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DESIGN OF TIMBER BRIDGES IN EUROPE

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ABSTRACT

Design rules of Timber Bridges are published as EN 1995-2:2010-12 [1]. The second generation implements new knowledge gained the last 20 years. The aim especially was to improve the structure and clarity of the code family. Consolidation on European design practice has been a great part of the work. Although the calculation of timber bridges has become a common practice, the protection of timber is as much a tradition as it is an architectural taste. A timber bridge according to the Eurocode is expected to resist for its design service life independent on being located far south or far north in Europe, in the Alpes at high altitude as well as on a windy coast. The term protected timber bridge is introduced, where weathering is not expected to govern the design service life. All parts of EN 1995-2 [1] have been examined and updated if needed, as presented here.

Keywords: Timber Bridges, Design rules, Eurocode

1 INTRODUCTION

In 2004, the EU (including GB) and several EFTA states introduced uniform design codes, the so-called EUROCODEs (ECs). The goal of the European Committee for Standardization (CEN) was to replace the member states differing or even missing design guidelines by a common set of technical rules that provide the same level of safety and thereby to further minimise barriers within Europe. In 2012, the European Commission issued a mandate for the development of a 2 generation of the ECs to ensure their long-term applicability and reflect the constant technical developments and knowledge gains, see Figure 1.

In the work of 2nd generation ECs, updates in EC 0 and 1 forced updates for the other EC's. For the series of standards "EN 1995 – Design of timber structures" (EC 5) experts regularly prepared drafts for specific topics in timber construction (see [2]). After extensive revision of the entire EC 5 series, new versions were available for all members states for Formal Vote (FV), which ends 2025-04 and publication around 2027 [3], [4].

The meaning of the used verb forms are as follows (in all EC's):

shall **requirement;** strictly to be followed ➔ former ()P principle
should **recommendation** (highly); alternative approach where technically justified
may **permission** within the limits of Eurocodes
can **possibility** and capability ➔ only in NOTEs

Figure 1. European design codes – Eurocodes (Source: European Commission, 2021)

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2 SUSTAINABLE TIMBER BRIDGE CONSTRUCTION

One of the main topics of editing EN 1995-2 [1] was the implementation of the specifications of EN 1990 [5] and EN 1991-2 [6], in particular requirements for reaching a design service life of 100 years. Since construction professionals speak the language of implementation planning, a new Annex D is suggested with simplified figures exemplifies how timber bridges can be protected given proper service. Service is topic in another new suggested Annex E covering inspection and maintenance of timber bridges. Both annexes are informative and may be subject to changes nationally.

Like the building construction code, the code for timber bridges was extended to include requirements and regulations for the durability of structures, taking into account the issues of corrosion protection, and special structures like transvers post-tensioned timber decks or timber-concrete composites. The creep factors for concrete in timber-concrete composite bridges are different from those in building constructions, as the cross-sections are significantly larger. Accordingly, a new normative Annex A of FprEN 1995-2 [7] provides relevant conditional equations. Most regulations on timber decks (deck plates) were now added to the normative Annex C of FprEN 1995-1-1 [8].

Eurocode 8, Part 2 ("Design of structures for earthquake resistance"), takes in 2nd generation also timber bridges into account. In an Informative Annex C of FprEN 1995-2 [7], additional hints for the design of bearings are given. It is also relevant to point to the Informative Annex B, which contains suggestions to be considered in view of deformations and dimensional changes of timber constructions under changing environmental conditions such as temperature or timber moisture, and notes on transversely prestressed timber deck plates (among other things for the "cupping" of the deck sides) [2]. It was also decided to move fatigue requirements into the general part 1-1 as these may be necessary also for buildings with cyclic loads such as industrial buildings, crane structures, highway traffic sign posts, wind turbine tower, or bell towers.

With the technical work being done, the document is being translated into German and French. The remaining steps of the standardisation process are shown in [3] and [4].

3 DURABILITY

3.1 Durability of wooden members

General requirements regarding expected service life, i.e. design service life T_{lf}, that form the basis for all bridge design in Eurocodes are given in EN 1990, A.2 [5]. Together with recommendations on Quality Management the requirements on Durability as well as on Inspection and Maintenance form the basis of a bridge building. These are defined as:

Definition **Maintenance:** Set of activities performed during the service life of the structure so that it fulfils the requirements for reliability.

Chapter 6 **Durability:** All structural parts that rely on a design to satisfy their durability requirements over the design service life **shall** be designed to permit inspection and maintenance. Matters of durability, moisture and moisture content **shall** be given particular attention in the design, see 4.1.2 and 6. Bridges shall be designed to avoid damages from excessive deformation during the intended design service life.

