CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2023; 33 (2): 0106-0116
DOI: 10.59440/ceer/174568
Original Research Article

RESTRICTIONS AND NEW POSSIBILITIES OF TECHNICAL AND CONSERVATION DIAGNOSTICS OF WOOD IN HERITAGE BUILDINGS

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A b s t r a c t

Identifying the mechanical properties of wood in existing buildings allows the search for an effective way to renovate wooden structures. Tests conducted on the historic structure's tissue preclude the use of destructive testing. Individual elements of the structure can be subjected to non-destructive testing (NDT) conducted in situ. The NDT testing methodology presented in the article is based on the use of ultrasonic and sclerometric technology. These methods can be used to determine the sites of biological corrosion and determine the effect of internal defects on the quality of wood. Ultrasonic testing usually uses devices that emit a longitudinal wave. The study additionally applied the author's method using devices analyzing the velocity of transverse wave flow for testing historic wood. The research was conducted on the roof truss of the heritage church of the Sacred Heart of Jesus in Jastrzębie Zdrój.

Keywords: diagnostics of wooden structures, non-destructive testing, ultrasonic method, sclerometric method, roof truss construction

1. INTRODUCTION

The renovation of historic wooden structures is conditioned by knowledge of the mechanical capabilities of the preserved elements [1, 2]. All research, carried out on the historic structure's tissue, in addition to the application of normative guidelines, is connected with additional obligations related to the compliance with conservation requirements [3-6]. In situ testing methods conducted in historic structures have many restrictions and eliminate the use of destructive testing. However, individual elements of the structure can be subjected to non-destructive testing (NDT) conducted in situ [7-11]. The NDT testing methodology presented in the article was based on the use of ultrasonic and sclerometric techniques. Wooden elements have been subjected to this type of analysis since the 1950s [12, 13]. Ultrasonic testing usually uses devices that emit longitudinal waves [14-17]. The innovation

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of the presented research is the use of a device analyzing the velocity of transverse wave flow for testing historic wood. The roof truss of the heritage church of the Sacred Heart of Jesus in Jastrzębie Zdrój was tested.

2. CHARACTERISTICS OF THE STUDY OBJECT

The church building of the Sacred Heart of Jesus in Jastrzębie Zdrój dates to 1898. A view of the church is shown in Fig. 1. The roof truss, which is the subject of the study, was made as a purlin hanger double-hung truss. It is a partially open truss with a trapezoidal ceiling and horizontal overhanging [18, 19]. A view of the truss from the church side is shown in Figures 2 and 3, and from the side of the attic in Figure 4.

