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COMBINE USE OF NDT/SDT METHODS FOR ASSESSMENT OF STRUCTURAL TIMBER MEMBERS

Editors:
José Saporiti Machado and Mariapaola Riggio

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Application of imaging techniques for detection of defects, damage and decay in timber structures on-site

Mariapaola Riggio[1)], **Jakub Sandak**[1)], **Steffen Franke**[2)]

1) CNR Timber and Trees Institute IVALSA, S.Michele all'Adige (TN), Italy, riggio@ivalsa.cnr.it; sandak@ivalsa.cnr.it

2) Bern University of Applied Sciences, Biel/Bienne, Switzerland, steffen.franke@bfh.ch

Abstract This section deals with the application of NDT imaging techniques as complementary tools to be used during visual inspection. NDT imaging can be used to map inhomogeneity and to identify the areas at the highest risk for damage in timber structures. The paper highlights the potential of some imaging techniques accepted and practiced for the assessment of timber structures.

Introduction

Visual inspection is the basic approach for the assessment of timber structures, allowing for the detection of external wood decay, moisture stains on exposed surfaces, visible mechanical damage, and defects. Non-destructive imaging techniques can complement visual information. According to the penetration depth of the wave field, imaging techniques make it possible to analyse either surface/subsurface features or internal heterogeneities of the wood material.

Imaging methods use wave-based techniques: they analyse the response of the material to wave fields of different nature.

Two different kinds of waves can be utilized: they are elastic or mechanical waves (or called stress waves) and electromagnetic waves (i.e. X-rays, gamma rays, ultraviolet rays, visible light, infrared, microwaves).

Non-destructive images can be a 2D map of the measured physical parameter, over a defined plane perpendicular to the direction of the radiation/wave transmission (e.g. radiographs, thermograms).

Tomographic techniques, instead, allow cross sectional imaging, mapping parameter values on a plane across the object and parallel to the direction of the radiation/wave transmission.

Reflectometric techniques, such as the ultrasound echo technique and the GPR, allow different kind of scans, in particular:

- A-scan: a trace that show the wave transition time and the intensity of the pulse;
- B-scan: a profile composing different A- scans recorded at a given distance, resulting in 2D cross sectional map on a plane parallel to the direction of the wave transmission;
- C-scan: 2D cross sectional map on a plane perpendicular to the direction of the wave transmission, obtained by interpolating a horizontal layer from several B-scans.

Depending on the feature of interest and the related properties, a specific imaging technique can be selected [1].

Non-destructive imaging methods for inspection of timber members.

In the following chapter some imaging techniques applicable for the inspection of timber members on site are described.

Optical methods: photogrammetry

Principle of the method

Photogrammetry (wave field in the visible range) can be used to extract three-dimensional metric models from photographic images. Moreover, it permits to create very accurate textural database for the selected surfaces of the object. It can be adopted for analysing the superficial extent and position of material features, visible on the element surface [2]. Close range photogrammetry basically involves the use of a network of photographs of an object taken from different angles. In monoscopic photogrammetry, convergent shots at different scale can be used, thus allowing the adoption of much more flexible geometric acquisition schemes than those of the stereoscopic method. Non-metric camera can be also used for this purpose. In this case, preliminary calibration is required. The accuracy of the restitution depends on several factors: primarily on the scale of the photogram, secondarily on the geometry of the acquisition scheme and on the accuracy of the interior and exterior orientation [3].

Very important part of optical system is illumination. Different types of light sources could be utilized for enlightenment. The illumination angle and light source position in relation to the specific heterogeneity and camera are crucial to obtain good detecting capabilities.

Applications

Photogrammetric techniques permit to obtain reliable metric information of defects, damage and distortions, from the analysis of orthophotos.

From image data, geometrical data of the detected features can be extracted, for further analysis (measurement of strength affecting characteristics, 3D visualization and modelling of the macroscopic material features). Therefore, photogrammetry can be used for supporting advanced visual strength grading of timber elements in service and for the acquisition of metric/geometric data for the numerical analysis of wooden elements.

General remarks

Site conditions and accessibility can strongly affect the applicability of the method.

Metric accuracy of orthophotos depends on the acquisition methods and the camera used.

It can be advisable to use natural points (e.g. features of the wooden texture) for buddle adjustment.

The photogrammetric survey should be coupled with a topographic survey of control points. In case of elements with very rough/non-planar faces, the use of orthophotos can be insufficient to completely describe the material characteristics.

Radiometric quality of photographs should be ensured using constant uniform lighting.

Thermography

Principle of the method

Thermography is a technique used for visualization of the temperature distribution on the surface of the object, providing information related to the thermal properties of the sample.

Because of the low thermal conductivity of wood, thermography allows the detection of defects near the surface (approx. 1 mm).

There are two main variations of thermography the active method (i.e. inspected element is illuminated by a heat source) or the passive one (wood surface is subjected to natural heating).

The most popular device for thermal imaging is the infrared camera, which is a thermal wave detector in the infrared domain, detecting infrared radiation emitted from the object.