Subclause **Quality Management:** Appropriate quality-management measures **should** be implemented to provide a structure corresponds to the design requirements and assumptions. The following quality-management measures **should** be implemented:

- organizational procedures in design, execution, use and maintenance
- controls at the stages of design, detailing, execution, use and maintenance.

Based on this, different categories are defined for design service life. For bridges, 100 years is the basic option or choice - independent of material types. Lower service life may be relevant for simple bridges used for instance in recreational purposes where consequence of failure is very little, but still 50 years are expected. Further, lower service life is given for replaceable structures (25 years) and temporary or unprotected structures (10 years).

For the design of durable timber bridges the term **Protected and Unprotected Member** are included. The definitions are:

Protected Member

Structural member not exposed to direct weathering such as rain, snow, or other sources of moisture ingress.

Examples of protected timber bridges are given e.g. in Figure 2.

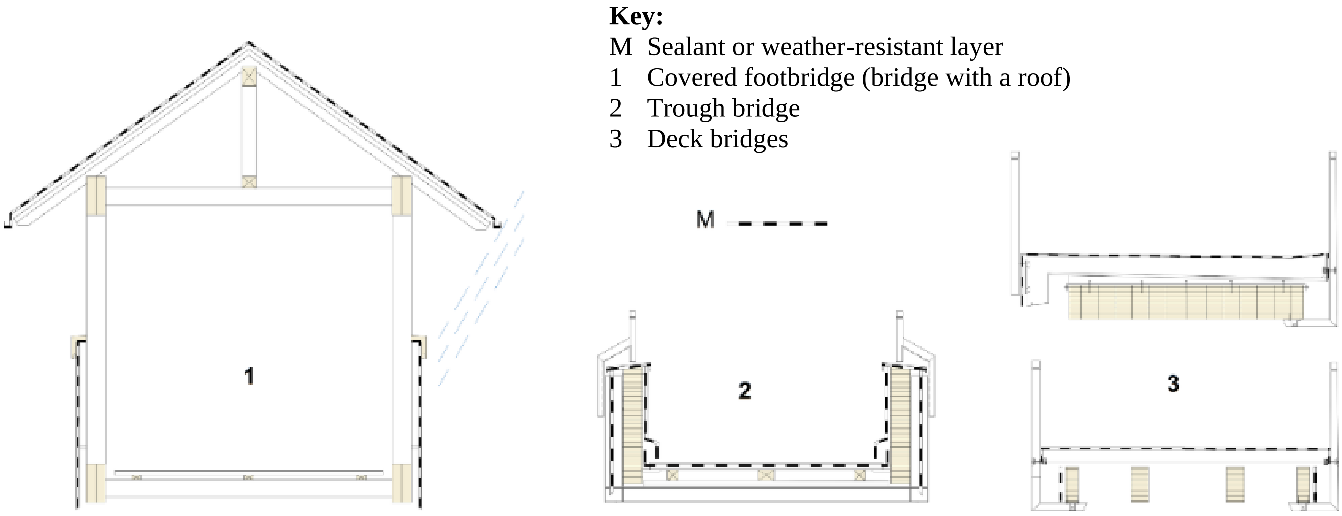


Figure 2. Examples of protected bridges (Source: FprEN 1995-2, Figure 3.2 [7])

Unprotected Member

Structural member that is not protected or partially unprotected from weathering but is within the limits of Service Class (SC) 3.

The methodology is that a protected timber bridge is expected to last for 100 years. When parts of a structures are not within the definition of a protected member these must either be easily replaceable or the expected service life will be less than 100 years. Durability and thus sustainability ensure the economic viability of timber structures. Therefore, the following so-called “magic triangle” must be observed, Figure 3:

Requirements on basic structural protection are given in FprEN 1995-1-1 [8] and EN 1995-2 [1], in some countries with additional nation requirements. This leads to a higher robustness of the expected service life, expecting to lower maintenance costs.

2nd generation of EN 1995-2 includes detailing by figures in Annex D how timber bridges can generally be protected. Five possibilities for basic structural timber protections are given (see Figure 4), together with more detailed examples on expansion joints between superstructure and road (three possible solutions) and bridge caps (2 examples). Furthermore, a suggested monitoring scheme is included as monitoring timber bridges may be a useful addition to inspection, in some European countries mandatory. Currently an arch bridge is taken as example showing which part of the bridge is expected to be critical and thus wise instrumenting, also with regard to the Use Class (UC) according to EN 335 [9].

