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Redevelopment of a wooden roof construction under preservation order – strength grading of the timber members

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Abstract

The considerate redevelopment of existing timber structures requires a high standard of care and accuracy in all phases of planning and execution. To plan a substance-careful and economical redevelopment a detailed assessment and evaluation of the structure is required.

Such an exact evaluation of the structural stability is only possible if the present load-bearing capacity of the timber members is determined. A simple visual investigation is not sufficient. Therefore, non- and semi-destructive test methods are additionally applied to ensure a reliable and accurate determination of the material properties.

The in-situ strength grading of timber members in existing structures is described for an example of a wooden roof construction which is listed as national heritage. The investigation carried out (visual inspection and grading, ultrasonic time-of-flight measurements and the extraction and laboratory testing of core samples) provided a detailed evaluation of the roof construction as well as of single members. Therefore, reserves and deficits in the load-bearing capacity could be revealed reliably. Based on this information, the development of detailed, member specific redevelopment solution was possible.

Keywords

redevelopment, historic timber structures, national heritage, strength grading

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1 Introduction

The considerate redevelopment of existing timber structures requires a high standard of care and accuracy in all phases of planning and execution. To enable a substance-careful redevelopment, a detailed structural survey is required (see Fig. 1.1). In addition to the structural geometry, this also includes an exact assessment of the stability (Lißner & Rug, 2015 and 2018).

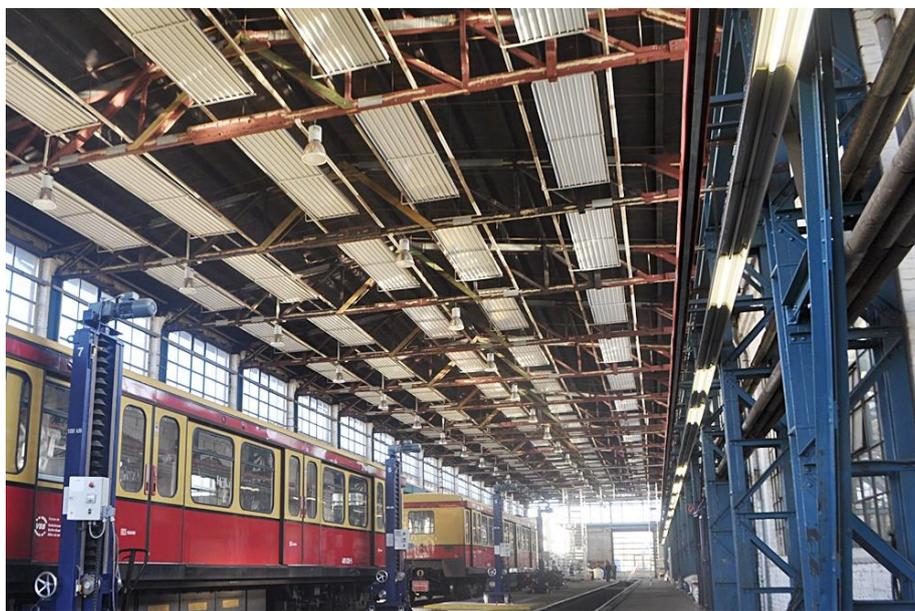


Fig. 1.1 wooden roof construction of a storage and repairing facility from the 1950s, the redevelopment required the comprehensive evaluation of the building conditions

Such an evaluation can only be carried out if the load-bearing capacity of the timber members is determined as accurate and reliable as possible beforehand (Loebjinski, Rug & Pasternak, 2017).

In the field of new structural timber this is achieved by strength grading acc. DIN EN 14081-1. There, it is differentiated between the visual and mechanical grading. The visual grading is focussed on superficial visible and measurable growth characteristics. If structural timber is graded mechanically, the material properties are determined with the help of non-destructive measurement and test methods. The methods used are deflection measurement, radiography and dynamic test methods such as the ultrasonic method (Linke, Rug & Pasternak, 2017 and 2018).

These grading techniques which were developed for new structural timber cannot or at least with large restrictions be applied on timber members in existing structures. Essentially, this concerns the restricted visibility and accessibility of the timber member, the non-existing personnel qualification as well as the lack of test apparatuses which is certified by the building authorities and flexible enough to be used in-situ (Lißner & Rug, 2015).

