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REINFORCEMENT OF TIMBER STRUCTURES – A NEW SECTION FOR EUROCODE 5

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ABSTRACT: The reinforcement of timber structures has seen considerable research and development in recent years. New materials and methods for reinforcement have been developed and are now used in practice. Eurocode 5 in its current edition, however, lacks approaches to design reinforcement for timber members. To close this gap, CEN/TC 250/SC 5, the standardization committee responsible for drafting Eurocode 5, has decided to establish a Working Group (WG) on this item. This Working Group is supported by a Project Team, mandated to draft the associated sections for Eurocode 5. This paper reports on the approach to this task, the work items of WG 7 "Reinforcement", the current status and the work scheduled for the coming years. The proposed structure of the new section as well as examples of design approaches and the related background information are presented.

KEYWORDS: Timber structures, stresses perpendicular to the grain, reinforcement, self-tapping screws, rods, wood-based panels, standard, Eurocode 5

1 INTRODUCTION

The reinforcement of timber structures has seen considerable research and development in recent years, see e.g. [1]. New materials like self-tapping screws or wood-based panels offer potential also in view of their use as reinforcement. The European timber design standard, Eurocode 5, in its current edition [2] lacks approaches to design reinforcement for timber members. The standardized use of reinforcement is enabled only in a few European countries by means of non-contradictory information (NCI), given in the National Annexes to Eurocode 5 [3], [4]. Closing the obvious gap between recent developments and practical needs on the one side and missing standardization on the other, reinforcement for stresses perpendicular to the grain was classified high priority when defining the list of work items to be dealt with during the upcoming revision of Eurocode 5 [5]. In 2011, the European standardization committee responsible for Eurocode 5, CEN/TC 250/SC 5, decided to form a Working Group 7 "Reinforcement". In addition, reinforcement of timber members was prioritized for Phase 1 (of 4 phases) of the standardization work to be mandated by the European Commission. The contracts for this mandated work were signed in 2014, enabling the formation of Project Teams that are mandated to draft specific sections for the Eurocodes.

Within Phase 1, two Project Teams to draft new sections for Eurocode 5 were established and equipped with experts, namely PT SC5.T1 - to draft the sections on cross-laminated timber and reinforcement - and SC5.T2 - to draft a new part on timber-concrete composites.

2 APPROACH

Standardization is the culmination of successful research and development that has seen positive application and acceptance in practice, see Figure 1. According to the European position on future standardization [6], harmonized technical rules shall be prepared for "common design cases" and shall contain "only commonly accepted results of research and validated through sufficient practical experience". The target audience for such rules is "competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields".

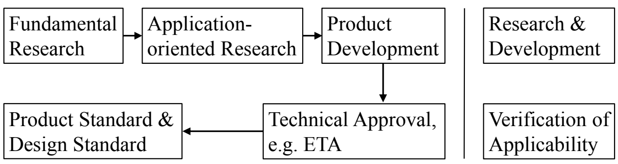

Figure 1: *Development of products or methods and their legalization*

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3 ORGANIZATION

Different committees and groups of experts are contributing to European standardization in the field of of the design of structures, see Figure 2 for the example of Timber structures. In the following, a short description of the main structure and organisation within these committees and groups is given. For an in-depth description of the structure, the interested reader is referred to [7].