Because of translation of European standards all figures are language neutral, creating rather lengthy keys to each figure, e.g. in Figure D.4 FprEN 1995-2 [7], see Figure 4.

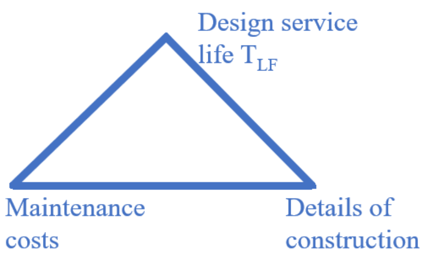
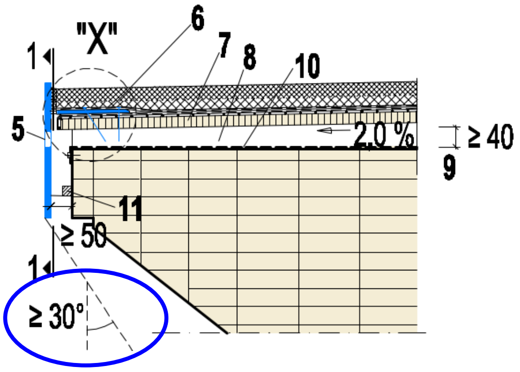
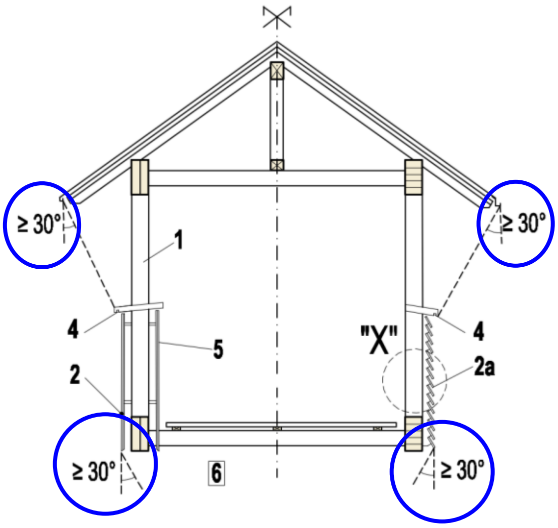
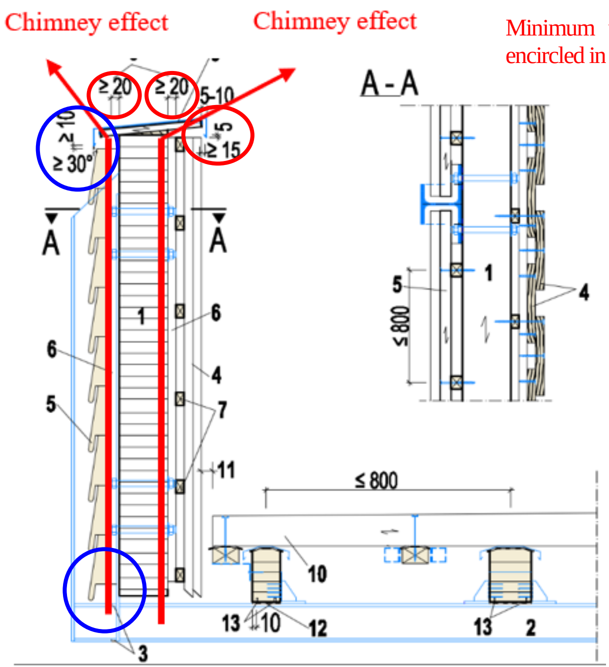


Figure 3. Magic Triangle (Source: Matthias Gerold)





The angle of at least 30o to the vertical at which windblown rain is assumed to fall is shown in blue



Minimum ventilation openings for the chimney effect encircled in red

Key

M Sealant or weather-resistant layer

A-ASection A-A

1 main girder

2 steel frame

3 borehole in top and bottom flange

*4 cladding (generally outside) *)*

*5 vertical weather boarding (outside) *)*

6 vertical battens

7 horizontal battens

8 ventilation openings, horizontal ≤ 100 cm³/m, vertical ≤ 50 cm²/m

9 aluminium plate or equivalent

10 insect mesh

11 grooved deck planks

*) Shuttering elements partially easy to dismantle for inspection.