Therefore, an in-situ strength grading of timber members is carried out only in very rare cases. The present load-bearing capacity of the timber members is assessed intuitively in most cases. The evaluation of the structural stability is then carried out considering the load-bearing capacity of “average-quality timber”– i.e. timber belonging to the grading class S10 acc. DIN 4074-1 (coniferous wood) resp. LS10 acc. DIN 4074-5 (deciduous wood). Reserves in the load-bearing capacity (i.e. members and connections with a higher load-bearing capacity) as well as deficits (i.e. members or connections with a less load-bearing capacity) cannot be detected by this procedure. This leads to possibly less considerate and unprofessional redevelopment measurements.

The strength grading of timber in existing structures in connection with the application of non- and semi-destructive test methods allows the exact and reliable determination of the material properties. A purely visual evaluation of the timber members is in most cases not sufficient enough due to the weak correlation between the visually determinable material features and the present strength and stiffness properties (Glos, 1995). With the additional application of non- and semi-destructive test methods a significant improvement of the accuracy and reliability of the in-situ evaluation of timber members can be achieved (Linke, Rug & Pasternak, 2017 and 2018).

The following contribution shows the procedure of the in-situ strength grading of timber members in existing structures on the example of a wooden roof construction which is listed as national heritage.

2 Object description and problem definition

The investigated roof construction is part of a storage and repairing facility. The roof construction was erected in the 1950s and consists of 21 timber trusses with a span width of 15,7 m (see Fig. 2.1).

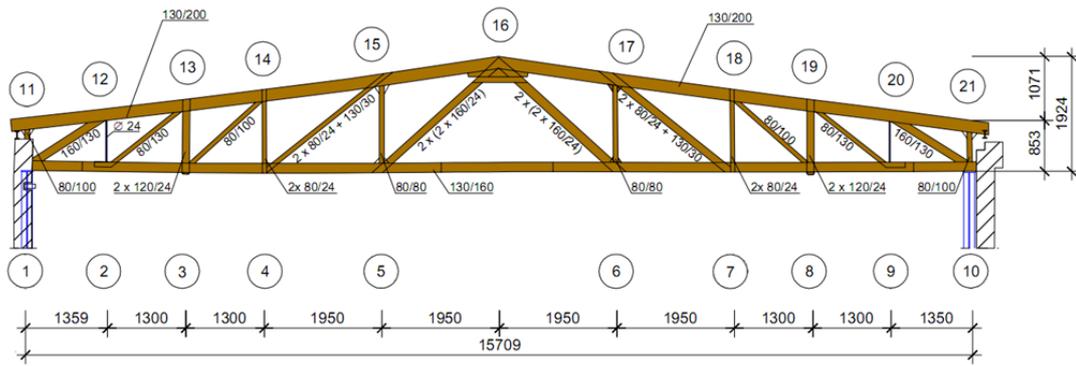


Fig. 2.1 graphic depiction of the timber trusses

The connections between the members are executed as carpentry joints (staggered joints and tenons) as well as nailed and bolted joints (partially with rectangular hardwood dowels).

Due to its exemplary role for the timber-saving construction methods in Germany in the post-war period, it is nowadays listed as a national heritage.

During the recommissioning the facility a redevelopment of the roof construction was required. In the stage of preliminary planning a random visual inspection and calculations on the structural stability were carried out by a structural engineer. The structural calculations were conducted under the assumption of „average-quality timber“ (grading class S10 acc. to DIN 4074-1 / strength class C24 acc. to EN 338). A comprehensive investigation on the building condition has not been carried out.

The results of the preliminary investigations showed the necessity of a reinforcement of the timber trusses. Overall, the condition of the roof construction was evaluated as “poor”. The structural engineer’s redevelopment solution intended the reinforcement of the bottom chords with steel belts. Additionally, the tension rods (originally lateral boards with nailed joints) should be replaced with threaded rods due to the poor state of the nailed joints (see Fig. 2.2).

