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

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Quantitative assessment of the load-bearing capacity of structural components using NDT, SDT and DT inspection methods

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1 Introduction

In timber constructions a significant number of failures and damages have been detected within the last decades, well-known documentations are e.g. Frühwald et al. (2007), Blaß & Frese (2010) and Kohler et al. (2011). In many cases, only a partly damage of the construction accord (e.g. a single structural component, a single connection, a group of components, etc.), whereas the remaining (non-failed) structural members are apparently unaffected – they might be also damaged due to additional loading caused by load redistribution.

In such cases the corresponding engineer has to make a decision for the repair alternatives. This might be an exchange of the failed member(s), a reinforcement of the non-failed members or in the worst case a complete renovation of the entire construction. However, to make the optimal decision, it is essential to estimate the load-bearing capacities of the remaining structural members; thereby it has to be considered that the load-bearing capacity is composed of the load-bearing capacity at the time of construction and the deterioration during utilization (Fink & Kohler 2014b).

In many situations the estimation of the remaining load-bearing capacity is rather complicated and connected to large uncertainties. However, under the consideration of information available, such as the target material properties, the age of the building, the history of load (e.g. amount and duration of load) or the amount of the damage, a first estimation can be made. Often this first estimation is not sufficient to make a final decision. In such cases different non-destructive, semi-destructive and destructive inspection methods (referred to as NDT, SDT and DT) can be performed to enhance the estimation.

In this chapter a summary about the quantitative assessment of the load-bearing capacity of structural components based on information available and the results of different NDT, SDT and DT inspection methods using Bayes updating is presented (for a more detailed description see Fink & Kohler 2014a). At first information is classified according their characteristics in respect to a qualitative assessment of the load-bearing capacity of structural components. Afterwards, the corresponding updating-procedure is introduced. The application of the updating procedure is illustrated on two selected examples. In the last part of this chapter, the application of Bayes updating for the decision support is introduced.

2 Updating

For the estimation of the actual load and the resistance of a structural system, the way of treating available information is of particular importance. To do this, the structural model (static system), the applied load, the geometrical properties and especially the material properties of the structural components have to be considered.

One handsome approach to combine different types of information is the so-called *Bayes updating*. Using Bayes updating, given information (so-called *prior information*) will be updated with additional information; e.g. the results of a NDT inspection. The prior information can be the planed conditions (if available), such as the target material properties or (if nothing better available) the assessment of an expert.

The Bayes approach is related to the quality of the prior information and the characteristics of the information used for updating. For this purpose, the information is classified according the characteristics necessary for Bayes updating. Thereby it can be distinguished between so-called *equality type information* and *inequality type information*. *Equality type information* are measured variables, whereas *inequality type information* denotes information that some variable is greater than or less than some predefined limit. Furthermore, it can be differentiated between direct information (direct measurements of the quantity of interest) and indirect information (measurement of some indicator of the quantity).

For the different types of information the corresponding updating procedure is introduced (according to Rackwitz 1983, Faber 2012, Faber et al. 2000, Fink & Kohler 2014b). The general scheme for updating the parameters having *equality type information* is given in Eq. (1). The inspected parameter, here the load-bearing capacity of the structural members, is represented by the variable X with the probability distribution function $F_X(x)$. The parameters $\boldsymbol{\theta} = (\theta_1, \theta_2, ..., \theta_n)^T$ of the distribution function are not precisely known; they are product of engineering knowledge, physical understanding or earlier observations of the quantity. In general the parameters $\boldsymbol{\theta}$ are expressed as random variables specified by the so-called prior density function $f'_\Theta(\boldsymbol{\theta})$. The uncertain parameters $\boldsymbol{\theta}$ can be updated with new information (new observations of realizations of the variable X, $\hat{\mathbf{x}} = (\hat{x}_1, \hat{x}_2, ..., \hat{x}_n)^T$). $f''_\Theta(\boldsymbol{\theta}|\hat{\mathbf{x}})$ denote the posterior distribution function of the parameters $\boldsymbol{\theta}$, $L(\boldsymbol{\theta}|\hat{\mathbf{x}})$ denote the likelihood function (representing the knowledge gained by the new information), and n is the number of observations.

