – Load measuring device

Fig. 4. Schematic representation of testing setup used, using the indications from CEN/EN 14229 (2010)

RESULTS AND DISCUSSION

Table 2 presents the results of the visual characterization campaign undertaken in this study.

Table 2. Visual Properties of UPRFS

	Group 1 (45 specimens)		**Group 2** (6 specimens)	
	Mean	Std. Dev.	Mean	Std. Dev.
Length (m)	8.0	0.04	7.3	0.29
Nominal diameter (mm)				
Ground-line	179.2	16.0	182.4	17.9
Loading point	135.9	13.5	138.4	15.6
Ovality (%)				
Ground-line	6.1	3.0	6.2	2.5
Loading point	6.6	3.4	6.5	3.0
Taper (mm/m)	6.9	2.5	7.7	3.0
Slope of grain (cm/m)	4.5	3.1	3.9	2.4
Growth rate (rings/25mm)				
Butt	10.3	4.3	9.9	5.6
Tip	9.3	4.3	6.3	2.5
Density* (kg/m^3)	571	71	578	72

* - The density values correspond to a moisture content of 12%.

The mean values for the visual properties of UPRFS, split into the two groups previously mentioned, are presented. These results are also compared with the ones obtained by Martins and Dias (2012) for new utility poles.

The utility poles tested in both studies (Group 1 and Martin and Dias (2012)) had the same length. Compared with new utility poles (Martins and Dias 2012), UPRFS had smaller mean values of nominal diameter at the ground-line and at load cross section. The ovality was higher in UPRFS at both the ground-line and at the loading cross section. The taper of utility poles from Group 1 was equal to the new utility poles, but with a lower standard deviation. UPRFS presented lower values for slope of grain and less growth rings per 25 mm, indicating that the trees used to make the utility poles had faster growth. The density values obtained for a moisture content of 12% were very similar in both studies, which was expected because UPRFS and the new utility poles were produced from the same species.

Table 3 presents the results both for non-destructive and destructive tests. As shown, there were slight differences in the mean values of MOE and MOR between Group 1 and Group 2, but both these differences were not statistically significant (α=0.05). MOE_{dyn} calculated from non-destructive tests was higher on average than the MOE obtained through the mechanical tests. In these case the observed difference between the mean values of the mentioned features is statistically significant (α=0.05). As consequence, to accurately predict the mechanical properties of UPRFS through MOE_{dyn}, more tests must be performed for calibration.

Table 3. Non-destructive and Destructive Tests

	Moisture Content	Density	Non-destructive Tests		Destructive Tests		
	w (%)	ρ* (kg/m^3)	*f* (Hz)	MOE_{dyn} (MPa)	MOE (MPa)	MOR (MPa)	F_{max} (kg)
Mean Value							
Group 1	42.6	571.1	265.0	12270.3	10225.4	43.1	402.2
Group 2	40.5	578.4	288.0	11989.4	9848.5	48.5	527.0
Minimum Value							
Group 1	16.0	397.3	223.1	8439.7	5754.2	11.7	100.0
Group 2	17.9	480.4	268.0	9478.3	5365.1	22.2	308.0
Maximum Value							
Group 1	101.7	721.8	312.0	18537.4	18618.4	80.4	1013.0
Group 2	76.6	664.0	298.0	13916.3	12954.1	72.1	872.0
Std. Deviation							
Group 1	15.9	71.4	20.0	2077.7	2294.1	13.5	159.0
Group 2	24.5	72.0	13.8	1695.0	2485.2	16.2	192.5
Number of specimens							
Group 1	**45**						
Group 2	**6**						

* - The presented values of density correspond to a moisture content of 12%.

The average distance to the ground-line of the failure location was 875 mm (standard deviation of 732 mm), and knots were present in the failure section in 55% of all utility poles tested. The main cause of failure was tension stresses in the utility poles (88.2%), but in a smaller number of samples, failures were due to compression associated with tension stresses (9.8%). One utility pole suffered a great deflection during testing, reaching the maximum load without any apparent signs of failure. This specimen presented one of the lowest values of static MOE (7649 MPa) which influenced its behavior leading to the great deflection during destructive test. This specimen also had the particularity of presenting the highest value for slope of grain, however this visual property did not present any noticeable correlation with mechanical properties (r = -0.15 and r = 0.13 for MOE and MOR, respectively).

A comparison of the results obtained from the destructive tests of Group 1 (Table 4) and the results from Martins and Dias (2012) was made in order to identify the influence of the service period and the damages found in some specimens in the mechanical properties of UPRFS.

Compared with new utility poles, with MOR_k = 37.0 MPa (Martins and Dias 2012), UPRFS exhibited a 49% decrease in the characteristic value of MOR. This difference is directly related with the higher standard deviation of UPRFS, which leads to a coefficient of variation of 31.3%, against the 13.1% coefficient of variation of the new utility poles. The cause for the higher standard deviation for UPRFS was the wide range of MOR values. Not only low values were obtained, due to the several damages found in UPRFS, but also high values, as it is showed in the frequencies distribution of MOR values, in Fig. 5. However, the reduction of the MOR mean value of UPRFS was only 14% when compared with the mean value of the new utility poles (50.2 MPa). Regarding MOE, the mean value of UPRFS was 6% lower than in new utility poles (10.9 GPa).

