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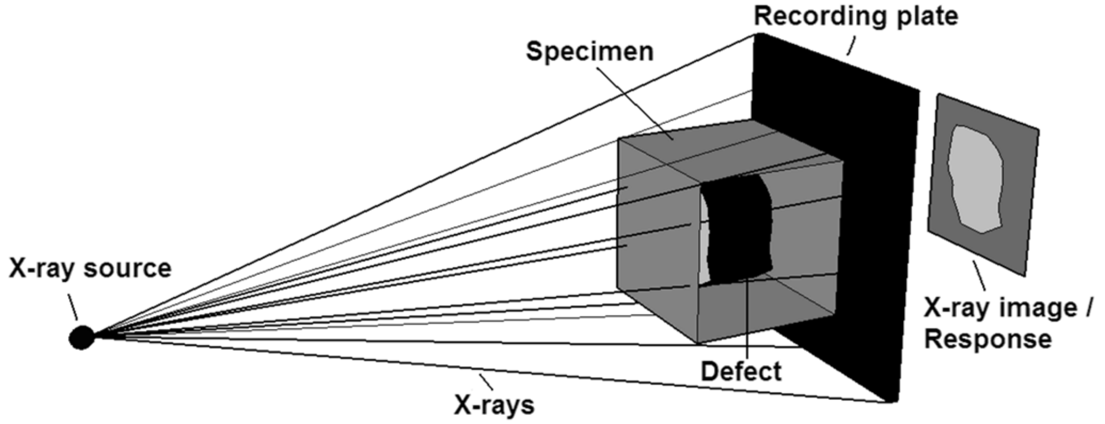

A Guideline for In-Situ Determination of Density in Timber Structures Using X-ray

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Cover:
The cover picture shows an example of an X-ray system and recording process.

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ABSTRACT

This report provides a guideline and instructions for the in-situ assessment of density properties using X-ray equipment.

The first part describes the set-up on site and the second part, the X-ray equipment used is shortly described as well as the recommended procedure for the evaluation of the X-ray images. Finally, the application of this method is described. This method can be preferably used when the density of the timber used in a structure is unknown, especially to assess the condition of the structure and to preserve the cultural heritage.

Keywords: In-situ assessment, non-destructive testing (NDT), density determination, X-ray, calibration procedure.

Contents

1 Introduction

Wood density is strongly related to stiffness and strength properties and can therefore be used in the evaluation of timber structures (Dinwoodie, 2000). The described method provides local property values of density measurements using X-ray. Furthermore, this procedure can also be used to evaluate density distribution in all timber structures. The timber component's local variation in density can be reflected using the photographic imaging (Anthony, 2003).

2 General specifications of the X-ray equipment

The X-ray-system consists of an X-ray generator, a digital imaging system and a reusable phosphor layered imaging plate that capture the intensity levels from the X-ray exposed objectives. A principle example of X-ray set-up is shown in Figure 1.1.

The generator produces short pulsed duration X-rays up to a certain energy level across the X-ray vacuum tube. Both the distance to the object and the intensity level (energy level) should be adapted to achieve the right exposure level, see the producer's specification manual.

The X-rays leave the tube in a certain exit angle, which is decisive for the minimum distance to the specific object for maximum utilization of the imaging plate.

There exist a number of digital image plate systems that can be used to scan the photographic X-ray images. The laser scanner releases the accumulated energy from the image plate and stores the image at selectable resolution on the laptop's imaging software where every single image can be post-processed regarding particular details. There are several other and more modern alternatives that can be used.

The safety instructions from the manufacturer regarding the danger of X-rays shall be followed carefully in order to avoid any kind of harm.

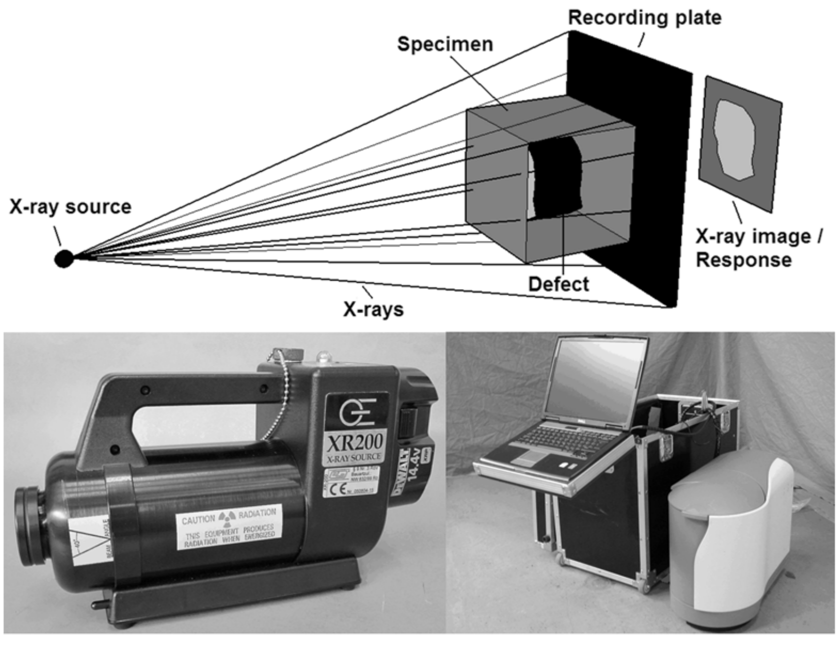

Figure 1.1 Example of X-ray system and recording process.