Figure 4. Constructional wood protection - possibilities:
top: Asphalt surface (Source: FprEN 1995-2, Figure D.5 [7])
middle: Roof and claddings (Source: FprEN 1995-2, Figure D.3 [7])
bottom: Sheating of through bridge (Source: FprEN 1995-2, Figure D.4 [7])

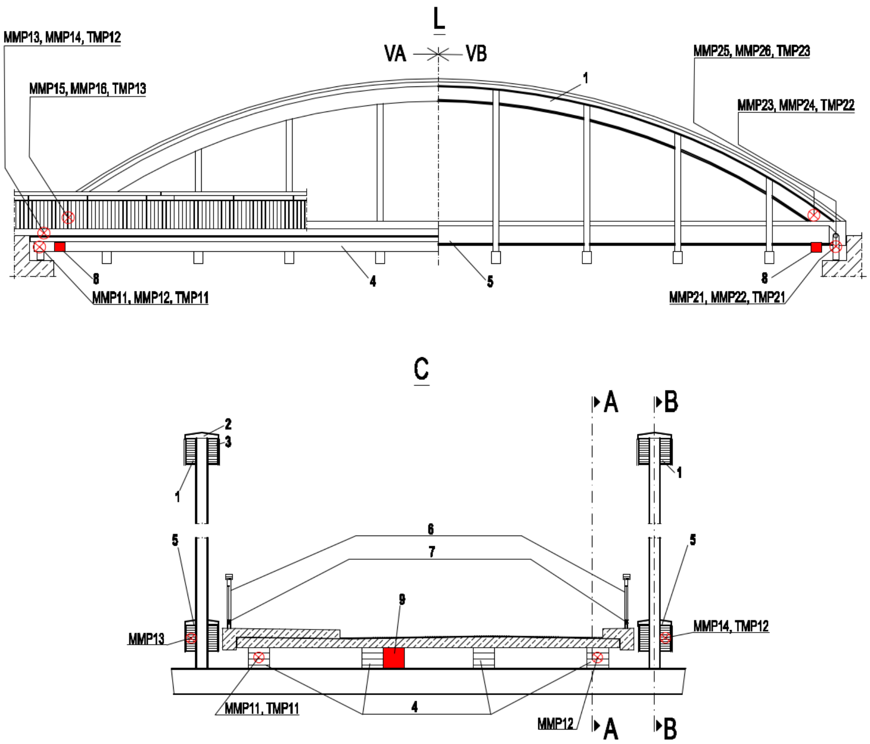
3.2 Durability of steel members

For steel members the updated standard gives requirements of protection of steel members in wooden structures by declaring a timber exposure category T_E. Different protection levels depending on an atmospheric exposure category C_E, the service class SC and the design service life of 100 years [in brackets 50 years] results in different recommendations of minimum protection either by steel grade or zinc coverage (see Table 1). Requirements of protection of steel in general is covered by Eurocode 3.

Informative typical atmospheric exposures are given in FprEN 1995-2 [7], Table 6.2; e.g. in case of TE3/TE4 and CE2: L_{sea} > 10 km and L_{street} > 100 m and/or low polluted area (< 5 µg/m³ of SO_2).

Table 1. Timber exposure T_E-categories and atmospheric exposure C_E-categories with examples of minimum requirement for thicknesses for pure zinc coating, hot-dipped galvanized coating, and types of stainless steels for timber bridges (outdoor) with a design service life of 100 years [50 years] (Excerpt from source: FprEN 1995-2, Table 6.2 [7])

Situation	***Timber exposure category T_E***	***Atmospheric exposure category C_E***	***Examples of minimum***	
			zinc thickness	***stainless steel grade (type)***
Protected outdoor with access of pollution (SC2 and SC3)	*T_E3/T_E4*	*C_E2*	*T_R3: 40 µm (n/a if T_E4) [20 µm (55 µm if T_E4)]*	*CRC II (e.g. 1.4301)*
	T_E3/T_E4	*C_E3*	*C_R3: 110 µm [80 µm]*	*CRC III (e.g. 1.4401)*
	T_E3/T_E4	*C_E4*	*C_R4: n/a [110 µm]$^{)}$*	*CRC III (e.g. 1.4401)*
	T_E3/T_E4	*C_E5*	*C_R5: n/a$^{)}$*	*CRC III (e.g. 1.4529)*
Permanent in contact with ground- or fresh-water (SC4)	*T_E5*	*n/a $^{g)}$*	*C_R5: n/a*	*CRC III to CRC V*



Key

1 arch truss UC 2
2 roof board
3 lead sheet
4 longitudinal beam UC 2
5 pliers beam UC 2
6 railing vertical components UC 3.1
7 railing horizontal component UC 3.2
8 instrument box 1 (or 2)

MMP Moisture measurement point
TMP Temperature measurement point

Figure 5. Moisture monitoring – example arch truss (Source: FprEN 1995-2, Figure D.13 [7])

4 INSPECTION AND MAINTENANCE

See introduction clause 2 and subclause 2.1 (→ Annex B)

Regarding sealant systems see [12].

