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Assessment of the possibility of using modern diagnostic methods to determine the changes in the properties of timber elements installed in a river bed

P. Kotásková[1], J. Fialová[1], J. Tippner[2] and J Marková[1]

[1] Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Landscape Management, Czech Republic
[2] Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science, Czech Republic

Abstract. The aim of the research was to find out which non-destructive methods can be used for determining the properties of wood placed in humid area and water. The research was carried out in order to propose suitable methods for detecting state of timber during regular inspection and maintenance of timber structures and elements in the watercourse. Wooden thresholds located in the watercourse belonging to the Divoká Orlice River Basin were selected for the measurement. The measured timber elements were already 9 years in the flow and the degree of damage to the built-in wood had to be assessed. The extent of biotic damage to water-soaked wood cannot only be determined by sensory methods. Resistance stop devices, a non-destructive ultrasonic device, a micro drill and an acoustic tomograph were selected for the evaluation. However, all commonly used modern diagnostic methods used for measurements in dry environment surveys cannot be used in the above terrain.

1. Introduction

It is recommended to use two natural materials - stone and wood - for buildings in the landscape environment. Wood from forests is the ideal building material that one can use in the natural environment. A significant advantage of wood is its impact on the environment. Wood is an environmentally friendly material with minimal energy costs for mining, processing and waste, a renewable resource. Compared to its weight, it exhibits high strength and rigidity. Small watercourses, as stated by Zuna [1], make it necessary to maintain acceptable living conditions even in low flows, which is particularly important for mountain streams and streams whose flow rates are very volatile. Thus, wood can be used for transverse gravity objects (thresholds, steps, dams) to reduce the inclination of the bottom level and to stabilize the channel profile. Wooden objects on watercourses are built where there is enough wood and it would be difficult to transport other building materials and also where different materials would be inappropriate in terms of integration into the landscape. The disadvantage is that the durability of the wood is reduced if the wood is not in a dry environment.

To find out what changes occur in wood that is installed in a damp environment or directly in the water, a watercourse was selected where wooden strips and sills were installed as part of the modifications. The reason for conducting research on wood elements was the detection of the occurrence of biological attack after 9 years. In addition, a fresh sample placed in the laboratory water was measured to compare the values.

Observed cross-threshold objects from debarked round timber are formed by the threshold body itself, 4 or 5 pieces of debarked round timber diameter 190 to 250 mm, lengths 5 and 6 m in the base part, damping round timber from 1 piece of debarked round timber of 100 to 140 mm, 6.0 m long, which

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is mounted on the air side of the threshold between two upper logs 0.10 m lower than the upper edge of the threshold. A flow section with a width of 1.6 m in the bottom is created by means of the side wings, which consists of 1 piece of debarked round 200 mm diameter 2.3 m in length with a minimum binding of 1.6 m. Netex geotextile is attached to the upstream side of the wooden sill section.

It is obvious that the individual threshold elements are alternately in the wet or in the water all year round, some are only exposed to increased humidity. The ends of the elements are bound to the shore where humidity is increased. The largest differences in humidity are exposed to the side wings of the building, which may dry out in dry periods of the year.

Water absorption of wood is the ability of wood to absorb water into which it is immersed. The maximum amount of water the wood can absorb is called water capacity. The wood will reach full water capacity, ie it will not stop absorbing water until after a very long time. [2]

Water absorption is the ability of wood to absorb water in the form of a liquid due to the porous structure. Wood is fully soaked in water if it has the maximum amount of bound water (per hygroscopicity) and the greatest amount of water available. As a rule, the higher the density of wood, the lower its ability to absorb water. [3]

It follows that water absorption depends mainly on the pore volume of the wood. [2] States that water absorption depends on other factors in addition to bulk density, such as the anatomical and chemical composition of wood.

Wood with high humidity is attacked by wood-destroying and wood-staining fungi, which only cause deterioration of mechanical properties to wood degradation. It is clear from the information provided by the flow managers that the timber element life is about 10-15 years. The need to reconstruct the watercourse is currently based on visual inspection only. The extent of the damage determined by modern diagnostic methods would be important in the possibility of postponing the reconstruction, thus saving savings. Or, on the contrary, the early detection of the need for repairs and thus the prevention of damage by the sudden destruction of the object.

2. Materials and Methods

The determination of the condition and degree of damage to the wooden elements is done by visual evaluation, but the instrumental methods, which are used, for example, in the assessment of historical trusses, can be used to more accurately assess the condition of the elements.

The research was carried out in-situ on spruce wooden transverse thresholds of the height of 0.2 m, made of debarked round timber of 6 m. side wings of the object. The measurement points are shown in Figure 1. Several thresholds have been selected to compare the status of the individual wood elements. Furthermore, measurements were made in a laboratory on a 500 mm spruce log sample with a diameter of approximately 200 mm. The sample was measured before immersion in water, then immersed in water and the saturation state was measured by weighing on a KERN CB 12 K1N laboratory balance. Further measurements were made at the time of maximum saturation. The sample was then dried, first freely, followed by an oven.