The lowest MOR value (11.7 MPa) was from a utility pole that presented biological degradation in the previously buried area and the damage influenced the mechanical behavior of the utility pole. Therefore, special attention needs to be paid to the level of damage of UPRFS if they are to be reused for structural applications. UPRFS could be used in other structural applications if a good selection is made, refusing severely damaged specimens. If a damage-free utility pole selection is not possible, the alternative is to process the utility poles and remove damaged areas, usually near the ground-line and/or near the top.

Table 4. Summary of the Results from Destructive Tests (Group 1)

	MOE (GPa)	***MOR (MPa)***
Mean Value	10.2	43.1
Characteristic Value	-	18.7
Minimum Value	5.8	11.7
Maximum Value	18.6	80.4
Std. Deviation	2.3	13.5
Coefficient of Variation (%)	22.3	31.3
Number of specimens	45	

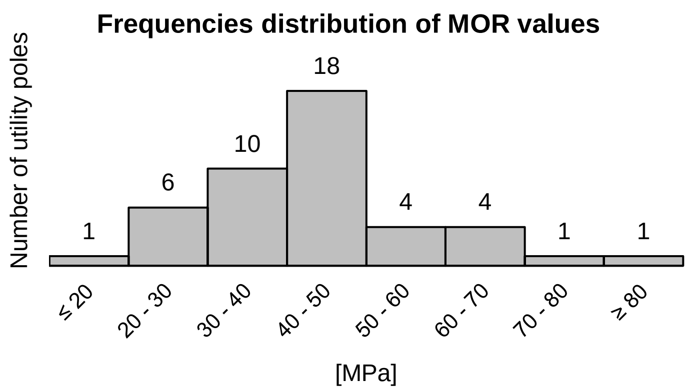


Fig. 5. Distribution of the frequencies of the MOR values obtained in destructive tests

A linear regression analysis was used to assess correlations between visual and mechanical properties. With regard to geometric properties and MOR, the highest correlation was obtained for taper (r = -0.27) followed by nominal diameter at the ground-line (r = -0.26). In a first analysis these correlation coefficients indicate a weak correlation between the mentioned properties; therefore a statistical test was done to evaluate their significance. It was concluded that both correlations were not statistically significant (at a significance level of 0.05), which means that these r values were statistically equal to zero and that no notorious correlation was found between MOR, taper and nominal diameter at the ground-line.

For MOE, the highest correlation with geometric properties was obtained for nominal diameter at the ground-line (r = -0.43) and taper (r = -0.28). The coefficient correlation between MOE and nominal diameter at the ground-line was statistically significant (at a significance level of 0.05), meaning that an actual correlation exists between these properties. In contrast, the r value between MOE and taper was also not statistically significant (significance level of 0.05). The density (adjusted to 12% moisture according to CEN/EN 384 (2004)) showed a coefficient of correlation of r = 0.37 with MOE and although it is not a high correlation value, the statistical test showed that it was statistically significant (significance level of 0.05).

Moisture content usually influences the mechanical properties of timber elements and UPRFS presented a significant variation regarding this feature, for this reason correlations with the mechanical properties were also performed. Correlation coefficients of $r = -0.45$ and $r = -0.41$ were obtained between moisture content, MOR and MOE, respectively, and both correlations were statistically significant (significance level of 0.05).

For the mechanical properties, the best correlation with MOR was MOE, with a coefficient of r = 0.67. Natural vibration frequency, measured in the dynamic tests, was the second best correlation (r = 0.61) with MOR.

MOE_{dyn} showed a lower correlation with MOR ($r = 0.43$), which might be related to the value of the density used in calculation. The value was determined in the field at the time of the tests, where the utility poles were weighed and density was calculated using utility pole weight and its approximate geometry, taking into account the corresponding taper for each utility pole. The correlation would be higher (r = 0.51), if density value determined in the laboratory were used.

The best coefficient of correlation with MOE was r = 0.74 for frequency, and the correlation between MOE and MOE_{dyn} was the second best, with a coefficient r = 0.71.

In summary, the best correlation with MOR was established by MOE, but the value of the coefficient was lower than that of unused utility poles (Martins and Dias 2012). This result may be related to the different levels of damage on the UPRFS. Also, the visual property with the highest correlation with MOR was taper, similar to the previous report (Martins and Dias 2012).

CONCLUSIONS

1. MOR was influenced by damages in utility poles, resulting in high variation of this property. Very low values were obtained in damaged specimens; the utility pole with the lowest MOR value (11.7 MPa) showed signs of severe deterioration in the failure section. Therefore, in order to reuse utility poles for other structural applications a strict selection is required, rejecting the ones showing damages or, if not possible, remove the damaged areas in the utility poles.
2. Compared with new utility poles, UPRFS demonstrated a 14% reduction in the mean value of MOR.
3. The mean MOE of maritime pine UPRFS was only 6% lower than in new utility poles.
4. The dynamic tests used to evaluate MOE_{dyn} showed correlation factors of r = 0.74 between natural vibration frequency and MOE and r = 0.61 between natural vibration frequency and MOR. MOE_{dyn} showed a lower correlation with MOR (r = 0.43).

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