Fig. 1. View of the church building from the north side

Fig. 2. Parts of the lower truss structure, view from the church side

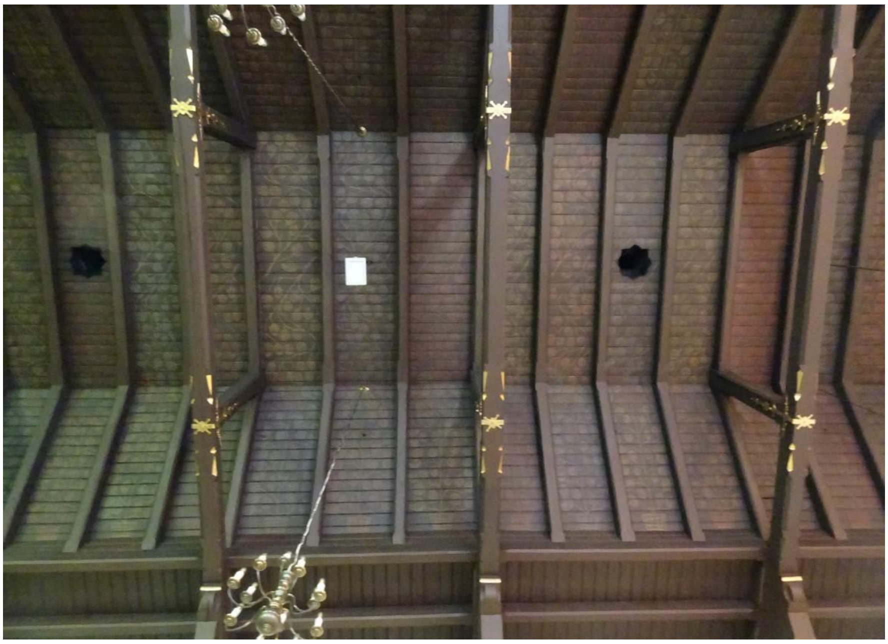

Fig 3. Parts of the lower truss structure, view from the church side

Fig. 4. Upper part of the truss structure, view from the attic side

This construction of the truss has additional braces and struts, on which the ceiling was built in. Purlins were placed on the rafter hangers, and rafters were placed on them. The truss elements on the church side are additionally carved and painted. The ceiling was painted brown and decorated with plant ornaments.

3. TESTING OF WOODEN STRUCTURAL ELEMENTS

The roof truss was subjected to semi-destructive testing with a Wood Peker DRC 19C0085M wood hammer (Fig. 5a). In addition, ultrasonic tests were carried out using a UK 1401 SURFER device (Fig. 5b) measuring the velocity of the transverse wave along the fibers, and using a UK 1410 PULSAR device (Fig. 5c) measuring the velocity of the longitudinal ultrasonic wave across the fibers. In addition, the moisture content of the elements of the tested structure was also measured.

Fig. 5. Devices used in the study:
a) Wood Peker DRC 19C0085M, b) UK 1401 SURFER, c) UK 1410 PULSAR

3.1. Semi-destructive testing of truss elements with a wood hammer

The wood hammer test is based on driving a needle with a diameter of 2.5 mm, length of 50 mm, made of steel with a hardness of 60 HRC and ending in a cone with an angle of 35°. The impact energy is 2.207 Nm. After striking the hammer five times, the needle's cavity is measured using a dial indicator, and the strength parameters of the wood are determined on this basis from tables or formulas. An example view of the Schmidt wood hammer during testing is shown in Figure 6a, and an example of the needle measurement result is shown in Figure 6b.

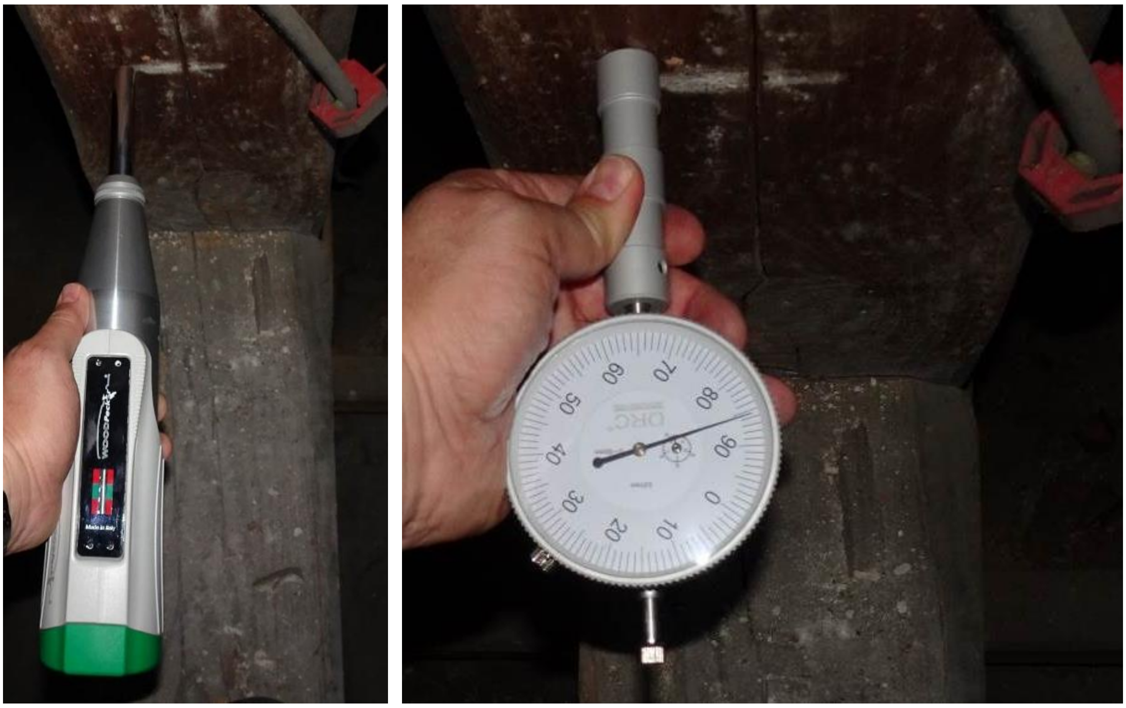

Fig. 6. Testing with a Schmidt wood hammer (hanger of hanger trusses)