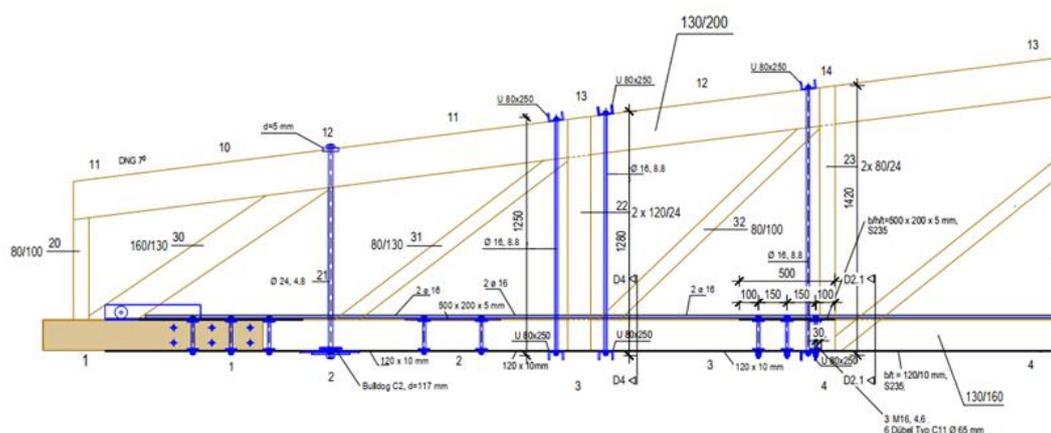


Fig. 2.2 Detail of the preliminary redevelopment solution (marked blue: reinforcement)

Furthermore, this redevelopment solution could only be executed, if the timber members have the estimated material quality. Therefore, the nominated testing engineer demanded the detailed investigation of the roof construction concerning the present material quality and possible defective timber members.

Corresponding to this requirement a detailed appraisal of the timber members in connection with a quasi-apparatus-supported strength grading was necessary and has been carried out.

3 Investigation on the material quality

The investigation on the material quality of the timber members was divided in the following steps:

Visual strength grading:

The timber members of the trusses were visually graded acc. DIN 4074-1:2012. Due to the partial restricted accessibility and visibility only, the following grading criteria have been taken into account: knots, slope of grain, cracks, wane, curvature, decay and damage caused by insects (s. Fig. 3.1, Fig. 3.2). The grading criteria pith, width of annual rings, discolouration and compression wood could not be considered.

Additionally, the moisture content was measured acc. DIN EN 13183-2:2002 with electrical resistance measurement. The climate conditions were recorded with a climate datalogger.

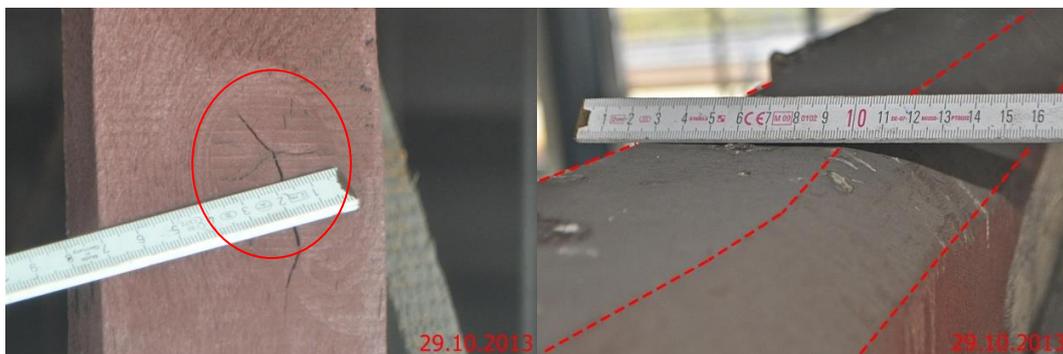


Fig. 3.1 measuring of grading criteria – left: knots; right: wane



Fig. 3.2 measuring of grading criteria – left: torsion; right: slope of grain

In total 441 timber members were inspected and visually graded.

Ultrasonic time-of-flight measurement:

The ultrasonic method uses the strong relation between the propagation velocity of an ultrasonic pulse and the stiffness and density of the material.

The applicability of this ndt method for the determination of material properties was proven by numerous studies (compare Linke, Rug, & Pasternak, 2017 & 2018). Nowadays it is state of the art of the strength grading of structural timber – especially in smaller sawmills.

The ultrasonic time-of-flight measurements were carried out with the test apparatus Sylvatest Trio[®] (see Fig. 3.3). This apparatus generates an ultrasonic pulse and measures the time which the pulse needs to travel from the emitter to the receiver.



