Guideline on the Assessment of Timber Structures - Summary

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Abstract

The domain “assessment of existing timber structures” has experienced increased interest and gained application in practice over the last years. The objective of the guideline which is summarized in this short communication is to provide the reader with a collection of applicable assessment methods which have been evaluated by a group of experts against keywords like applicability, expenditure of time/cost, validity of results and possible constraints. Since each method only allows the assessment of certain types of material properties, damages or degradation processes, it becomes necessary to combine different methods in order to derive a full picture of the residual performance of the structure. Against this background, common approaches towards the assessment of timber structures are given.

The results received from an assessment should be incorporated into analytical models. Different approaches towards the modelling and updating of existing structures are presented, including deterministic, semi-probabilistic as well as probabilistic verification methods.

The guideline concludes with a discussion on the present state-of-the art for the assessment of timber structures. Potential objectives towards an optimization of the methods with respect to a simplified application are defined and necessary developments that finally enable more consistent estimations of the reliability of existing timber structures are highlighted.

Keywords

timber structure; inspection; maintenance; assessment methods; monitoring; deterministic analysis; probabilistic analysis; verification methods; structural reliability; updating

1 Introduction

Within the field of timber construction, the last decades were characterized by significant technical advances and developments, widening the range of application of timber structures in the building sector. This resulted in the fact that timber was increasingly utilized as building material for e.g. large-span structures. Since such structures are typically part of buildings which are classified into higher consequence classes, this led to a growing importance of the assessment of large-span timber structures. Naturally, this provoked an increased interest of the professional community in assessment methods for existing timber structures.

Therefore it was decided to form a task group within COST Action E55 with the objective to collect feasible assessment methods and to evaluate each of them with regard to the following objectives:

- What can be determined / what can not be determined?
- How exact and valid are the results (e.g. degree and size of damage; local/global results)?
- How complex and time consuming is its application (on-site, (non-) destructive)?
- Which combinations of methods are useful to derive a clear picture of the structural integrity of the assessed structure?
- How are the test results related to the properties of interest?

To support the work of the task group, a master thesis was initiated at TUM in the lead-up to the task group meeting with the objective to collect background material and to describe the state-of-the-art of the methods to be evaluated [1]. This preparatory work should function as basis for the discussions between the experts.

The task group decided to publish its results in a guideline “Assessment of Timber Structures” [2]. It should not only present the assessment methods evaluated but also general information on how to approach an assessment (including relevant codes), combinations of methods according to the phase (depth) of assessment and analytical methods to evaluate on the data received. All members of this task group contributed to the guideline within their area of expertise. It was subsequently presented for discussion to all members of COST Action E55 and reviewed by four independent members of the same Action. The following section shall give an overview of the structure and contents of the guideline.

4 Structure and contents of the guideline on the assessment of timber structures

4.1 General

The need for an assessment of an existing structure can be based upon a multitude of reasons. Amongst the most typical are (e.g. given in [3]):

- if errors in the planning or construction process become known;
- on the occasion of change of use of the building;
- in case of doubts about the structural safety, caused by visible damage;
- due to apparently inadequate serviceability and usability;
- because of exceptional incidents or accidental loads which might have damaged the structure;
- in the case of arising suspicion due to material-, construction- or system inherent impairment of the structural safety;
- if a simple, initially unfounded suspicion shall be eliminated;
- when the remaining lifetime, determined during a previous assessment, has expired.

The assessment itself is divided into different phases, structured by the detailedness of the investigations on the structure or elements of the structure, see Figure 1. The number of phases necessary is dependent on the remaining level of doubt, the feasibility and simplicity of repair/strengthening (or demolition), always in combination with economical considerations. The phases approach is presented in the guideline, including typical actions to be carried out during each phase as well as applicable assessment methods.