Tests were conducted on selected 11 elements of the trusses, and the test sites were designated M1÷M11 (Fig.7). Tests were conducted on elements without biological corrosion and on elements showing damage. The results of the tests are shown in Table 1.

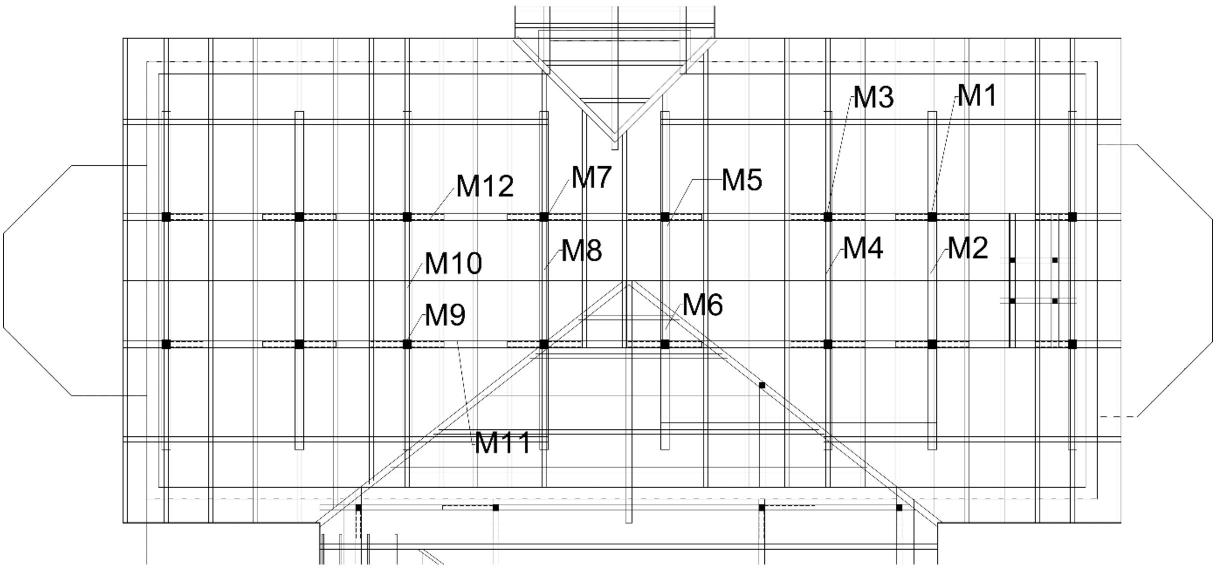

Fig. 7. Roof truss plan- Schmidt hammer test sites

Table 1. Results of the Schmidt wood hammer tests

Test site	Biological corrosion	Depth of needle penetration, mm
M1 (hanger)	yes	32,15
M2 (collar)	no	25,2
M3 (hanger)	no	26,45
M4 (collar)	yes	36,53
M5 (hanger)	yes, a minor	28,35
M6 (collar)	no	23,12
M7 (hanger)	yes, a minor	28,54
M8 (collar)	yes	31,71
M9 (hanger)	yes	30,46
M10 (collar)	no	22,25
M11 (purlin)	no	22,08
M12 (purlin)	no	23,08

3.2. Non-destructive ultrasonic testing of truss elements

Non-destructive ultrasonic testing of truss members was carried out. The test involves measuring the time of passage of the ultrasonic wave through the wood. The devices record the time of passage of the ultrasonic wave and automatically calculate the speed of the ultrasonic wave based on the distance between the transmitting and receiving heads. The UK1401 Surfer uses an ultrasonic transverse wave, and the test itself is conducted along the wood fibers of the test piece. The UK1410 Pulsar uses a longitudinal ultrasonic wave, and the test is performed across the fibers. Both devices are equipped with ultrasonic exposure (spot) heads, which do not require additional acoustic coupling. The UK1401 Surfer has two heads built in at a fixed spacing of 15 cm, while the UK1410 Pulsar has 2x 7 heads each. The devices use heads on springs, adjusting to the plane of the test piece. In both devices it is possible to perform tests through wood defects (e.g. knots). A view of the devices during testing is shown in Figure 8.