As already mentioned, a monitoring of timber bridges may be a useful in addition to inspection. Currently an arch bridge is taken as example (see Figure 5) showing which part of the bridge is expected to be critical and thus wise instrumenting, also with regard to the Use Class (UC) according to EN 335 [9] (Table 2).

5 OTHER MEMBERS

5.1 Timber-Concrete Composites (TCC) and Integral abutments

TCC decks are included in the updated bridge standard, giving requirements on design and recommendations on durability and design. In the Technical Specification CEN TS 19103 the load-bearing capacity and deformation behaviour of a notched connection in a girder as a shear connection is regulated. Looking on the uplift forces of the notch the loading for the waver-head screw (see Figure 6) are given.

Table 2. Components of an arch road bridge (example), Source: FprEN 1995-2 [7], Table D.1

Component	***Use class (UC) [Service class SC]***	***Protective measure***	***Wood type***	***Durability Class (DC)***
	EN 350 [10] [FprEN 1995-1-1]	***FprEN 1995-2 Sample drawings***	***EN 13556 [11]***	***EN 350 [10], Table B.1***
Longitudinal beam	*2 [4]*	*Weather protection through roadway slab and deck planks and transition, protection of the edges (grain-cut timber), protection against insect attack through technical drying, visibility and control of insect infestation*	*Larch or Pine or Douglas fir as glulam*	*4*
Arch truss / pliers beam	*2 [4]*	*Weather protection by cladding and shuttering, protection against insects by technical drying and insect protection grid, visual inspection every 6 years by removal of claddings*	*Larch or Pine or Douglas fir as glulam*	*4*
Railing	*Vertical: 3.1 [2]* *Horizontal: 3.2 [2]*	*None, maintenance component*	*European larch*	*3*

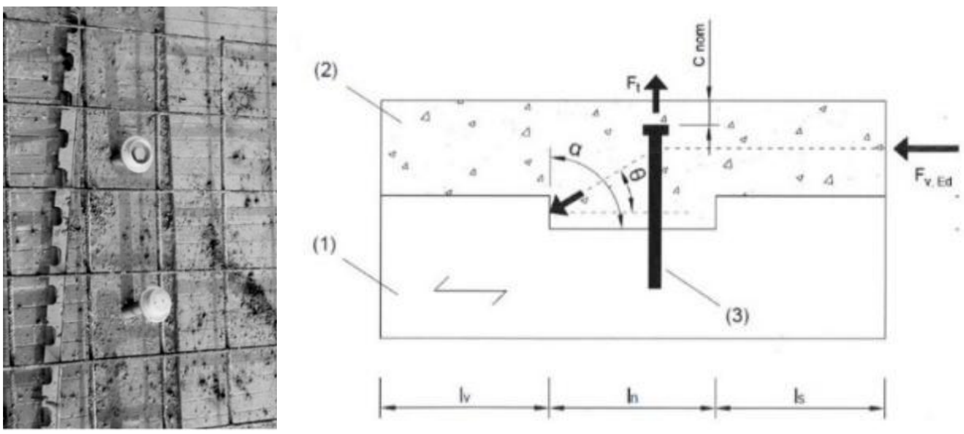


Figure 6. Weaver head screws and notched connection, Source: Mattias Gerold, CEN/TS 19103

Based on the research mainly made at the University of Stuttgart the rheological material behaviour (shrinkage and swelling) is temporary conversely. Therefor the period from 3 to 7 years has to be taken into account.

Creep must be evaluated carefully and as such this is also topic in the updated draft. Basically, all connectors regulated by a national technical approval or European Technical Assessment (ETA) may be used.

Integral timber bridges, bridges with a flexural connection to a concrete abutment (see Figure 6 and Figure 7 showing the Rokoko- and the Bahnhofsbrücke in Schwäbisch Gmünd, Germany) have gained some experience and are also included in the timber bridge code.