$$f'''(x) = \int f_X(x|\boldsymbol{\theta}) f''_\Theta(\boldsymbol{\theta}|\hat{\mathbf{x}}) d\boldsymbol{\theta} \qquad f''_\Theta(\boldsymbol{\theta}|\hat{\mathbf{x}}) = \frac{f'_\Theta(\boldsymbol{\theta}) L(\boldsymbol{\theta}|\hat{\mathbf{x}})}{\int f'_\Theta(\boldsymbol{\theta}) L(\boldsymbol{\theta}|\hat{\mathbf{x}}) d\boldsymbol{\theta}} \tag{1}$$

The load-bearing capacity of the structural members can also be updated having *inequality type information*. Assuming a structural member will be proof loaded up to specific stresses effect σ_l without failure. Thus the load-bearing capacity of the structural members can be represented by the variable X following a truncated distribution function. In Faber et al. (2000) the following approach is proposed to calculate the load-bearing capacity $F''_R(r)$; here $F'_R(r)$ is the prior distribution function of the resistance:

$$F''_R(r) = \frac{F'_R(r) - F'_R(\sigma_l)}{1 - F'_R(\sigma_l)} \qquad r \geq \sigma_l \tag{2}$$

The principle of updating using *equality type information* and updating using *inequality type information* is illustrated in Fig. 1 on two examples. In both examples, the bending strength of GLT beams (strength class GL24h) is updated. One time with *equality type information* and one time with *inequality type information*. The characteristic value of the bending strength f_m of strength class GL24 is $f_\mathrm{m,k} = 24$ MPa. The bending strength f_m is assumed to be log-normal distributed with COV = 0.15, in accordance to JCSS (2006). Thus, the logarithm of the bending strength is normal distributed: $ln(f_m) \sim N(\mu', \sigma_z)$, with $\sigma_z \approx COV = 0.15$. In Fig. 1 (left), the bending strength f_m of GLT beams is updated with the results of three bending tests $f_{\mathrm{m},i} = 22, 30, 35$ MPa (*equality type information*). All three test results are within the expected range, but slightly below the expected value. As a result the predictive bending strength of the not tested GLT beams is slightly reduced, in particular within the upper tale of the distribution function. In the second example (Fig. 1, right), the bending strength f_m of the GLT beams is updated after proof loading. The load

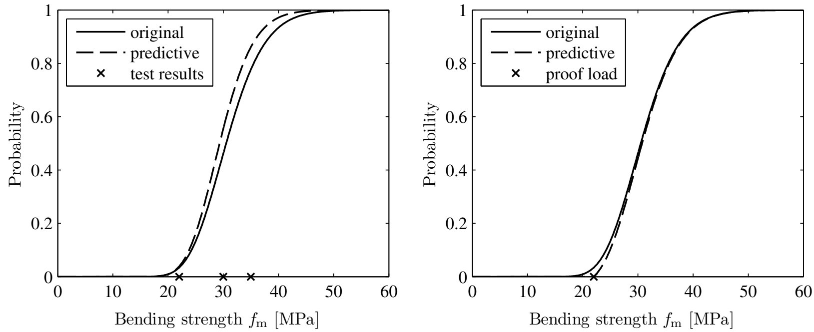

Fig. 1: Schematic illustration of the principle of (left) updating using *equality type information*, and (right) updating using *inequality type information*

is applied constantly over the entire construction and corresponds to $\sigma_l = 22$ MPa. In this example no GLT beam failed under this load and thus it is obvious that the load-bearing capacity of all GLT beams is at least equal to the specific load effect: $f_m \geq \sigma_l = 22$ MPa. As a result, in Fig. 1 (right), the lower tail of the predictive distribution function is truncated.

3 Decision support

The presented summary about the quantitative assessment of the load-bearing capacity of structural components using NDT, SDT and DT inspection methods concludes with a discussion about the application of Bayes updating for the decision support. Two fields of application are discussed:

- ***Support the corresponding engineer to choose the optimal inspection methods:*** Using the Bayes updating combined with the assumption of possible outcomes the optimal inspection method as well as the optimal number essential test can be estimated. Such pre-investigations can be very efficient for the choice (type and amount) of inspection methods. As a result useless inspections can be avoided and the total cost of the renovation (inspection costs and repair costs) can be minimised.
- ***Support the corresponding engineer to find the optimal decision:*** Under consideration of the information available and all test results (NDT, SDT, and DT) the load-bearing capacity of the non-failed structural members can be estimated using Bayes updating. This can support the corresponding engineer to make a final decision.

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