Fig. 3.3 apparatus for the ultrasonic time-of-flight measurement (left to right: test apparatus Sylvatest Trio[®], emitter/reciver probes and cables, handheld PC with evaluation software)

The measurements were carried out on the top and bottom chords as well as the compression rods (see Fig. 3.4 & 3.5).



Fig. 3.4 procedure of the ultrasonic time-of-flight measurements – definition of the measuring zone (left), drilling of the holes for the probes (right)



Fig. 3.5 procedure of the ultrasonic time-of-flight measurements – conical hole for the probes (left), measuring of the time-of-flight (right)

The bending strength and the modulus of elasticity were determined with an evaluation software. The here fore used relations were assessed in extensive laboratory tests. After that the timber member could be assigned to one of the strength classes acc. EN 338. Overall 235 measurements were carried out, selected by engineering judgement.

Extraction and testing of core drill samples:

In addition to the visual grading and the ultrasonic time-of-flight measurements core drill samples have been extracted from selected members of the trusses (see Fig. 3.6).



Fig. 3.6 procedure of core drill sample extraction – fixing of the drilling jig on the timber member (top left); core drilling (top right); extracted sample (bottom left); sealing of the hole with a wooden dowel (bottom right)

The core drill samples were used for the following laboratory tests:

- Determination of the density according DIN 52182:1976
- Determination of the compressive strength following DIN 52185:1976

- Determination of the moisture content according DIN EN 13183-1:2002

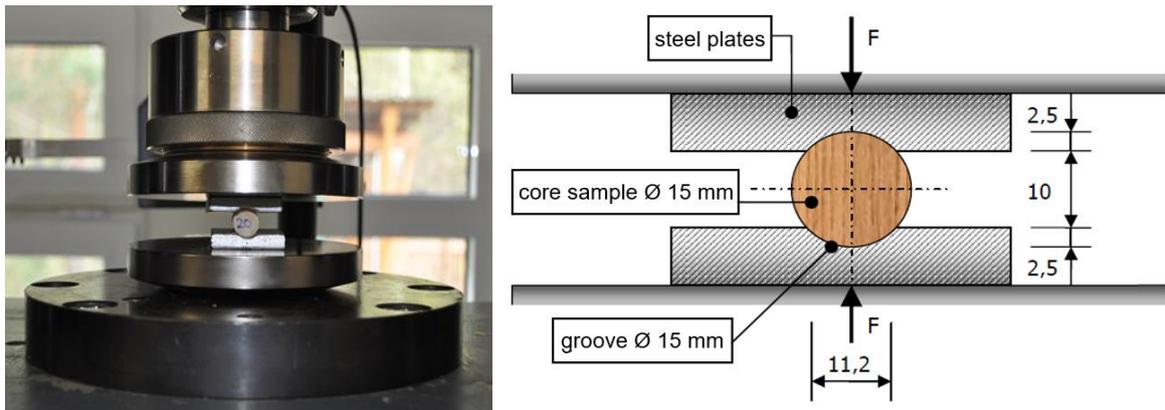


Fig. 3.7 test setup for the determination of the compression strength on core drill samples

The results of the laboratory test on the core drill samples were used to determine material properties which can be used to assign the sample material to one of the strength classes acc. EN 338. This grading method was applied to verify resp. to ensure the visual grading of the timber members acc. DIN 4074-1:2012.

Overall 238 core drill samples were taken from 82 selected timber members.

4 Results

The results of the visual grading show that only one truss can be completely assigned at least to the class S10 acc. DIN 4074-1 resp. to the class C24 acc. EN 338. Overall, there were 100 from 441 visually graded timber members which could not be assigned to the class S10 acc. DIN 4074-1. 20 of these 100 members can be assigned to the class S7 acc. DIN 4074-1 resp. class C18 acc. EN 338. The remaining 80 members could not be assigned to any class acc. DIN 4074-1 and EN 338.

