DE GRUYTER OPEN

Vol. 14, Issue 1/2018, 54-60, DOI: 10.2478/cee-2018-0007

DIAGNOSTICS OF WOODEN POLES SITUATED IN THE OPEN - AIR MUSEUM USING SONIC TOMOGRAPHY

Oto MAKÝŠ[1], Peter KRUŠINSKÝ[2,*], Renáta KORENKOVÁ[3], Dominika ŠROBÁROVÁ[1]

[1] Faculty of Civil Engineering, Slovak Technical University, Vazovova 5, 811 07 Bratislava, Slovakia.
[2] Faculty of Civil Engineering, University of Žilina, Univerzitná 8251/1, 010 26 Žilina, Slovakia.
[3] Alfaprojekt, Borová 21, 010 07 Žilina, Slovakia.
[*] corresponding author: krusop@fstav.uniza.sk.

Abstract

The paper deals with the lifetime of wooden poles, situated in the archaeological open-air museum Liptovská Mara - Havránok, which were erected outdoors about 12 years ago. It is aimed at diagnosing their condition using sonic tomography. The poles differ from each other in the location, anchorage, and positioning in terms of the terrain slope. Investigation was focused on the free-standing poles (quasi sacrifice poles) and the poles that are part of the fortification (gates and walls). Measurements were carried out using the device Fakopp ArborSonic 3D Sonic Tomograph that has 18 sensors. It measures the sonic response (sound velocity) in a tree stem. Sound wave velocity within sound wood depends on its species, moisture content, and the direction of measurement. Measurements brought remarkable results.

Keywords:

Sonic tomograph;
Wooden element;
Wood damage.

1 Introduction

The archaeological locality on Mount Havránok near the Liptovská Mara dam is one of the most important Celtic culture sites of the late Iron Age/early Roman period (2nd century BC - 1st century AD) [1] not only in Slovakia, but also in Central Europe. The research has been running here since 1965; it is conducted by Mgr. Karol Pieta, PhD. from the Archaeological Institute of Slovak Academy of Sciences. In 1986 - 1992, the first phase of the project was finished - a gradual model and experimental reconstruction of selected parts in the area in order to bring visitors a three-dimensional view of the mentioned age directly in its original location. The fortification of the sacrifice site on the eastern terrace was reconstructed using various methods. All the reconstructed objects came under the Liptov Museum, a founder of this archaeological open-air museum in Slovakia.

2 Archaeological open-air museum Havránok

In 2002 - 2007, the team from the Archaeological Institute of the Slovak Science Academy, Liptov Museum, Faculty of Civil Engineering of the Slovak Technical University in Bratislava, and the civic association Tree of Life managed to organize maintenance and renovation works to make good certain damage - especially in the sacrifice site. After the works had been finished, the problem of adequate maintenance reappeared, so the area is now damaged again. It should be added that the material and design solution used (the other one cannot be applied in the open-air museum of this type) will require repairs or interventions sometime later. The question is to what extent the degradation of wooden structures have moved after about 12 years since their renovation.

3 Sacrifice site

The sacrifice site of Celtic culture in Havránok is among the most important archaeological sites of its kind in Central Europe. Owing to its authentic founding and use, only a few fragments survived, which provided space for artistic interpretation. The site is unique because it was originally fortified and entered through the curved space in front of the gate protected by a tower, which is the oldest evidence of such an entrance into a protected area in our country. Further similar entrances occurred thousand years later.

Extensive damage to the structures came 12 - 15 years later. It was caused by using an inadequate building material (a significant portion of poorly treated wood) and construction details (wooden poles fixed into the ground). The situation was worsened by unstable waterlogged mount slope situated in the landslide area. A considerable part of problems was managed to solve in 2002 - 2007, so the major part of the site could be restored (Figs. 1 and 2).

Fig. 1: View of the sacrifice site.