3 Application

This part describes the in-situ procedure and the preparation of the equipment at hand.

3.1 Procedure

The thickness of the member and the moisture of the X-rayed component have to be measured for calibration purposes.

The calibration wedge, see Figure 1.2, is placed at the component that is going to be imaged. In order to minimize the effects of the exit angle from the X-rays in the tube (larger dosage in the centre and less dosage at the edges), the aimed distance from the generator to the X-rayed object is between 2.5 and 3 meter (Hughes et al., 1975). In practical applications, this distance is seldom possible to achieve, so the effects on the image have to be judged subjectively in the evaluation process when the density variation is obtained. A number of parameters that affect the dosage that the object is excited for are the distance to the object, the exposure time and the energy level.

Subsequently, the density evaluation process of the X-rayed component starts using image processing software. The first step here is to establish a density relationship from the calibration wedge through determining the mean greyscale values from the specimens with different density properties. The density variation between specimens can be represented by a trend-line equation, see Figure 1.2.

The correlation coefficient (R^2) in the equation should be 0.90 or higher, and the number of specimens from the calibration wedge included on the image should be at least 8. The number of specimens included in the equation is dependent on the image disturbances and the distance to the X-rayed object. So, the number of specimens has to be judged subjectively from image to image. As a result, the calibration wedge should consist of 10 to 15 specimens with dimensions that can be captured on the image plate, see Section 3.2.

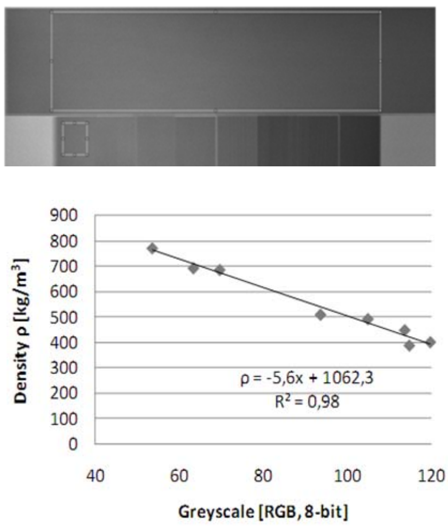

Figure 1.2 Example of X-rayed beam (on top); calibration wedge (below), consisting of 8 clear wood specimens with various density properties and its established trend-line equation (bottom).

The mean greyscale of the inspected area (μ_{mean}) has to be determined and corrected towards reference values for moisture ($\pm\mu_{MC}$). This mean value is then inserted in the trend-line equation where a preliminary density value is achieved. Finally, this value is corrected towards reference values from the calibration wedge with a correction factor (Δ_{RGB}) for the thickness according to Eq. (1). The Δ_{RGB} -value is tabulated in Section 3.3, see, and the μ_{MC}-value is tabulated in Section 3.4, see **Fel! Hittar inte referenskälla.**.

$$\mu_{mean\_corr} = \mu_{mean} + (\Delta\mu_{MC}) + \Delta_{RGB} \qquad \text{Eq. (1)}$$

3.2 Calibration wedge

The X-ray images of beams and joints can be calibrated in a further step towards its density by a calibration specimen built up upon at least 8 to 15 different wood specimens with different density characteristics, see example in Figure 1.3. The thickness (depth) of the specimens is restricted to 30 mm, which is the reference thickness for the thickness calibration.

The specimens need to be conditioned at a relative humidity (RH) level of about 66%, which corresponds to about 12% (air-dried density reference level) in moisture content (MC). The conditioning process can be performed in a climate chamber with constant temperature level of 20ºC, or preferably, the specimens stored in a climate controlled box where a saline solution ($NaNO_2$; sodium nitrite) maintains the RH at a level of about 66% (Nevander et al., 1994).

Figure 1.3 Calibration wedge composed of wood specimens (in that case 13) with increasing density.

3.3 Correction for thickness

This chapter mainly provides the instructions for the use of the tabulated Δ_{RGB}-values, see Table 1.1. The Δ_{RGB}-values are based on the reference thickness of 30 mm of the calibration wedge. The values were achieved from the study carried out at Chalmers University of Technology, and is the result of the absorption of radiation energy when X-rays passes through the object, Beer's Law (Bateni et al., 2008).

