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Design, construction and maintenance of structurally protected timber bridges

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1 Introduction

Timber construction is experiencing a renaissance due to the current debate on sustainability and decarbonisation. However, developments in timber bridge construction have been declining for years. Since 2008, when a timber footbridge collapsed in North Rhine-Westphalia, timber bridges have seldom been built in Germany. This damage and numerous other unprotected timber bridges that were improperly planned and built have caused considerable image loss for timber bridge construction.

Using timber as a structural material is a matter of conviction as well as responsibility. An increased application of this ecological and sustainable material should be supported and promoted in bridge construction. For the planning and construction of new timber bridges, it is a basic requirement to provide technical standards that are state of the art. In Germany, comprehensive guidelines are available for the construction of bridges made of reinforced concrete, prestressed concrete, steel and steel-concrete composite. These rules were developed and will be continuously updated by the Federal Highway Research Institute (BASt). A comparable rulebook does not exist for timber bridges. Thus, bridges made of this sustainable material have a considerable competitive disadvantage. The research project ProTimB was initiated in 2016 to rectify that shortfall. Initial results of the project were presented at the ICTB 2017 [1], [2]. The project was concluded in 2019 [3]. This paper presents the results of the research project.

2 The research project ProTimB

2.1 Overview

Technical guidelines guarantee professional state of the art design and construction standards. On the one hand, waiving the rules opens a comprehensive field for creativeness. On the other hand, the risk of serious mistakes in design and construction may rise enormously as a consequence. Especially for timber bridges, insufficient weather protection for the wood can often be identified as a problem. Also, the planning effort increases when details that could actually be standardised have to be newly developed for every new project. Therefore, the research project ProTimB aimed to define standards for structurally protected timber bridges following the generally accepted sets of rules for other materials. The project focused on protected bridges, because the long-term durability of timber bridges can only be achieved by using structural protection measures consistently in all stages of planning, construction and service life.

The outcome of the project is a set of technical guidelines for the design, construction and maintenance of protected timber bridges (Figure 1). Formally, it is inspired by the existing sets of rules for other materials to facilitate their application in practice. The design rules consist of references for planning, samples for structural analysis and 36 new sample drawings (MuZ-HolzBr) [4]. “Recommendations for technical contractual terms for timber bridges (ETV-HolzBr)” have been developed for construction [5]. Regarding maintenance, sample handbooks for the maintenance and inspection of timber bridges and recommendations for object-related damage analysis (OSA-HolzBr) have been compiled. Furthermore, an advanced training course has been conceptualised for timber bridge inspectors. Additionally, nine protected timber bridges crossing rivers were comprehensively monitored [6]. The most important guidelines will be presented in the following. For further details see [3].

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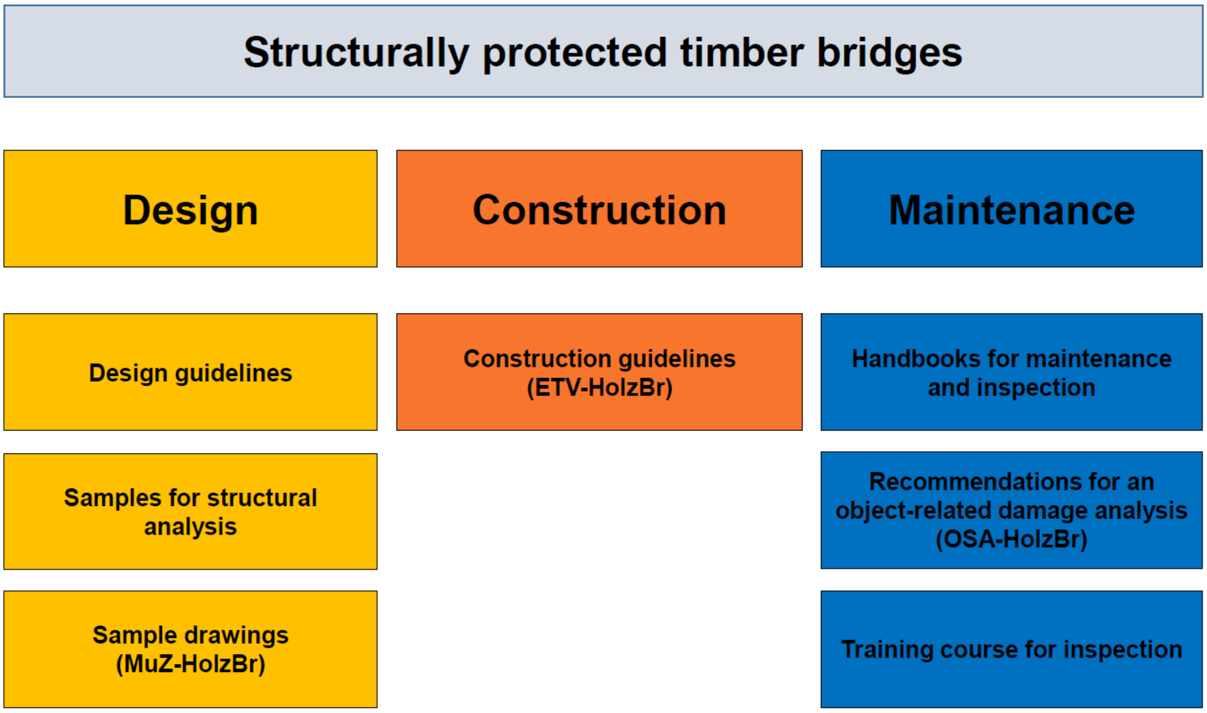