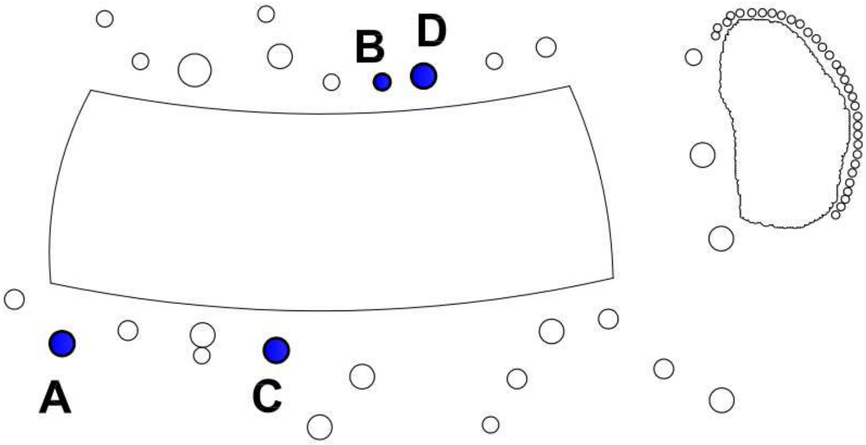


Fig. 2: Arrangement of wooden poles investigated in the sacrifice site.

When the open-air museum was created, the wooden and totem poles (trees modified in various manners) were fixed into the original pole pits. Unfortunately, almost none of the original totem poles survived; their lower or upper parts decayed due to the contact with the ground. A few original pieces of artwork were saved and now they are put on display in the open-air museum building. There are their good copies in the sacrifice site.

4 Design solution

In 2003 - 2007, totem poles in the sacrifice site were restored using green larch wood. The bark was immediately removed and 3 weeks later the stems were decorated with carvings inspired by the original motifs. The poles were then fixed into pits considering diameters of the original Celtic poles. They were experimentally fixed into different materials. Some poles were fixed directly into the ground, i.e. into soil; others were fixed into the lime-mortar, cement-mortar, or concrete bed. The beds were made relatively massive; each had a 5 - 7 cm thick mortar layer on the bottom. After that mortar was poured around the pole to create a 10 cm thick layer and wrap the pole as far as the ground level. Mortar was covered by turf to camouflage it. Such complicated works were chosen because of the research purpose. Different fixations were supposed to be evaluated some years later, what have just happened. It was also supposed that concrete fixation would prolong the lifetime of the poles, which has been proved. It should also be added that the terrain in the sacrifice site is often saturated with rainwater running down the slope.

5 Experimental measurements

The Fakopp 3D Sonic Tomograph is used in practice to diagnose latent, i.e. internal, damage to living trees. This device was used for decay detection within wooden elements in the archaeological open-air museum Havránok. The method is semi-invasive; there are minimal interventions in wood. In fact it is the measuring of time taken for sound stress waves to pass through the wood of a tree or a wooden element. Longer time indicates internal biotic damage, possibly a cavity in a tree stem or wooden element.

In general, the denser wood, the higher speed of sound. If the wood moisture content is higher, sound waves pass through it more slowly because the capillaries contain water instead of the air [2]. It results in higher sound-wave resistance. The velocity of sound waves within sound wood depends on its species, moisture content, and the direction of measurement [1]. Average sound wave velocity for different tree species is given in Table 1 and made according to [1]. The paper presents in-situ measurements of wooden elements using the Fakopp 3D Sonic Tomograph.

Table 1: Average sound wave velocity in some tree species.

Average sound wave velocity measured across the grains (m/s)			
Degree of damage	**Tree species**		
	Spruce and Fir	**Pine**	**Oak**
1	1260 - 1800	1160 – 1750	1640 – 2100
2	920 - 1260	840 – 1160	1180 – 1640
3	750 - 920	680 – 840	850 – 1180
4	500 - 750	500 - 680	600 - 850

Fig. 3: Colour range of a sonic scan - approximate evaluation of a wooden element.

Sonic scans of measured elements record sound wave velocity among the individual sensors. In fact, sensors are steel nails hammered into a wooden element around its perimeter at regular distances. Hammering on a sensor create sound waves whose velocity is recorded in other sensor. Sensors/nails are hammered about 15 mm deeply, i.e. the sonic scan of a particular section of the measured element is miniaturised when compared with its real dimension (Fig. 3).