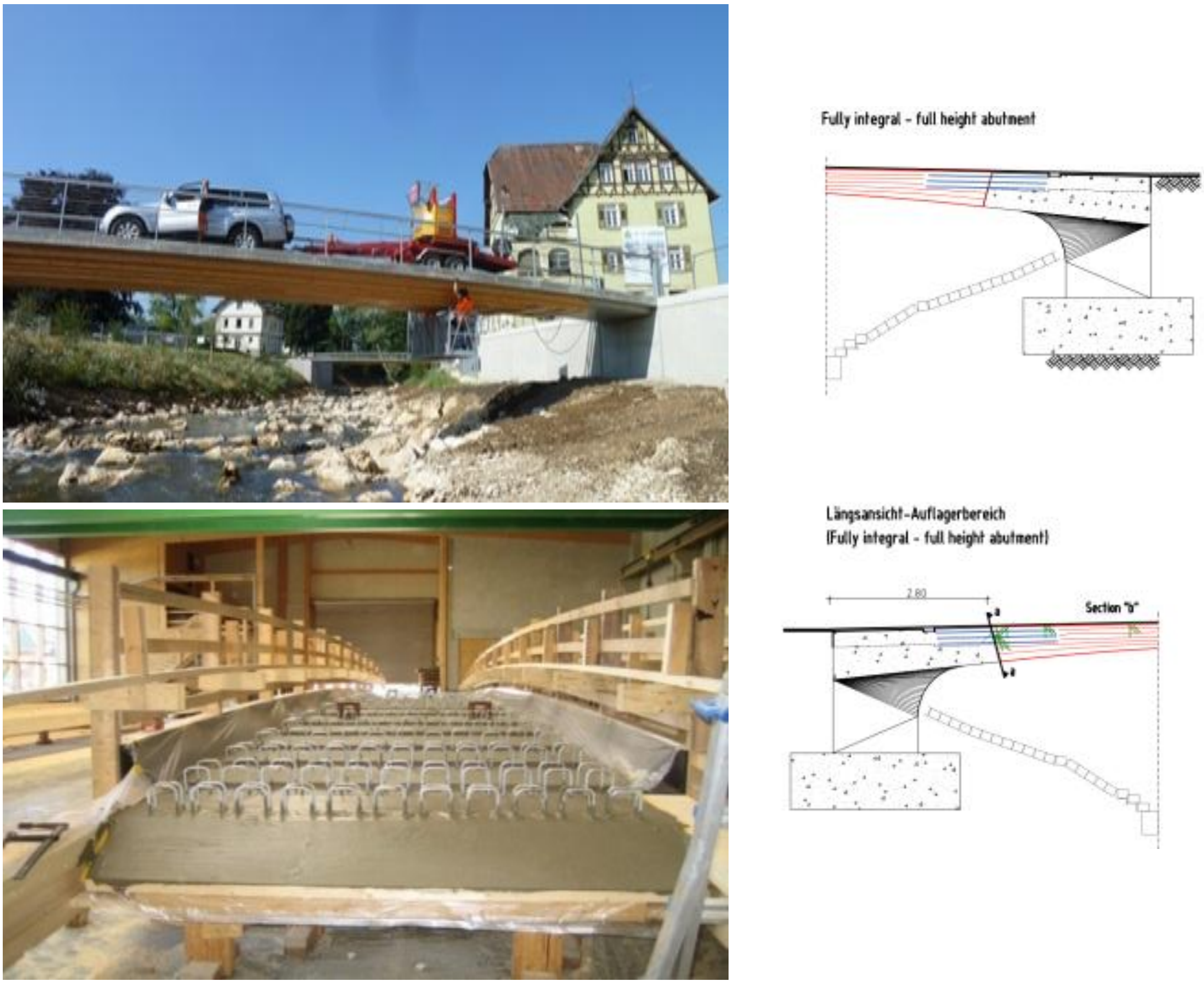
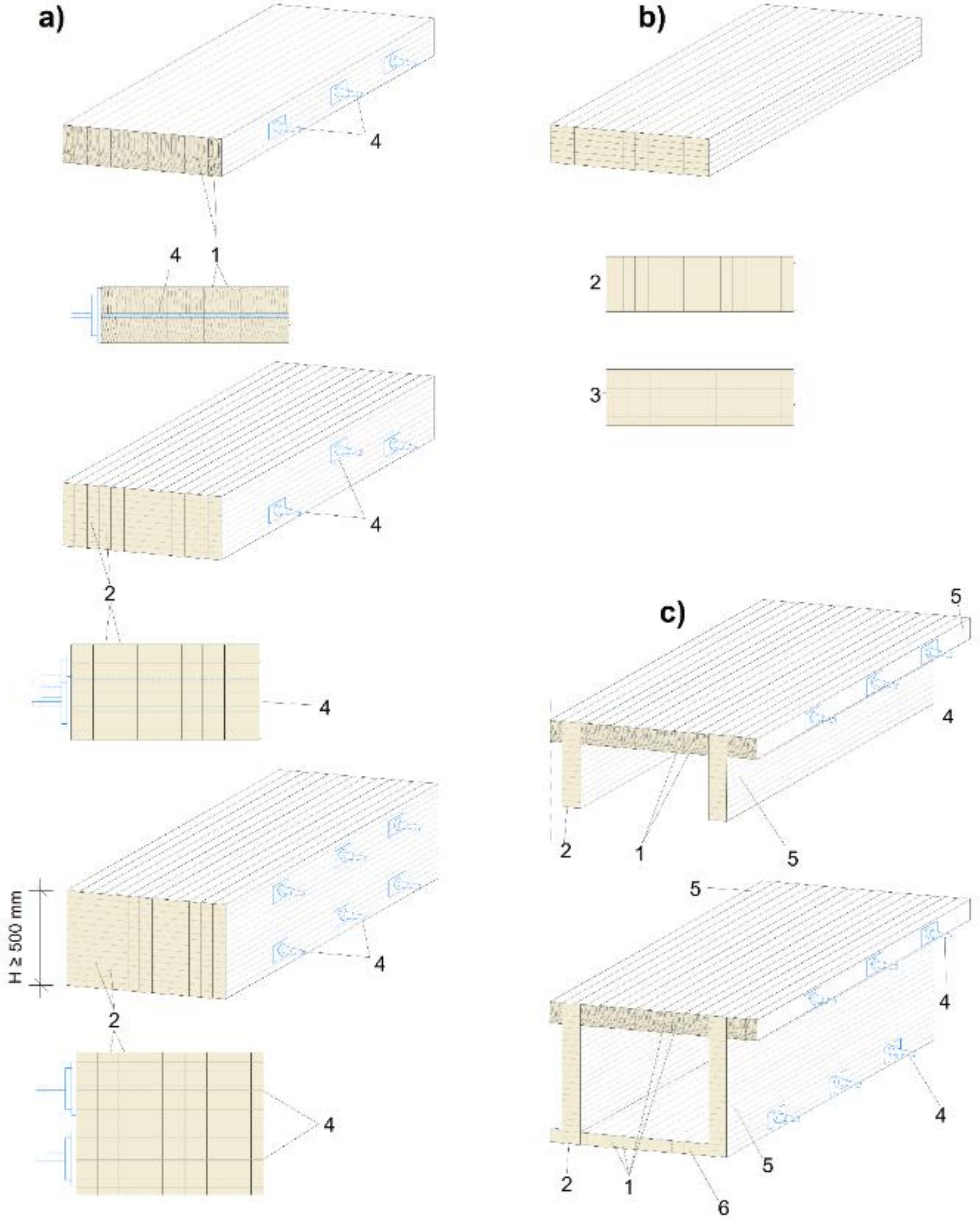


