Joanna Drobiec

ANALYSIS OF THE POSSIBILITIES OF USING NON-DESTRUCTIVE AND SEMI-NON-DESTRUCTIVE METHODS TO DETERMINE THE STRENGTH OF HISTORIC WOOD

ABSTRACT

Determining the mechanical parameters of historic timber without the ability to extract samples for laboratory testing presents a significant challenge. There are no standardized guidelines or established literature addressing procedures in such cases. This study analyzes the feasibility of using non-destructive and semi-destructive testing methods to assess the strength of aged timber. The work comprises ten chapters.

Chapter 1 outlines the genesis of the research topic along with the aims and scope of the study. Chapter 2 presents a comprehensive review of the current state of knowledge. It discusses timber defects, visual and laboratory methods for assessing timber strength, and the results of selected non-destructive and semi-destructive tests. Based on the literature review, it can be concluded that defects significantly influence the mechanical properties of timber, and visual inspections alone cannot detect all flaws—many are concealed within the internal structure of the element. Non-destructive techniques, particularly ultrasonic and penetration methods, can be employed to identify internal defects. Ultrasonic tomography, in particular, proves useful for locating internal flaws. These non-destructive techniques are also used to estimate mechanical and physical parameters of timber, such as bending and compressive strength, modulus of elasticity, and density. Correlations are often developed to relate non-destructive indicators to mechanical properties; however, such correlations typically pertain to new timber. Those applicable to historic wood are generally derived from small samples and do not account for the presence of natural defects. No literature was found presenting correlations between destructive and non-destructive tests performed on a large number of full-scale historic timber samples from Polish heritage buildings.

Chapter 3 defines the research theses and objectives based on the literature review. Three hypotheses are proposed:

- It is feasible to detect internal defects in historic timber using non-destructive testing methods.
- It is feasible to determine the strength parameters of historic timber using non-destructive testing methods.
- It is possible to develop a methodology for assigning strength grades to historic timber based on non-destructive testing, taking into account internal defects present in the examined elements.

To verify these hypotheses, the following research objectives were established:

- Conduct preliminary testing on a historical structure to confirm the applicability of non-destructive methods in identifying timber defects.
- Develop correlations between non-destructive indicators and timber strength for historic Polish wood, utilizing multiple testing methods.

- Propose a method for rapid, non-destructive localization of defects, including internal anomalies.
- Develop a methodology for strength grading of historic timber, accounting for existing internal defects.

Chapter 4 details the preliminary investigations conducted on the roof truss of a historic church in Sieroty, partly dating to 1427 and partly to 1707. Seven structural elements were selected for analysis using ultrasonic tomography, a wood testing hammer, and two ultrasonic devices—one emitting longitudinal waves and the other transverse waves. The preliminary studies revealed that visual inspection identified approximately 30–50% of the existing damage, while comprehensive imaging was achieved using ultrasonic tomography. Semi-destructive and non-destructive methods were found suitable for pinpoint diagnostics, though high measurement resolution was necessary to ensure accuracy. Superior results were obtained by combining multiple non-destructive techniques. However, testing on a dense grid is labor-intensive, and semi-destructive testing (e.g., using a hammer) may be impractical in heritage contexts due to excessive perforation.

Chapter 5 presents the outcomes of non-destructive testing. Several dozen historic timber elements, originating from various regions of Poland and spanning the last 500 years (from the early 15th to the early 20th century), were subjected to non-destructive and semi-destructive tests using the same instruments as in the preliminary phase. Additional moisture content measurements were also carried out.

Chapter 6 reports on destructive tests performed on the previously non-destructively tested historic timber elements. Beams were evaluated under a four-point bending scheme in accordance with PN-EN 408 and PN-EN 384 standards. Shorter beams were tested in a three-point bending setup. Deflections were measured using displacement transducers and the optical Aramis system. The strength of each timber element was determined.

Chapter 7 analyzes the results from destructive and non-destructive testing, including charts and formulas that illustrate correlations between them.

Chapter 8 outlines a proposed methodology for conducting tests on historic structures. The method involves identifying the number of defects in a given timber element using ultrasonic tomography and conducting point-based non-destructive tests using the three instruments employed in Chapters 4 and 5. Depending on the number of identified defects, either average correlation values or the lower bound of test results are recommended for estimating bending strength.

Chapter 9 illustrates the practical application of the proposed methodology on roof trusses from two buildings: a former spa facility from 1912 in Jastrzębie-Zdrój and the Church of St. Stanislaus the Bishop and Martyr in Czeladź from 1913. In both cases, the results were validated through destructive testing. Additionally, the methodology was applied to the roof truss of the Warmian Chapter Castle in Olsztyn, dating from the 14th and 15th centuries. Due to the structure’s historical significance, destructive verification was not conducted in this instance.

Chapter 10 offers a summary and final conclusions, along with recommendations for further research