5.1 Wooden pole fixed in plain concrete (A point in Fig. 2)

Measurements were carried out on 5 May 2016 at 14:46 hours in a round barked larch pole. The pole is fixed 80 cm deeply; the pit is filled up with plain concrete. The first measurement was taken at ground level, i.e. 0 cm above the ground (Figs. 4a and 4b). The second measurement was taken 30 cm above the ground (Fig. 4c).

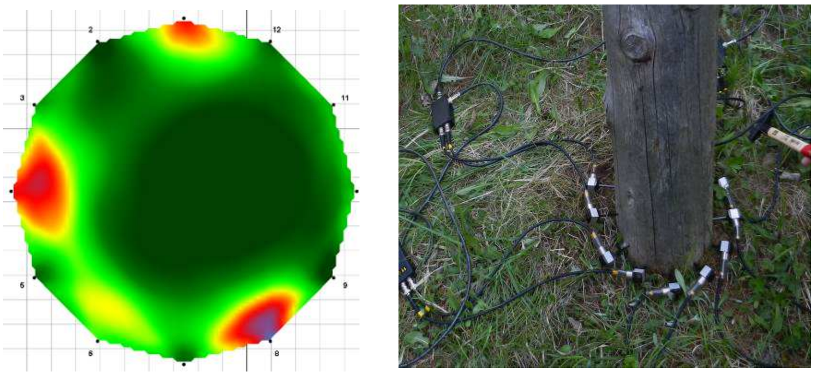
4a 4b 4c

Fig. 4: Sonic scans.

The absolute moisture content of the wooden element, temperature, and relative air humidity was measured along with the sound wave velocity. The sonic scan evaluation shows the lower part of the pole is more damaged, compared to the second measurement. Inside the wooden element, there is neither hollow nor damaged wood. There is a surface damage near the ground. Decayed parts reach into the diameter. The extent of damage in the first layer is 23 % (Fig. 4a) and in the second layer 3 % of a diameter (Fig. 4c).

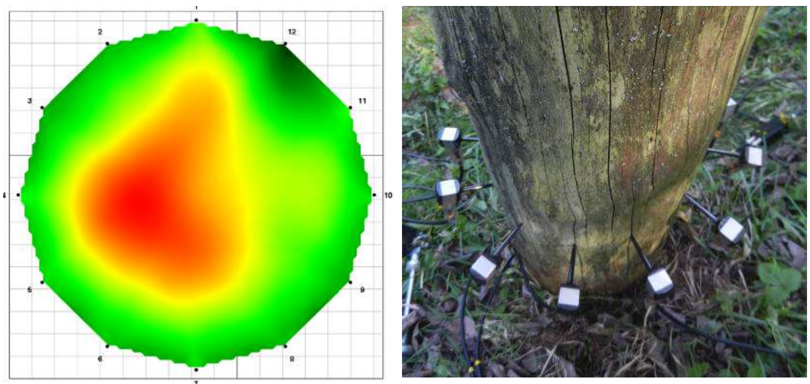
5.2 Wooden pole fixed in lime mortar (B point in Fig. 2)

Measurements were carried out on 5 May 5 2016 at 15:32 hours in a round barked larch pole. The pole is fixed 80 cm deeply; the pit is filled up with lime mortar. The first measurement was taken at ground level, i.e. 0 cm above the ground (Figs. 5a and 5b). The second measurement was taken 50 cm above the ground (Figs. 6a and 6b).



5a 5b

Fig. 5: Sonic scan at ground level.



6a 6b

Fig. 6: Sonic scan 50 cm above the ground.

The sonic scan shows the lower part of the pole is more damaged due to the contact with the ground. Inside the wooden element, there is neither hollow nor damaged wood. The second measurement shows no surface damage, but the investigated section contains internal damage - probably damaged wood in the middle. The extent of damage in the first layer is 9 % and in the second layer 31 % of a diameter.