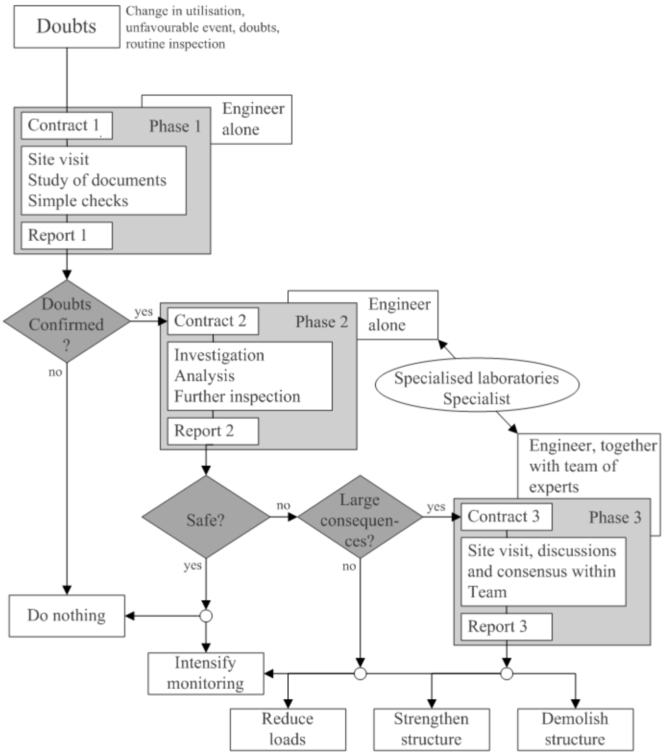

Figure 1. Illustration of the phases approach (from [4])

Over the last years, a multitude of guidelines on how to approach the inspection and maintenance of existing structures have been published, e.g. [5]. However, only a few countries have published applicable code-type documents for the assessment of existing structures. One code-type document is presented in detail, resulting from efforts in Switzerland aiming at editing a new series of standards for the maintenance and reassessment of existing structures (e.g. [6] and [7]). This includes a description of assessment procedures, updating, verification and decision making. It is finalized by a numerical example on which the deterministic, semi-probabilistic and probabilistic verification approaches are demonstrated.

The documentation of the structure is of most importance for the expert carrying out the assessment. Existing documentation can aid to receive a clearer picture of the structure before the actual assessment on site. It helps to determine, if the structure was carried out according to plans and to carry out comparative calculations in order to check which members are highly utilized. Hence it can sometimes eliminate the necessity to apply costly and time-expensive methods. It is self-explanatory that the assessment itself is also well-documented. Thereby, the benefits of photography as part of an easily accessible and comprehensive documentation are obvious. The building book has proven to be a good tool to facilitate future inspections and to guarantee a consistent documentation, even with the change of authorized personnel. If not already available, it should be set up by the structural engineer in conjunction with a detailed inspection and should include all available information. If necessary information (e.g. planning documents) is lost, an agreement with the owner should be found, if and to which extent the missing information shall be newly generated. The aspect of maintainability and crucial elements to be inspected should also be included. A possible layout of the building book is given in the guidelines. It is only fully beneficial, if it is utilized as a “Building Diary”, meaning it is continued by the owner and future inspectors.

4.2 Assessment methods

In the second (and main) section, the following common assessment methods for timber structures are introduced:

- Visual (hands-on) inspection
- Tapping (sounding)
- Mapping of cracks
- Measurement of environmental conditions
- Measurement of timber moisture content
- Endoscopy
- Penetration resistance
- Pullout resistance
- Drill resistance
- Core drilling
- Shear tests on core samples
- Stress waves
- X-Ray
- Dynamic response
- Load tests (proof loading)
- Strain measurement
- Microscopic and chemical laboratory methods
- Macroscopic laboratory methods – testing of specimen

Each chapter is subdivided into “principle”, “application”, “evaluation” and “literature resources”. It represents a collection of information from other publications, which is combined with the practical experience of the task group members. Since the listing of bibliographical references for these manifold subjects is beyond the scope of this short communication, the reader is kindly referred to the comprehensive bibliographical references given in the full guideline [2].
All methods presented have been discussed within the task group; the results of the discussion and the evaluation of the method by the task group are reflected in the respective chapters. The following example on the assessment of cracks in timber members is taken from the report but reproduced here to illustrate the chosen approach and layout.