Figure 7. Examples of integral timber bridge designs, Source: Matthias Gerold

5.2 Timber Deck Plates

Timber deck plates comprise decks made of solid-wood beams arranged side by side in the direction of span, clamped together (see Figure 8). As a result, the (punctual) wheel loads can be distributed over several beams. Nowadays, these deck plates (timber decks) are largely used in Scandinavian and Baltic states often using glued laminated timber (GL) as beams and stressed together with steel rods. Requirements regarding these structures have been updated representing state of the art including newer research on the topics.



Key

a) Stress-laminated decks, b) Solid timber or glulam beams, c) Stress-laminated T-beams and box girders

1	solid timber beam	4	prestressing bar or tendon
2	glulam beam	5	glulam / GLVL beams as web
3	block glued glulam beam		

Figure 8. Examples of transvers post-timber decks for bridges made of lamellas, Source: FprEN 1995-2, Figure 8.1 [7]

6 SERVICE LIMIT STATE

6.1 Deflections and deformations

Requirements on deflections due to traffic-load and wind-force have been updated (see Table 3) due to the requirements in EC 0 [5]. These actions should be verified and limited in order to prevent unwanted dynamic impact due to traffic, infringe of required clearances and cracking of surfacing layer, ensuring also sufficient run-off from standing water.