5.3 Wooden pole without treatment fixed in soil (C point in Fig. 2)

Measurements were carried out on 5 May 2016 at 15:32 hours in a round barked larch pole. The pole is fixed 80 cm deeply; the pit is filled up with soil. The first measurement was taken at ground level, i.e. 0 cm above the ground (Figs. 7a and 7b). The second measurement was taken 30 cm above ground level (Fig. 7c).

The sonic scan shows the lower part of the pole is more damaged due to the contact with the ground. Inside the wooden element, there is neither hollow nor damaged wood. The second measurement shows no surface damage, but the investigated section contains surface damage. The extent of damage in the first layer is 33 % and in the second layer 15 % of a diameter.

7a 7b 7c

Fig. 7: Sonic scans.

Further measurements were taken on 30 May 2016 at 15:34 hours in a round barked larch pole. The pole is fixed 80 cm deeply; the pit is filled up with soil. One measurement was taken at ground level after the grass had been removed. The pole is fixed in a soil. The visual inspection shows evident damage on the side facing the slope (Fig. 8). The extent of damage is 39 % of a diameter. The wooden pole is significantly attacked by rainwater running down the slope.

8a 8b 8c

Fig. 8: Measuring of the pole fixed in soil: a - sonic scan, b - view of measurement, c - view of the damaged side - a hollow.

6 Wooden pole fixed in soil using birch bark (D point in Fig. 2)

Measurements were carried out on 30 May 2016 at 16:40 hours in a round barked larch pole. The pole is fixed 80 cm deeply and its underground part is wrapped into birch bark; the pit is filled up with birch bark. The first measurement was taken at ground level, i.e. 0 cm above the ground, after bark and grass had been removed (Figs. 9a and 9b). The second measurement was taken 30 cm above the ground (Fig. 9c).

9a 9b 9c

Fig. 9: Sonic scans.

The visual inspection shows wood damage at ground level. Wood degradation is 1 cm deep. The sonic scan shows the lower part of the pole is more damaged due to the contact with the ground. Inside the wooden element, there is neither hollow nor damaged wood. The second measurement shows no surface damage. The extent of damage in the first layer is 9 % and in the second layer 3 % of a diameter.

7 Discussion

Gathered data indicated that wooden poles fixed in and covered up with soil are the most damaged. An important factor in this case is the shape of the terrain. In the case of slope, the wooden elements are much more attacked by rainwater. All the visually inspected poles showed significant damage on the side facing the slope. Wooden elements gradually degraded in the contact zone with the terrain.

As for poles fixed in lime mortar and plain concrete, it can be stated that wood damage in the contact zone with the terrain was more extensive when fixed in plain concrete. The poles fixed in lime mortar showed less damage in the contact zone, but above ground level they were more damaged inside the diameter.

8 Conclusion

The paper deals with the investigation of wooden poles situated in the sacrifice site of the archaeological open-air museum Havránok. To know technical condition of wooden elements is of great importance, especially due to the safety of the wooden structure located in the area with people´s movement. The inspection was focused on the wooden poles fixed into the ground in 2003. We assessed the technical condition of wooden poles experimentally fixed into the ground using different materials. The poles were fixed 80 cm deeply in plain concrete, lime mortar, and soil; some were wrapped into birch bark. The technical condition of the poles was first assessed visually and tactually, then using the sonic tomograph. The above-mentioned device may be used to detect internal - hidden damage to wooden elements.

The paper evaluates and refers to the measurements of internal damage to wooden poles and looks for the appropriate solution and method to fix wooden poles in the sacrifice site. The technical condition of the poles was experimentally verified 13 years after they had been fixed into the ground. The diagnosing of their technical condition revealed the least damage to the poles wrapped into birch bark. All the poles showed significant damage in the contact zone with the terrain. It can be claimed that 13 years later the poles show weak damage which is not great risk in terms of the wooden structure´s safety.

Acknowledgements

This contribution is the result of the project implementation: „Supporting research and development center of excellence for civil engineering" (ITMS: 26220120031) supported by the Research & Development Operational Programme funded by the ERDF.

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