Fig. 8. Test locations with devices: a) UK1401 Surfer, b) UK1410 Pulsar

Tests were performed at selected 20 locations of the roof truss, which are shown in Figure 9. Tests conducted with the UK1401 Surfer device were marked with the symbol U, while tests conducted with the UK1410 Pulsar device were marked with the symbol UP. As in the case of the wood hammer tests, tests were conducted in undamaged areas and in areas showing biological corrosion. In addition, the speed of ultrasonic flow through wood defects (knots) was tested with the UK1401 Surfer device. The results of the tests are given in Table 2.

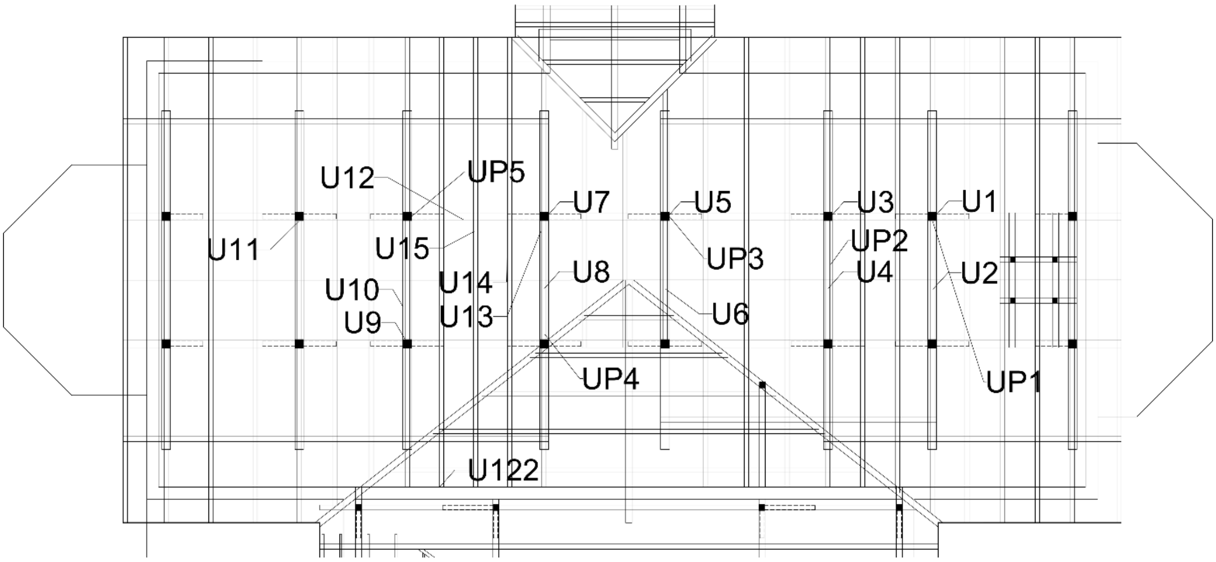

Fig. 9. Test sites with devices: a) UK1401 Surfer (marked U), b) UK1410 Pulsar (marked UP)

Table 2. Results of ultrasound tests

Test site	Biological corrosion	Wood defect	Ultrasonic velocity m/s
U1 (hanger)	yes	no	4920
U2 (collar)	no	yes	3850
U3 (hanger)	no	no	5310
U4 (collar)	yes	no	4710
U5 (hanger)	yes	no	4830
U6 (collar)	no	no	5150
U7 (hanger)	no	no	5300
U8 (collar)	yes, a minor	no	5110
U9 (hanger)	no	no	5630
U10 (collar)	no	yes	4520
U11 (hanger)	no	no	5810
U12 (purlin)	no	no	5680
U13 (rafter)	no	no	5410
U14 (rafter)	no	no	5460
U15 (rafter)	yes, a minor	no	5040
UP1 (hanger)	yes	no	1280
UP2(collar)	no	no	1950
UP3 (hanger)	yes	no	1380
UP4 (hanger)	yes	no	1430
UP5 (rafter)	no	no	1910

3.3. Testing the moisture content of wood

We carried out spot tests of wood moisture content with a T510 device from Trotec. In this moisture meter, the moisture content is measured through capacitive sensors using a dielectric measurement method, driven into the wood. The accuracy of measuring wood moisture with the T510 device is ±0.8% for moisture content up to 5%, ±0.2% for moisture content from 5 to 30%, and ±0.1% for higher moisture content.