Figure 1: Overview of the new guidelines und project results

2.2 Guidelines for design

The most important document for the design of timber bridges is a set of new sample drawings [7]. Based on formerly developed drawings [8] and [9], it updates and extends them. The 36 drawings show durable and proven solutions for special structural details (Table 1). They are closely related to the familiar drawings (RIZ-Ing) of the Federal Highway Research Institute (BASt).

Table 1: Content of the new sample drawings for protected timber bridges

Drawing	**Content**
H-Belag 1-4	Variants of pavement and their mounting (closed surfaces as asphalt sealings, concrete- and natural stone slabs and open surfaces using wooden planks)
H-Dicht 1-3	Design of sealings for the timber-superstructure
H-Gel 1-5	Variants of parapets and their fastening
H-Kap 1-2	Mounting of concrete caps on timber structures
H-Lag 1-3	Details for bearings
H-Schutz 1-8	Structural protection measures (covering, cladding, ventilation distances, protrusion)
H-Trog 1-2	Design of cross frames and bracing structures for trough bridges
H-Übe 1-4	Transition structures and expansion joints
H-Was 1-3	Details for drainage and dewatering
H-Zug 1	Accessibility of substructure

Figure 2 shows examples of the drawings explaining the structural protection measures.

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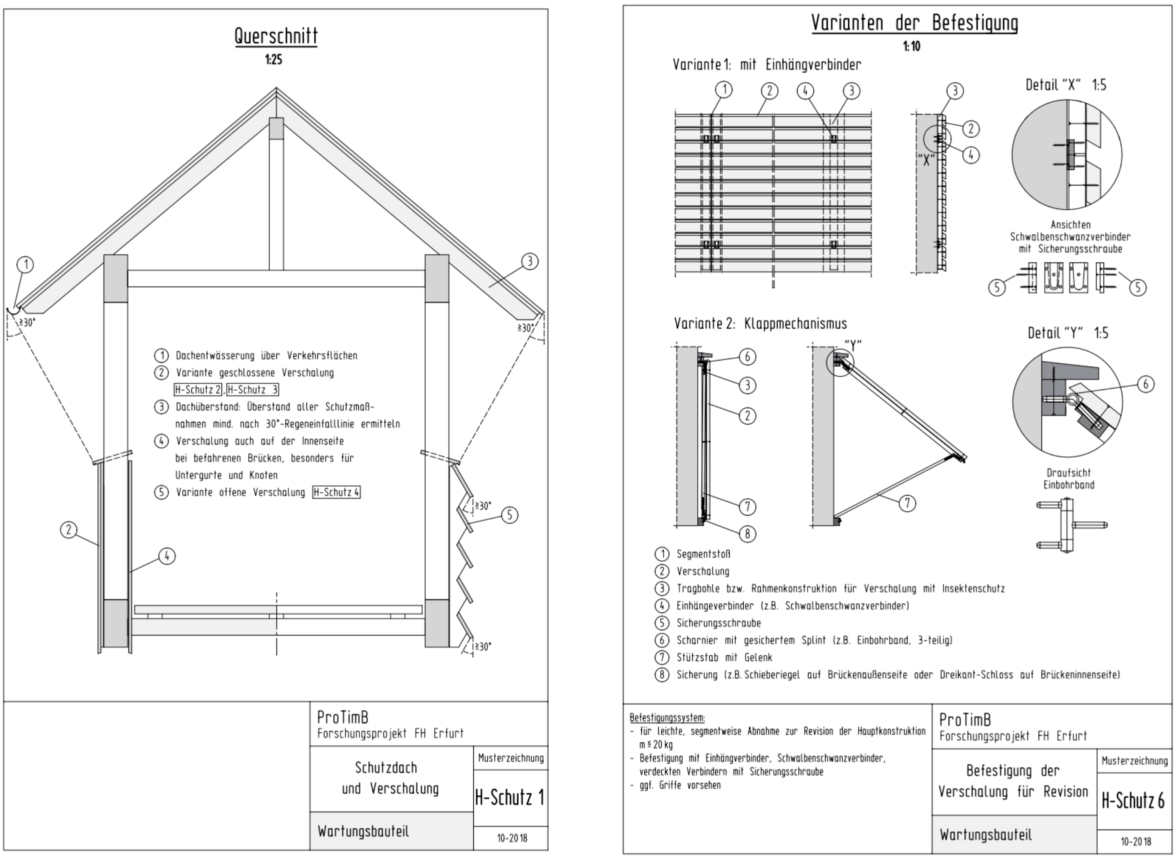