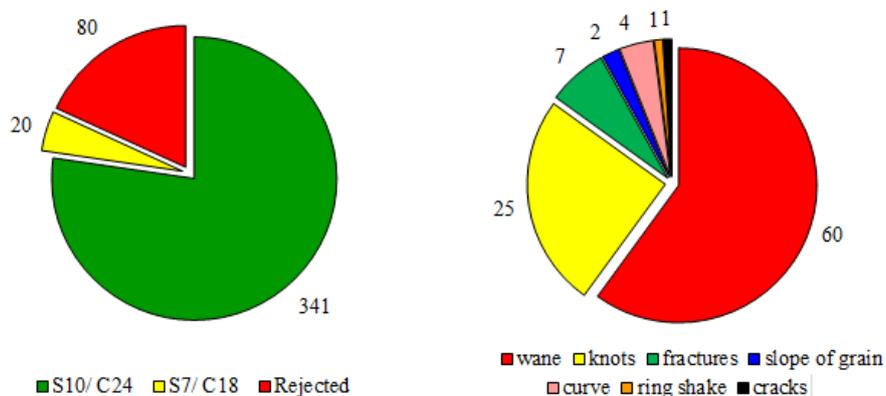


Fig. 4.1 Results of the visual grading – left: Distribution of the grading yield rate; right distribution of the determining grading criteria

The results of the visual grading are verified by the results of the ultrasonic time-of-flight measurements. Only 1 of the 235 measured members could not be assigned to the class C24 acc. DIN EN 338. Though, these to members could also not be assigned to the class S10 acc. DIN 4074-1 resp. class C24 acc. DIN EN 338 by the visual grading.

Furthermore, it was revealed that 127 out of 235 members could be assigned to a higher class on basis of the ultrasonic time-of-flight measurements than on basis of the visual grading (see Fig. 4.2).

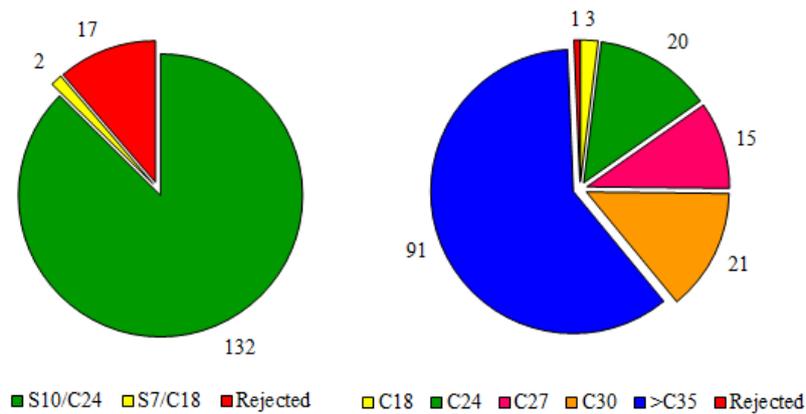


Fig. 4.2 Results of the visual grading (left) and the ultrasonic time-of-flight measurements (right) in comparison

This result was verified by the results of the laboratory test on the extracted core drill samples. As shown in Fig. 4.3, 60 out of 82 investigated members could be assigned to a higher class than purely on basis of the visual grading.

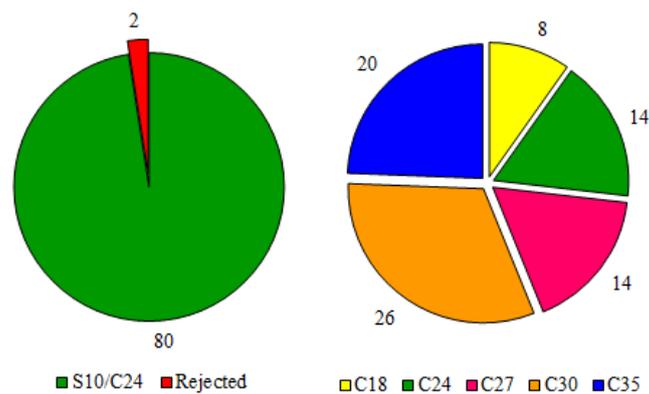


Fig. 4.3 Results of the visual grading (left) and the laboratory tests on the core drill samples (right) in comparison

5 Conclusions

The results of the applied non-/ semi-destructive test methods showed that a detailed investigation concerning the material quality of timber members in existing structures can add significant accuracy to the assessment and evaluation of the structural stability.

The exemplarily described investigation showed that there were significant reserves in the load-bearing capacity which otherwise could not be taken in consideration. Furthermore, this case also shows that deficits in the load-bearing capacity and defective members can only be reliably detected by a detailed investigation.

These results were used to create a detailed redevelopment solution for the trusses themselves as well as for single timber members.

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