Pilodyn 6J, a non-destructive Arborsonic Decay Detector, a Resistograph and a Fakopp 2D tomograph were selected for evaluation.

Increased water content can affect the results of non-destructive testing, so the moisture of wood elements was determined before each measurement. Hygrotest 6500 resistance hygrometer with stop probe was used to measure the humidity, a resistance humidity meter with integrated GMH 3810 measuring tips was used to measure the sample in the laboratory (see Figures 2 and 3). The principle of the method lies in the influence of moisture in the wood on the electrical resistance. Resistance hygrometers utilize electrical one-way resistance and wood conductivity.

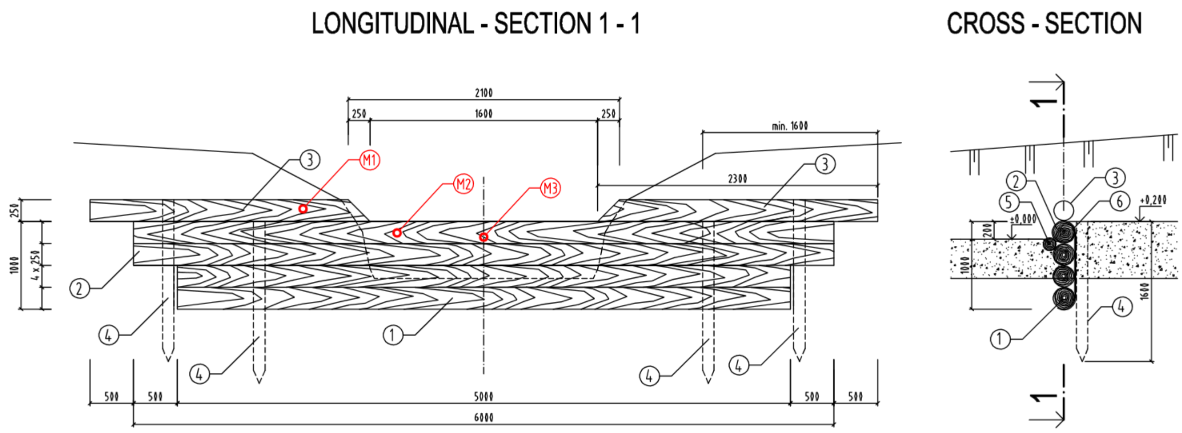


Figure 1. Measuring points on the wooden transverse threshold in the trough.
M1 - measurement on the side wing - wood in the wet, M2 - measurement on the overflow edge in the edge of the visible part - wood in the water, M3 - measurement on the overflow edge in the middle - wood in the water. 1 - foundation section of the building - debarked round Ø 250 mm, length 5 m; 2 - overflow section of the building - debarked logs Ø 250 mm, length 6 m; 3 - side wings of the building - debarked round Ø 250 mm, length 2.3 m min. commitment to shore 1.6 m; 4 - vertical stabilizing piles - debarked rod Ø 100 to 140 mm, length 1.6 m; 5 - damping logs - debarked logs Ø 150 mm, length 6 m; 6 - Netex geotextile on the upstream side of the wooden threshold


Figures 2 and 3. Hygrotest 6500 Resistance Hygrometer and Resistive Moisture Meter with GMH 3810 Integrated Probes.

Determination of moisture

Based on the determined wood sample weights in the wet, wet and absolutely dry laboratory after laboratory drying, moisture was determined and compared to the moisture measured. Subsequently, saturation and drying courses were evaluated by Excel.

Pilodyn

Measurement with the Pilodyn 6J Forest is a semi-destructive diagnostic method because the damage to the test material is very small and almost negligible. It is a simple mechanical device to measure the penetration depth of a 2.5 mm mandrel fired in wood at a constant driving force of 6 J (see Figures 4 and 5). The tip penetrates the surface of the material while the penetration depth is measured. The maximum penetration depth of the mandrel is limited to 40 mm by the device design. With Pilodyn, a low-invasive wood density estimate can be made. Density is a parameter closely related to the hardness of the wood, as Bonamini et al. [4] suggest; Kasal and Antony [5].

By assessing the depth of penetration of the tip, the degree of decomposition of the wood or its biotic damage can be estimated. In case of insect damage or decay caused by rotting, the tip will penetrate significantly deeper. However, this method provides us with a new way to measure the degree of damage to the surface affected by soft rot, which primarily affects the surface of the wood. The same is true for wood damage by insects, which causes the greatest damage in the surface layers.