Tests of wood moisture content were conducted at selected locations on roof truss members. During the tests, the temperature in the interior was 18 degrees Celsius, the relative humidity was 55 %. Example test results are shown in Figure 10.

Fig. 10. Measurement results of the T510 moisture meter: a) hanger - moisture content of 10.7%, b) strut - moisture content of 9.5%

In the paper [20], it is stated that wooden elements located in unheated indoor spaces should have an equilibrium moisture content of 12%±3%. Such a result was obtained in the tested elements of the truss in question. According to [20], the equilibrium moisture content for structures exposed to the weather is 18%±6%. The literature [20] further states that at a moisture content of <20% there is no wood fungus. The moisture content <20% (12.8% at most) was always obtained in the tests, and no traces of mold or the characteristic musty smell were found during the inspection.

4. ANALYSIS OF THE RESULTS

When tested with a wood hammer, the strength of the wood could not be determined. The manufacturer of the device does give a correlation of the depth of the steel needle penetration to the bending strength of the wood, but for Italian wood species: fir, chestnut and oak. The truss was made of domestic spruce wood. In addition, the manufacturer reports a correlation only in the 12÷18 mm driving depth range. In the case in question, the needle was driven deeper. Therefore, it was not possible to use the needle insertion depth - wood strength curves developed by the manufacturer.
However, based on the results, a qualitative assessment of the wood can be made. In corroded elements, the needle penetrated deeper. In undamaged elements, the average depth of needle penetration was 23.7 mm, with a standard deviation of 1.75 mm (coefficient of variation of 7.4%), while in heavily damaged elements the average depth of needle penetration was 32.7 mm, with a standard deviation of 2.64 mm (coefficient of variation of 8.1%).
In the case of ultrasonic testing, the strength of the wood could not be determined either, since the correlation curves available in the literature do not apply to domestic antique wood. In addition, correlation curves describing the relationship between wood strength and the speed of the transverse ultrasonic wave were not found in the domestic and foreign literature.
However, a qualitative analysis can be made on the basis of the tests performed. In the case of testing with the UK1401 Surfer device (ultrasonic transverse wave), an average ultrasonic velocity of 5469 m/s was obtained in undamaged elements, with a standard deviation of 222 m/s (coefficient of variation of 4.1%). In elements with biological corrosion, an average ultrasonic velocity of 4922 m/s was obtained, with a standard deviation of 160 m/s (coefficient of variation of 3.3%). The UK1401 Surfer device was further used to study defects (knots). Two defect sites were investigated by placing the device's heads

on both sides of the knot. An average ultrasonic velocity of 4185 m/s was obtained. Thus, it can be clearly seen that the ultrasonic velocity in the vicinity of the defect decreases by 25%, as the flow path of the ultrasonic wave lengthens (the wave bypasses the defect).

In the case of tests performed with the UK1410 Pulsar (ultrasonic longitudinal wave) device, an average ultrasonic velocity of 1930 m/s was obtained in undamaged parts, while in damaged parts the velocity was 70% lower at 1363 m/s.

5. CONCLUSIONS

The study showed that non-destructive and semi-non-destructive methods can be used for qualitative evaluation of wood in historic buildings. These methods can be used to determine the sites of biological corrosion and determine the effect of internal defects on the quality of wood. In the case of heritage buildings, all types of tests cannot be used, and destructive tests cannot be used to determine the strength of wood.

In order to determine the strength of wood, it is necessary to develop correlation curves describing the relationship of nondestructive test result - wood strength. This requires non-destructive and destructive laboratory testing of historic wood. Such tests are just conducted by the authors of the article on full-size beam elements obtained from historic buildings. In addition, ultrasonic tomography tests are conducted on these elements.

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