Table 3. Limiting values for deflections of timber beams, plates and trusses (NDP)

Action (Frequent load value)	**Range of limiting values**	
	vertical	**horizontal**
Traffic loads on road bridges	L/500 to L/650	-
Low traffic loads on footways, cycle tracks and pedestrian bridges	L/500 to L/900	-
Wind forces	-	L/600 to L/1500

6.2 Vibrations/Oscillations and damping

A rather large update has been conducted on the subjects vibrations and damping. Simplification regarding requirements given in other parts of Eurocodes are introduced in the timber bridge part, Annex F. An example is shown in Figure 9, where different requirements are gathered in one requirement, see black line in Figure 9.

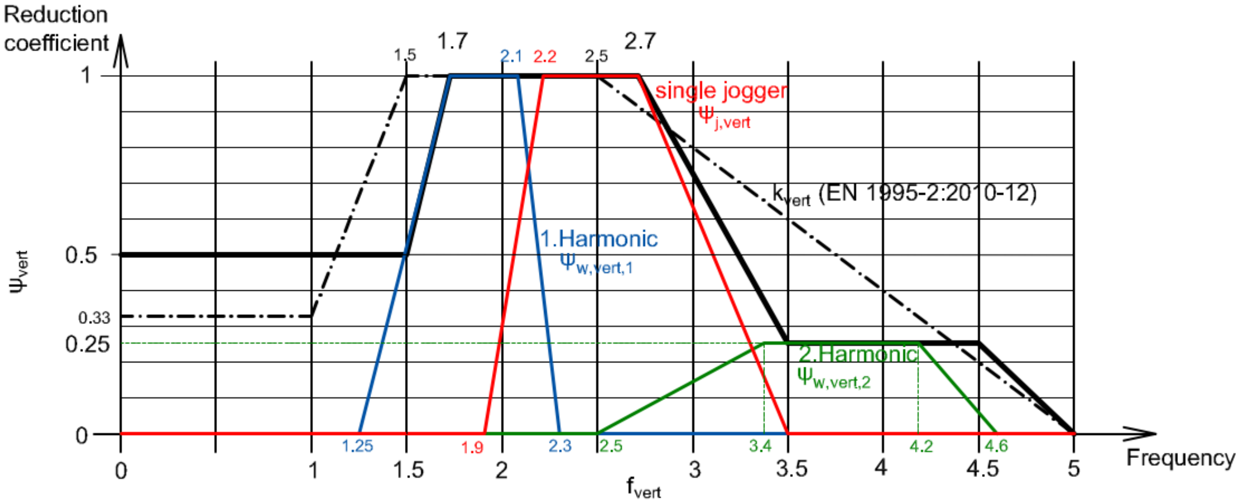


Figure 9. Relationship between the vertical eigenfrequency f_{vert} and the coefficient ψ_{vert} (Source: Matthias Gerold, Patricia Hamm)

7 FATIGUE

As already mentioned it was decided to move fatigue requirements into the general part FprEN 1995-1-1 [8]. This means that in FprEN 1995-2 [7], only those parts were kept that are relevant for timber bridges.

Basis in fatigue verification is the stress ratio R_T as the arithmetical minimum stress to the maximum stress of a particular stress cycle in timber design. Since the factor representing the reduction of fatigue strength with number of load cycles k_{fat} values depend on R_T, a simplification is given in the background document (BGD) to offer a real advantage over the ‘full’ k_{fat} verification. Therefore, it is proposed to consider only whether the fatigue loading is alternating or not and to use the k_{fat} values for $R_T = 0$ or $R_T = -1$, respectively.

The k_{fat} values were evaluated for two lanes and 2 x 106 cycles (trucks), giving anticipated 100 years design service life using an ß-factor equal to 3 (substantial consequences). This yields a design load cycle number of 1.2 x 109.

8 CONCLUSIONS

The completion of the work on the European timber construction standards is scheduled for 2026/2027. Current status for the timber bridge code is that the comments given in the public Enquiry 2023 (together with all other parts on timber structures; i.e. part 1-1 General rules and rules for buildings, part 1-2 Fire design and part -3 Execution) were answered. After FV, no new technical content will be added; only changes to what is suggested will be made, thus most of the essential changes are already known.

The scope of the standard will inevitably grow, as new timber construction products need to be considered and known design approaches need to be extended and optimised. The update is guided by the central interest of increasing the user-friendliness – not only by profiting from digital availability and efficient search options but also by restructuring, homogenising, and simplifying the regulations.

Nevertheless, as with the adjustment of the first generation of EC 5, an additional process of learning, training, and education will be necessary, with this process starting already prior to the final publication. In conclusion, it may be stated: the second generation of EC 5 is not a revolution but an evolution that consistently builds on the experiences and principles of the previous version.

Common practice design examples of a variety of bridge structures are presented e.g. in [13].

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