A disadvantage is that during penetration of the mandrel only surface penetration into the material occurs and thus only the surface information of the state of the structural member is known. The measurements are mainly influenced by the moisture content. With higher moisture content Pilodyn easily penetrates into wood. Therefore, it is necessary to correct the moisture content for each measurement.

However, as Micko [6] states, the effect of moisture is only evident at a moisture content of 0-30% (fiber saturation point) above the fiber saturation point, the change in moisture content has no effect on the test result.

Figures 4 and 5. Pilodyn 6J Resistance Stroke Instrument - Measurement on Threshold Side Wing.

Measurement of ultrasonic wave velocity - Arborsonic Decay Detector

Arborsonic is a detector that uses ultrasound to detect and evaluate the internal state of the wood based on ultrasound rate (see Figures 6 and 7).

The instrument measures the speed of the 77 kHz ultrasonic signal passing through the measured material between the two sensors (transmitter and receiver). Since the signal propagates the fastest in the solid wood mass, the signal rate slows down in each decay or defect area. In damaged areas by rotting, the sound speed will be significantly lower than in intact wood. [7]

Figures 6 and 7. Non-destructive Arborsonic Decay Detector - Measurement on the sill side.

According to scientific publications [8], dynamic modulus of elasticity can be calculated using a relationship:

$$E = \varsigma \cdot c^2$$

where:
E is the modulus of elasticity of the material [MPa]
ϱ is the density of the material [kg.m $^{-3}$]
c is the speed of sound propagation through the wood in a given direction [m.s $^{-1}$].

The sound propagation rate decreases with increasing wood moisture, as the water fills its capillaries in which air was found. As a result, the resistance of the environment to the sound wave propagation increases [9].

Resistograph 4453 Resistance Micrometer

Resistance drilling is based on measuring the resistance to slow penetration of the small diameter drill by the material being investigated. The advantage is that the device offers an overview of the internal state of the element. Due to the minimal material damage, the semi-destructive methods of determining the condition of timber structures are among the methods. [10]

Thin drill senses resistance when penetrating wood. This implies that less drilling resistance, which requires less engine torque, is due to less wood density, cavities, damage, splintering, and cracks. Resistograph output is a graphical record (density profile, dendrogram).

Figure 8 and 9. Resistograph 4453 Resistance Micrometer - Measurement on Overflow Edge in the Middle (Wood in Water).

The drilling record corresponds to the energy consumed to maintain a constant drilling speed on the y-axis and the x-axis shows the distance from the surface of the measured element. The peaks in the graphical record correspond to higher energy, ie higher resistance and higher density, while lower points are associated with lower energy, ie lower resistance and density. [11]

The Fakopp 2D acoustic tomograph

The Fakopp is capable of reconstructing the internal state of the strain by measuring the speed of the sound pulse caused by hammer blows into 2 interconnected probes (see Figures 10).

Two sensors are connected to each other and are connected to the meter (see Figures 11). An acoustic signal is emitted by tapping the hammer on the probe and the instrument senses the time it takes to pass the signal from the currently activated probe to the opposite probe. The generated pulse spreads through the material for some time and reaches the second probe - the receiver. The ultrasonic pulse transmission time is displayed on the device display in microseconds. Based on the passage times and the geometry of the cross-section, the velocity is calculated and the state of the strain is reconstructed.

Figures 10 and 11. Acoustic tomograph Fakopp 2D.

The sound velocity in wood is proportional to the density and stiffness of the wood being measured. As density increases, it increases with increasing modulus of elasticity. Both properties are a sensitive indicator of the condition of the wood, disturbance by wood-destroying fungi causes a change in the rate of propagation and can be detected. If there is a cavity inside the trunk, the sound wave must bypass the longer path and decrease the signal speed again and can be detected. [12]

3. Results

The measurements in the laboratory show a large water intake 14 days after immersion of the dried wood in the water. For the next 3 months, the weight gain was slow. Upon withdrawal from the water, the weight loss graph shows a greater weight loss for 7 days, then a gradual drying of the sample until the sample is put into the oven for complete drying. After removal from the dryer, there was a slight increase in moisture due to air humidity.