Figure 2: Examples of the new sample drawings regarding structural protection

In addition to the drawings, supplements for the technical design documents are recommended. The appropriate wood species and necessary structural protection measures have to be planned and documented for every single timber member based on their use class according to EN 335 [10] and DIN 68800-1 [11] as shown in Figure 3. Furthermore, it is advisable to plan a monitoring system for every new bridge to recognise structural defects in time. This recommendation has already been implemented in the new European code for timber bridges [12]. Also, the new annex D of EC5-2 showing sample drawings is inspired by the results of the ProTimB project. Samples of structural analyses for simple deck and trough bridges complete the design guidelines.

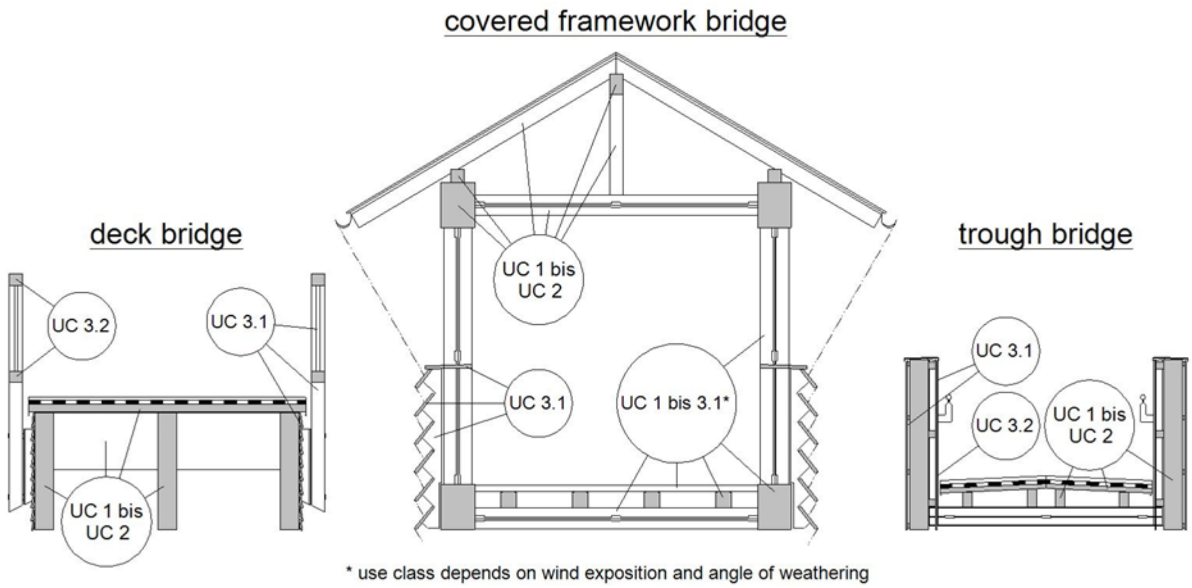

Figure 3: Assignment of timber members to use classes (UC) in different exposure situations

2.3 Guidelines for construction

"Recommendations for technical contractual terms for timber bridges (ETV-HolzBr)" have been developed for construction [5]. This document defines basic material requirements for the timber, engineered wood products, thermally and chemically modified wood, adhesives and steel members. Requirements are provided for minimum dimensions, surface qualities and limits for deformation due to shrinkage and swelling. The production, storage, delivery, quality control and assembly of structural timber members are regulated. Due to quality control, the recommendations define limits for dimensional and moisture tolerances, cracks and surface qualities at the factory and at the construction site. Furthermore, they contain necessary measures to be taken for structural timber protection and the corrosion protection of steel members in timber bridges. It is the first time that recommendations for the design and construction of timber-concrete composite bridges have been listed in a German guideline. Minimum concrete strength and variants of effective connections are defined. Information is given on the service classes and limits for temperature and moisture variation for the correct calculation of hygroexpansion. Suggestions for the design of wildlife bridges with a special focus on sealing and covering layers complete these guidelines.