First, a qualified expectation of the density range is made, since the Δ_{RGB}-value is based on density and its penetration through the thickness. This value can then be inserted in Eq. (1) and the corrected mean value (μ_{corr}) can be calculated.

depth [mm] Range [kg/m³]	Δ_{RGB} 300-500 [kg/m³]	Δ_{RGB} 520-580 [kg/m³]	Δ_{RGB} 600-1000 [kg/m³]
30	0	0	0
45	19	18	16
60	33	30	28
75	44	40	37
90	52	48	44
105	60	55	50
120	66	61	55
135	72	66	60
150	77	71	64
165	81	75	68
180	85	79	72
195	89	82	75
210	92	85	77
225	94	86	78
240	96	88	80
270	100	91	82
300	103	93	84
330	106	95	85
360	108	97	87
390	110	99	88
435	112	100	89
465	113	101	89
495	114	102	90
525	115	103	90
540	116	103	91
600	117	104	91
700	119	105	-

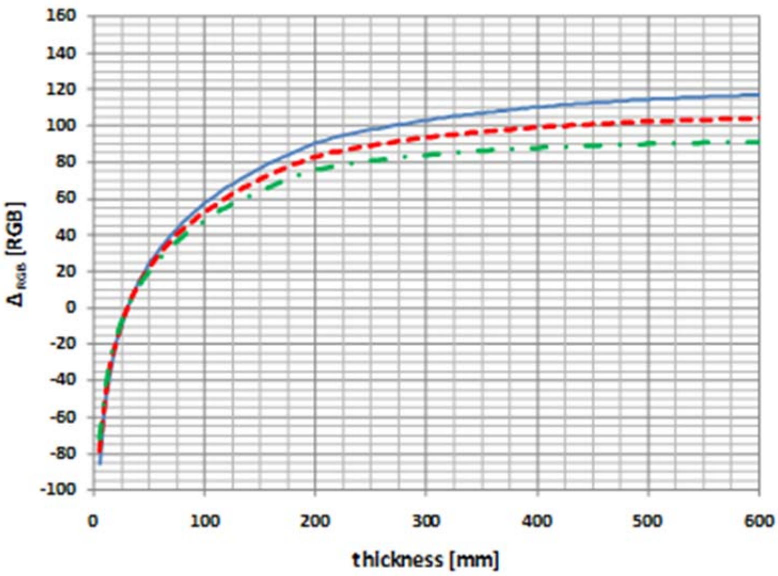

Table 1.1 *Change of Δ_{RGB} [RGB] on the image due to the influence of thickness of the specimen – tabulated and graphical.*

3.4 Correction for moisture

Here, the appropriate factor for the measured MC shall be inserted in Eq. (1). The μ_{MC}-value between two moisture ranges has to be interpolated from Table 1.2.

This procedure is optional, at least for the range between 8% and 16% MC, since the MC only had little influence on the attenuation of X-rays. Only a tendency of the influence of moisture could be captured in this study, as the scatter between different images was too large to make an adequate estimation, i.e. the variation lies in-between the source of error for the method.

The μ_{MC}-values are based on the reference MC for air-dried density conditions (12%) and decrease respectively increase linearly by approximately 1.25-1.75 [RGB] per 1%-change in MC.

Table 1.2 Linear change in $\Delta\mu_{MC}$ [RGB] on the image due to the influence of different moisture conditions in timber.

~MC [%]	6%	8%	10%	12%	14%	16%	20%	22%
~RH_{equ} [%]	35%	43%	50%	66%	79%	85%	90%	93%
$\Delta\mu_{MC}$ [RGB]	7.5-10.5	5.0-7.0	2.5-3.5	0.0	2.5-3.5	5.0-7.0	10.0-14.0	12.5-17.5

3.5 Limitations

- The calibration of the images occurs from a subjective point of view and has to be performed for each image at a time.
- The uneven distribution of radiation dosage (due to the exit angle) is restricted by the distance between the generator and the X-rayed object, so the light that appears from the power initiation of the X-ray tube has to be considered in the evaluation process, but the shadowed areas can easily be detected and excluded from the evaluation.
- The size of the image plate restricts the overall evaluation of the structural member. Several sizes of imaging plates are available
- The method cannot directly be applied on composite structures and needs therefore further investigations and improvement.
- The linear correlation is valid for a range from 250 kg/m^3 to 1000 kg/m^3.

4 Conclusions

Based on the results from a study carried out by Kruglowa et al. (Kruglowa et al., 2010), it has been proved to achieve accurate estimates of the in-situ density of timber using this procedure in combination with digital image processing.

Furthermore, adjustment for the thickness has a significant influence and cannot be neglected when density of wood is evaluated.

The influence of the moisture content can be ignored since it only had little influence on the attenuation of the X-rays; at least for the range between 8% and 16% MC. Only a tendency of the influence of moisture could be captured, as the scatter between different images was too large to make adequate estimations.

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