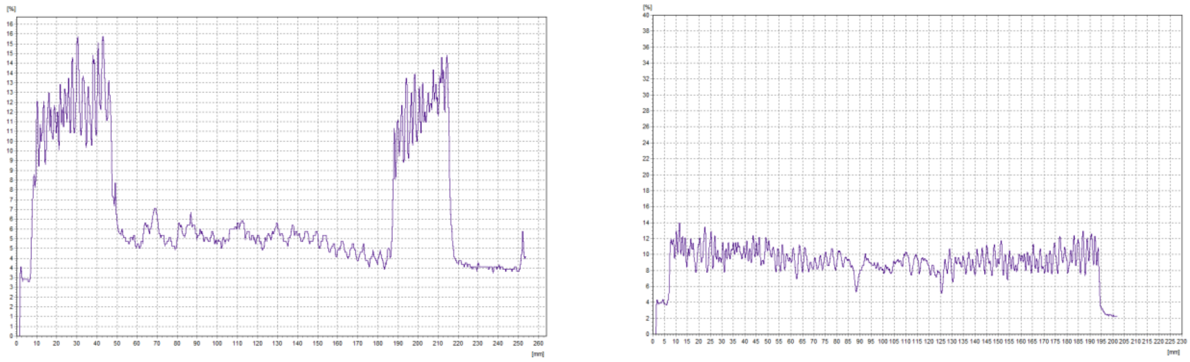
The wood moisture on the sample in the laboratory determined by calculation was compared with the measured values of the hygrometer. It was found that at higher humidity values above 50% the measured values did not correspond to the values calculated. Due to the high humidity values of wet wood in the stream (measured 90 to 137%), it can be stated that the measured values of wet wood in the field measured on the sash side wings are high, but they do not fully correspond to reality. The hygrometers used can be used more accurately for a range of 6 - 30%, as noted by the manufacturer, with considerable variations outside this range.

Since it was assumed that the timber elements in the stream would be soaked with water, only the listed instruments were selected for the measurements. This assumption was confirmed. The measured values were above 90%, although, as verified, this figure cannot be considered relevant.

It was not possible to use Fakopp for water and water-washed elements from the selected devices. It was used only on the side wings of the object. The calculated velocity of elastic wave propagation, based on the measured values and the distance between the measured points, is some 640 m / s for some elements, but up to 1112 m / s for some elements. Sound waves propagate through the shortest path, but only through intact cell walls of wood. If there are wood-destroying fungi in the wood, for example, the sound waves will bypass these places, which can then be determined by comparing the measured propagation speeds with the reference speeds. A certain disadvantage in the interpretation of the results is that other factors, such as changes in humidity, may cause modification of the sound wave propagation rate in wood. [13]

The Arborsonic was also used only on the side wings of the object, which are not in water, but the humidity of these parts is high. When measuring some elements, the instrument showed an error of 999 - no measurement can be made. Cross-fiber measurements were performed. The ultrasonic wave propagation speed of some elements was about 1080 m / s. According to Kloiber [11], it would be a moderately damaged element, as it ranges from 920 to 1260 m / s. However, this estimation of the degree of damage applies to wood moisture of 12 - 16%. Since the sound propagation rate in wood depends on the moisture content of the wood, this method cannot be relied upon for such soaked samples. With increasing humidity, the speed of sound wave propagation decreases. With a speed value of, for example, 757 m / s, it is not clear how heavily the element is damaged and how much wood moisture plays.

From the graphical records (see figures 14 and 15) it was possible to observe on the first view higher resistances for wood in water than for wood only in wet. Some measurements have seen a decrease in recorded resistances, which is probably due to the effect of rot. The best overview of internal damage is obtained when drilling at multiple locations of one element. However, the Resistograph measurement is very demanding in the watercourse. Although wood elements are known to have internal damage without surface changes, this method cannot be considered suitable for assessing elements in the presented environment.



Figures 14 and 15. Resistograph output - dendrogram of rot affected wood and Resistograph output - dendrogram of healthy wood - measurement in laboratory.

Pilodynem measurement is simple, but we only determine the surface densities of the wood and thus only the surface damage to the wood. From the visual survey it was clear that some elements of the transverse objects in the flow show signs of surface damage, mostly wet elements in contact with the earth, affected by the ground moisture. Due to the high humidity, the increased penetration depth of these elements is also evident. It can be seen from the measured values that the elements in water show lower values (reaching a lower depth) comparable to the element measured in the laboratory.

4. Discussion and conclusion

Within the framework of the research of timber structures on watercourses, it was ascertained whether it is possible to supplement the visual check of the condition of wooden elements with a more exact method, which would specify their evaluation. The survey includes the detection of moisture that affects measurements on all instruments. However, it was found that at higher humidity values above 50% the measured values no longer corresponded to the values calculated.

Pilodyn 6J, a non-destructive Arborsonic Decay Detector, a Resistograph and a Fakopp 2D tomograph were selected for evaluation. From the measurements made, it can be stated that the elements that are in the water are less damaged than the side wings, which are in a humid environment. However, none of the selected methods can be described as reliable. When measuring not only in water, the Arborsonic ultrasonic machine often has error messages. Resistograph measurement is very challenging in watercourse conditions, even if the outputs reveal the best internal damage, eg by fungi. Facopp was used only on the side wings and the measured values were compared with the sample in the laboratory. The effect of increased humidity is evident and therefore the results cannot be considered relevant. The only suitable device seems to be Pilodyn, which only reveals sub-surface damage.

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