The thermal gradient (and not the temperature itself) makes it possible to obtain information about the integrity of the structure. The thermal gradient is calculated from the temperature distribution.

Applications

Thermography has a great potential as preliminary non-contact screening procedure, to select areas for more detailed analysis.

For defects detection, active thermography is generally advisable while, in many circumstances, passive thermography can be apt to map areas with higher moisture content.

Thermography is also an advisable technique, for the geometrical survey of elements hidden/covered by plaster, or by other similar thin layers [4]. It can be also used to assist visual strength grading of coated timber elements (e.g. painted historical wooden structures).

General remarks

Analysis of temperature gradients is a good tool to detect most superficial and sub-superficial abnormalities. However, the thermal image does not provide any information about the depth of discontinuities. As regards information about moisture, only qualitative indication about location of moist areas can be gathered, while the technique is not appropriate for quantitative estimation of moisture content.

X-ray radiography

Principle of the method

X-ray radiography uses electromagnetic waves with wavelengths in vacuum between 10^{-8} m and 10^{-12} m. The X-rays are absorbed depending on the material density.

For wood, the X-ray absorption coefficient is defined as:

$$\mu = \mu' \cdot \rho$$

With μ' as the mass absorption coefficient in [m^2/kg] and ρ the density of the material in [kg/m^3].

The detectable X-ray waves on the film plate depends on the pulse intensity of the X-rays, the distance of the test object to the transmitter as well as to the film plate and also the thickness of the material. In the X-ray acquisition process, the test object is located between the X-ray transmitter and the film plate. The X-rays transmitted travel through the test object and will be absorbed with different intensities before they hit the film plate. The material specific absorption of the X-rays leads to the so called radiogram which will finally be transferred into a grayscale picture. The whole volume of the three dimensional test object in front of the film plate will be reproduced as a two dimensional picture.

Applications

The X-ray radiography is mainly used for the detection of internal heterogeneities. In typical timber elements the differentiation of various densities like soft- or hardwood, sap wood or heart wood, early or late wood. Furthermore the assumptions and growing direction of knots can be distinguished.

Fungal or insect decay can be observed within the X-ray radiography as well. Normally the visual inspection is used for fungal or insect decay, but in some cases structural elements are covered or only accessible from one side, so that the mobile X-ray system can be used for detailed analyses or specification of assumptions.

Further assessments of timber structures using the X-ray radiography are shown e.g. in [5-6-7].

General remarks

The general principle of the X-ray radiography is similar to taking a picture with a photo camera. But here for the quality of the radiogram the pulse intensity, the distance of the test specimen between the transmitter and the film plate and the thickness respectively the density of the object influence the resolution and accuracy of the method. The limitations described are observed using the X-ray unit XR 200 with a maximum photon energy of 150 KVP and X-ray dose per pulse of 0.026 - 0.040 mSv and a test object made of European Spruce with a density of 480 kg/m^3

and a moisture content of about 15%. The X-ray unit can be used within to the following regulations [5]:

- Increasing the distance between the transmitter and the test object results in the projection of a smaller area where the object is represented enlarged but with less sharpness and more noise.
- A minimum distance between the transmitter and the film plate of about 1 meter is necessary using a film plate of 30 by 40 cm. A further reduction of this distance leads to a clear “burned” spot and unusable radiograms.
- Typical structural timber elements with thicknesses up to 300 mm can reliable be assessed with the used system. For greater thicknesses the contrast vanishes and only objects with distinctly different densities, e.g. parts of steel embedded in wood are visible in the radiogram.

The safety requirements for the use of the mobile X-ray system do not restrict the practical use on existing timber structures. In practical use, the safety zone for this unit is specified as follows: 3 meters around the transmitter, 30 meters in measuring direction and 11 meters perpendicular to it.

In general the users carry a personal dosimeter to register any irradiation.

Microwave

Principle of the method

Microwaves are electromagnetic waves in the frequency range between about 300 MHz and 300 GHz. The microwave technique in connection with range or flight of time measurement can be termed as radar technique (radar: radio detection and ranging) or GPR (ground penetrating radar).

There are two basic microwave techniques, the transmission and the reflection. In a transmission scanner the transmitting antenna, illuminates the piece of wood, with a uniform microwave field.

The probes used to evaluate the signal of microwaves can be either scatterometers/radars, which measure the scattering properties, or reflectometers, which measure the reflectivity of the workpiece due to inhomogeneous and defects. In the first mode, the material is located between two antennas (one for transmission the other for reception), in the second mode, both antennas are located in front of the material. Usually, the following equipment is required for microwave imaging: a) two dipole or horn antennas (transmitting and receiving); b) generator of electromagnetic wave at relatively high frequency and low power; c) data acquisition system[10].

GPR system generates a series of short pulses that travel through the material and back-scatter.

GPR measurements consist in recording a profile by moving the antennas on the tested structure along a linear direction. A trace (A-scan) can be recorded every centimetre of the profile. From series of A-scans, B-scan can be generated.