The guidelines and drawings are available via the website of the University of Applied Sciences Erfurt and the quality association for timber bridges (Qualitätsgemeinschaft Holzbrückenbau).

2.4 Guidelines for maintenance

In Germany, bridge inspection is strictly regulated. Supervision consists of checks and inspections in regular cycles. Every bridge has to be visited twice a year and checked once a year. Additionally, the basic inspection and main inspection have to be performed alternately every three years. The main inspection requires a hands-on check of every structural member and is therefore the most complex and expensive one. Checklists have been developed for annual bridge inspection so that the corresponding road maintenance authority can work effectively (Figure 4). Additionally, a sample handbook for inspection has been written for special types of timber bridges such as framework bridges, cable-stayed bridges or bridges for wildlife. It recommends useful measurement methods and contains special hints for organisation, accessibility, documentation and traffic security during the inspection. Regarding individual structural characteristics, the regular inspection of every timber bridge can be optimized and performed economically using this handbook. If a regular inspection reveals complex damage of unclear cause or unclear dimension of defects, further recommendations are given for the implementation of an object-related damage analysis. This elaboration has been integrated into the guidelines of the BASt and the software for the documentation of bridge inspections.

Bridge Check
Bridge number: …………………………………… Road number: ………………………………… Bridge title: ....…………………………………………………………………………………………..
Occasion: □ yearly check □ after flood □ after accident □ storm damage □ others: ……………………………………………………………………………..………..
Date …………………………………… Checked by ……..……………………………………..
The following aspects have been checked: □ All structural protection members are intact and functional (covering, sealings, claddings…). □ All accessible members have been checked for moisture (marks of running water, timber with earth contact, growth of moss and algae…). □ The timber moisture content has been measured in damp and vulnerable areas. □ All accessible members have been checked for wood-destroying fungi, mycelium and starting rot. □ All accessible members have been checked for wood-destroying insects. □ Protruding connectors have been observed (screws in planks, dowels in knot areas…).
The following changes / damages / moisture content values have been detected: ………………………………………………………………………………………………………...... The following maintenance measures are necessary: ………………………………………………………………………………………………………...... ………………………………………………………………………………………………………......
Signature: …………………………..

Figure 4: Checklist for annual bridge checks

Respecting the principles of structural protection for durable timber bridges is mandatory but not sufficient. Their intended service life of 100 years can only be achieved in combination with regular maintenance. In ProTimB a sample handbook for maintenance has been developed. It explains all useful service measures, their necessary intervals and required technical equipment as well as means of access to facilitate economical maintenance. Service measures include:

- the cleaning of the superstructure, benchings, road surface, bridge drains and drainage channels,
- the removal of vegetation all around the bridge in a radius of at least 2 m,
- the renewal of coatings, sealants, joints,
- the repair of planks, asphalt layer, claddings, cover plates and parapet members.

For every measure, an interval is recommended, taking the structural element's service life and seasonal weathering and pollution into account.

Responsible inspection of timber bridges requires specialist knowledge about the special anisotropic, organic material timber und substantial experience in inspection practice. Bridge inspectors are seldom experts on checking timber bridges because most of the bridges they regularly inspect consist of concrete, brickwork or steel. To familiarise those engineers with the special challenges of timber bridge inspection, a certified advanced training course has been developed.

Besides writing the guidelines, a monitoring system has been installed within the ProTimB project to supervise the development of timber moisture content. It was planned, executed and evaluated at nine protected timber bridges crossing waters in Germany [6]. The bridges demonstrated a timber moisture content lower than the critical 20 mass% for fungal growth. These results prove that the structural protection of timber bridges enables long durability. Critical moisture content values were measured temporarily at two bridges, caused by a defective expansion joint and a special weathering exposition. In both cases, the bridge owners were informed immediately. As a result, they were able to repair the defect and to improve structural protection to prevent serious consequential damages. Providing such a benefit, the monitoring of moisture content at every new timber bridge is highly recommended for at least five years after their construction.

3 Conclusion and View

The new design and construction guidelines are basic regulations for the state of the art planning and construction of durable, aesthetic timber bridges. They formally follow the existing set of rules for concrete and steel and have been provided in a user-friendly format to facilitate their use in practice. Existing competitive disadvantages for timber as a structural material should be repealed by using the research results.

The research has also influenced the updating process for timber bridge code EN 1995-2. In the new code, regulations for structural protection and durability will be significantly extended. Drawing examples for detailing will be contained for the first time in a structural code.

Due to their ecological and sustainable advantages, a significant increase in the market for timber bridges is to be expected in Germany. Aesthetic, well-protected and durable timber bridges of a high-quality standard should characterise our landscape in the future.

4 Acknowledgement

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