4.2.1 Illustrative example of methods presented in the guideline

Mapping of cracks

<u>Principle:</u>
Detection and documentation of crack distribution as well as measurement of crack dimensions, for example by using a thickness gauge (0,1 mm) and measuring tape or pocket rule. A magnifying glass can aid in determining the age of a crack (dust, discoloration within crack) and potential adhesion or cohesion problems if cracks appear mainly in the glueline.

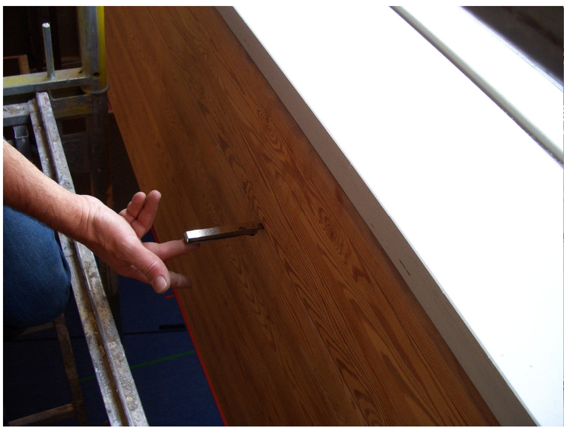


Figure 2. Measurement of crack depth with thickness gauge (0.1 mm)
Figure 3. Marking and mapping of cracks for rehabilitation

Application:
The detection and assessment of cracks is part of every assessment of timber structures, especially large-span structures. While a partial detection of cracks is performed during the first site-visit (Phase I), a detailed investigation, including a complete mapping of all cracks can be carried out during the detailed inspection (Phase II).
The determination of the crack dimensions aids to assess the remaining residual cross section of structural elements. In this context, the crack depth is of particular importance. The crack depth should be measured at multiple locations along the crack. [DIN 4074] indicates possible space intervals for the measurement of crack depths. For longer cracks, these intervals (measurement at each ¼ of the length) should be reduced.
Diverging cracks are problematic since their real depth cannot be measured with a thickness gauge. A core sample can give clearer information, nevertheless this remains a local and destructive measure. Other methods to assess the location and dimension of cracks are the ultrasound-echo-technique [Hasenstab 2007], [Aicher 2008-1] and radiography [Vogel]. Both techniques however need further development before they are widely applicable for this specific purpose. They are described in more detail in their respective chapters (in [2]).
Essential for the evaluation of the consequence are the crack dimensions (length, width, and depth) as well as their position within the structural element. It is also relevant, if the cracks appear predominantly/exclusively or with a certain frequency in the timber or in the glueline [Aicher 2008-2].
The measured crack dimensions and location are to be evaluated individually for each structure. To determine the causes and possible consequences of cracks, the relevance of the structural element, the building use and environmental boundary conditions have to be taken into account. Within the scope of structural boundary conditions it should be differentiated between cracks in areas of high shear and areas of high tension perpendicular to the grain stresses. Some literature indicates permissible crack depths for such areas [Radovic], [Frech], [Erler].
The marking/mapping of crack width, depth and crack tips is important to analyse possible changes in crack dimensions over time. This is essential for structures which are subjected to seasonal environmental changes, leading to changing timber moisture content which can have an influence on crack dimensions.

Evaluation:

Table 1: Evaluation of Assessment Methods – Mapping of Cracks

Method	Mapping of Cracks
Type	Visual; on-site; non-destructive
Frequency of application	Frequent (Phase I)
Extent of assessment	Local
Validity of results	Limited (incertitude about crack depth)
Expenditure of time / cost	Medium/Low
Constraints	Local and temporary assessment; depth of diverging cracks cannot be examined accurately; the investigation of larger areas can be very time-consuming

Literature:
Each section in the guideline [2] is concluded by a list of relevant publications on presented method, including the [literature] already mentioned in the text.