Applications

Depending on the microwave frequency and measurement hardware it is possible to detect the defect presence directly, or its presence can be noticed only by the introduction of “noise” into attenuation, phase and polarization signals.

In [9] a new system for the in situ evaluation of timber structures based on microwave reflectometry is presented. The obtained results show that the reflectometric methodology can clearly highlight the presence of discontinuities inside the wood, but nature and dimension of the heterogeneities cannot be characterised.

General remarks

Due to its high permittivity, free water in materials like wood strongly influences the reflection and transmission behaviour of microwaves. The changes of the microwave properties due to moisture can be used to treat the moisture as a material property and to detect, image and quantify it and its distribution in the object [10]. As a rule of thumb, the approximate minimum detectable defect size is around half of the wavelength of the microwave frequency used. By decreasing the microwave frequency generally the penetration depth will be enhanced, but the lateral resolution at imaging will be lowered. By taking into account the parameters of the test object (dimensions, shape, moisture content, fibre orientation) and of the measurement equipment (frequency, type of antenna, microwave power, distance of object, etc.) some optimization will be necessary to get a good compromise between the resolution and penetration depth.

Stress-wave tomography

Principle of the method

Acoustic tomography is a technique used to reconstruct the properties of the materials under inspection from stress-wave propagation data. In acoustic tomography, the most typical parameter to measure is the time of flight (TOF), i.e. the time that it takes for the wave to travel a distance through a medium. The transit times, recorded for each pair of transmitting-receiving points, as well as the coordinates of these points, are the input data for the tomographic analysis. Velocity maps are the output data. Local apparent velocities are computed over a Cartesian grid of square pixels, according to the geometric arrangement of the sensors on the element surface. Tomographic images are then generated as the velocity distribution throughout the inspected section.

The basic equipment for stress-wave TOF data acquisition is composed by:
an oscilloscope, for visualization and analysis of the signal;

- a function generator, with a given pulse repetition frequency;
- a timer, which controls both the trigger of the generator and the counter;
- a signal amplifier;
- a signal filter;
- an instrumented hammer for emitting low frequency signals (< 10 kHz); alternatively, transducers can be tapped with a steel hammer to generate sound waves;
- piezoelectric transducers, which are used for emitting high frequency signals (typically, 50÷100 kHz);
- piezoelectric transducers for receiving the signal (or micro-accelerometers, in case of low frequency signal);
- preamplifiers, which are required in most applications on wood, because of the high attenuation of the transmitted waves in the material, especially in case of thick elements.

For tomographic data acquisition, it is desirable to use a multi-channel device to speed up the measures. Alternatively, a set of probes, operating both as signal emitter and receiver, can be used.

The definition of the parameters for data acquisition depends on the experimental conditions and the scale of the investigated characteristics. The minimum size of the detectable defects is predetermined, depending on the frequencies used and the geometric resolution of the tomography.

Frequency range of the emitting source has to be chosen in order to optimize resolution of the analysis and attenuation of the signal. The acquisition scheme for each specific test should be carefully designed, considering the characteristics of the investigated section and the accessibility of the sensed surface [11].

Applications

Acoustic tomography can be applied to timber structural elements to detect strength affecting heterogeneities (i.e., knots) and damage (i.e., decay, cracks).

In particular, longitudinal tomograms are useful for screening the element along the entire length, identifying problematic areas, where low velocity values are mapped. Imaging of selected transverse sections is aimed at gross estimation of the heterogeneity extent. Very high velocity values in acoustic tomograms of wood are generally associated with knots. Low velocity areas are associated with low material density, often caused by decay. In particular, decay due to rot fungi and diffuse insect attacks can be detected by means of the acoustic tomography.

General remarks

The main methodological aspects, which influence acoustic tomography, are the applied frequency, the number of independent measurements, the adopted acquisition scheme and the applied inversion technique.

The technique permits only qualitative, large-scale analysis (e.g., maps of entire elements),whereas complementary non-destructive/semi-destructive methods should be used to obtain local quantitative information.

In general, it is recommended to couple acoustic tomography with local mechanical tests, such as resistance drilling tests, for the detection of internal zones of lower densities, and with visual/photographic analysis of the element faces for correlation of internal features and external indicators [11].

CONCLUSIONS

For inspection of timber structures it is important to reliably detect defects, damages and material heterogeneities in wooden members. Normal praxis based on visual inspection and point measurements of drill resistance can be improved through multi-sensor, multi-scale, multiresolution analysis.

Most of the techniques described in the paper allow qualitative analysis of the elements and detection of the presence and location of main gross defects and damage.

High-resolution photogrammetry and IR thermography have great potential as preliminary noncontact screening procedures, to select areas for introspective analysis.

Stress-wave ToF tomography and microwave scanning, thanks to their completely non-destructive nature and the possibility to map large timber sections, can be adopted as large-scale global evaluation method, for decay and defect detection in the interior of the wood material, to be followed by further investigation on anomalous velocity areas.

X-ray radiography can be used for more detailed investigation of specific points in the structure.

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