4.3 Evaluation of results

The conclusions from an assessment of an existing structure can either be based on a qualitative approach or a quantitative approach. The guideline indicates approaches as well as criteria for decision (if feasible). Although there are repeated requests from practice to specify concrete threshold values (e.g. permissible crack depths), the task group has decided to refrain from declaring general thresholds. The reason is that any result from an assessment is always to be interpreted in the context of the specific structure. The judgement on the results is in the responsibility of the expert engineer carrying out the assessment.

The results received from a quantitative assessment should be incorporated into the analytical model of the structure. The potential benefit, compared to the planning of a new structure, is the amount and quality of available information which could be used to update the structural model. When designing new structures, structural engineers have to rely on estimates, resulting in the fact that they have to apply e.g. 5^{th} percentile values for strength properties of the materials used. An existing building can potentially disclose more exact information, thereby replacing the estimates from the planning phase.
Different approaches towards the modelling and updating of existing structures are presented in the guideline, including deterministic, semi-probabilistic and probabilistic verification methods. However, the successful application of the approaches is mainly dependent on the question, if the assessment methods applied are able to deliver reliable and quantifiable information.

The guideline concludes with a discussion on the present state-of-the art for the assessment of timber structures. Potential objectives towards an optimization of the methods with respect to a simplified application are defined and the necessary developments that finally enable more consistent estimations of the reliability of existing timber structures are highlighted.

5 General conclusions

The domain “Assessment of Timber Structures” has seen increased interest and gained application in practice over the last years. This has led to an increased experience with feasible assessment methods. On the other hand, this has not yet actualized in significant advancements in the assessment methods itself.

Many methods exist to assess location and degree of damages in structures. In a more narrow sense, this is also true for the observation of damaging mechanisms by appropriate monitoring systems or by inspections e.g. visually or by means of non-destructive measurements. However, the current practice of the assessment of existing timber structures might not be considered suitable to facilitate confident decisions about the reliability of structures. Most methods assess certain properties of the structure non-destructively and deliver results in form of measurements. To date it is often not possible to relate these measurements to strength and stiffness related properties of the timber components with sufficient certainty. Therefore they do not allow a quantification of the reliability of the structural component under consideration. Any method only allows assessing certain types of material properties, damages or degradation processes. This makes it necessary to combine different methods to derive a full picture about the residual performance of the structure.

The task group found consent that most assessment methods utilized today can give qualitative information but only a few non-destructive methods can give quantifiable information. Applicable methods to determine strength parameters of built-in timber elements are very scarce, while a few more methods exist to derive timber stiffness parameters. Although there is a correlation of MOE and MOR, the task group stated that this correlation is too low for common brittle failure types like tension perpendicular to grain and shear failure, leaving a low level of confidence.

As a consequence, all data received requires a very careful evaluation by an experienced engineer. Expertises treating the structural safety of a timber structure will oftentimes be set up from a standpoint which could be summarized as “safe on the best knowledge we have”.

Abovementioned facts imply that more focus should be given to the optimization of assessment methods. This comprises the improvement of frequently applied methods (e.g. mapping of cracks and measurement of timber moisture content) in terms of applicability and expenditure of time/cost. In addition to that, emphasis should be laid on the development of methods for an in-situ determination of timber strength parameters. Only then can the objective to incorporate such results into updated models of structural systems (“system updating”) really be accomplished.

However, every assessment of a timber structure aids to increase the experience with existing timber structures. This collective experience represents an indispensable support when it comes to improving the design, production, execution and maintenance of timber structures. This can be accomplished by an improvement of codes (e.g. the introduction of block-shear verification or strengthening methods against tension perpendicular to grain stresses) or by the amendment of design guidelines (e.g. for the design of frame corners).

Acknowledgement

This short communication represents a small fraction of the joined experience and opinion of the COST E55 task group “Assessment of Timber Structures”. The commitment and contributions of all members of this task group are greatly appreciated. In addition, the task group would like to thank the external reviewers for their thorough review and valued comments of the guideline. Gratitude is addressed to the COST Office for funding the task group meeting and the publication of the guideline.

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