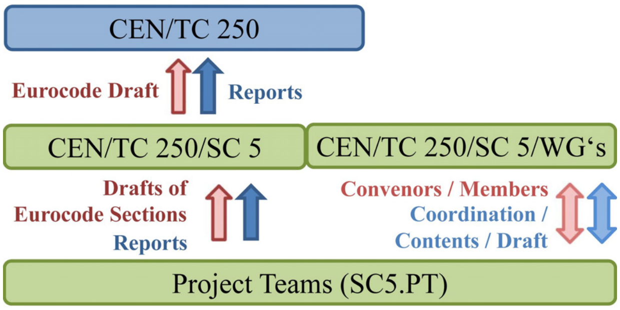

Figure 2: *Responsibilities within CEN/TC 250/SC 5*

CEN/TC 250 is the head committee, responsible for the development and definition of the design rules of common structural building and civil engineering structures. This committee is substructured into 11 sub committees (SCs), each sub committee being responsible for the development and revision of one Eurocode. CEN/TC 250/SC 5 is responsible for all parts of Eurocode 5 (EN 1995). The members of these sub committees are delegates sent by National Standardization Bodies (NSBs) that are members of CEN. For the technical work, each sub committee is supported by Working Groups (WGs) that deal with specific items within the Eurocode that the SC is responsible for. Within CEN/TC 250/SC 5 for example, WG 1 is responsible for cross-laminated timber [8], WG 2 is responsible for timber-concrete composite structures [9] and WG 7 is responsible for reinforcement of timber structures, see [7] for a full overview. The Working Groups are responsible to develop the work programme, i.e. the items to be covered within their responsibility. In this connection, the WGs are meant to serve as institution for technical discussions resulting in technical proposals (methods, design approaches, design equations and details) for the section(s) under their responsibility. To achieve this objective, the WGs are staffed with experts sent by the National Standardization Bodies. These experts may have a dual role as National Delegates within the SC and as experts in a WG or work solely as the latter. CEN/TC 250/SC 5/WG 7 “Reinforcement” currently has 13 members (experts and observers), about five experts contribute actively to the work.
The drafting of the standard text based on the technical proposals developed and agreed within the WGs is the responsibility of Project Teams (PTs), consisting of five members and one leader. The work of the Project Teams is supported by the European Commission, hence they are established in a tender process. Within a given time frame, the PTs have to deliver a draft of a new or revised Eurocode or a specific section of the same. In other words, the PTs have to bring the technical proposals into standard text including harmonized notations, terminology and references, adhering to the principles of “Ease-of-Use” [6]. In addition, the Project Teams have to develop so-called “background documents” describing the technical reasoning and scientific background of all new or changed technical contents under their scope. From the six members in Project Team SC5.T1 “Cross-laminated timber and reinforcement”, three members are actively involved in the drafting of the section on reinforcement while four members actively contribute to the drafting of the section on CLT [8].
The liaison between the SCs, WGs and PTs can be summarized as follows: the SC is the responsible control institution while the WGs and PTs are the executive institutions developing the technical contents (WGs) and the drafts of the standard (PTs).

4 WORK ITEMS

4.1 General

Adhering to the principles described in section 2, CEN/TC 250/SC 5/WG 7 “Reinforcement” decided to prioritize the following applications and reinforcement methods for preparation for the revised Eurocode 5. These items were also classified high priority during a pan-European survey carried out amongst a multitude of stakeholders in 2010 [5].

4.2 Applications

- Reinforcement of double tapered, curved and pitched cambered beams
- Reinforcement of notched beams
- Reinforcement of holes in beams
- Reinforcement of members with concentrated compression stresses perpendicular to the grain
- Reinforcement of connections with a force component perpendicular to the grain
- Reinforcement of connections ($n = n_{ef}$)

4.3 Materials and Methods

- Self-tapping screws or screwed-in rods
- Glued-in rods
- Glued-on timber, plywood, LVL

The choice of materials is explained by the precondition that (1) test procedures as well as (2) a product standard or Technical Approvals for the product / material are available. Without these, rules in a design standard cannot be used since the basic input parameters are missing. This situation can best be described by a 3-step pyramid, see Figure 3 and [10].
This pyramid is based on (1) test standards (containing rules on how to test products). Relating to these, product standards (2) are developed (giving strength and stiffness parameters, boundary conditions and rules for production and quality control). The design standards (3) represent the tip of this pyramid (providing design equations and formulating specific requirements in e.g. spacing, edge distance, minimum anchorage length, etc.).

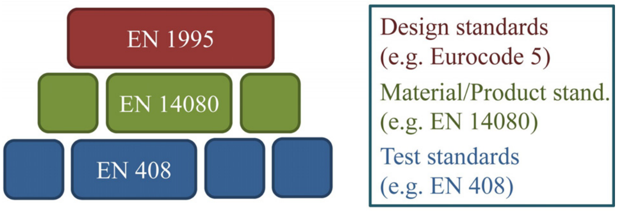

Figure 3: *Sketch of the 3-step-pyramid applied in international standardization for the construction sector [10].*

5 CURRENT STATUS AND WORK PLAN

By the end of April 2016, all Project Teams had to send the first drafts to their contractual partner, the Netherlands Standardization Institute (NEN). NEN then delivered the drafts to the respective CEN/TC 250/SCs for review and comments within a two-month period (May - June 2016). The SCs can draw upon the National Standardization Bodies (NSBs) for additional review and comments to the drafts.

The Project Team is requested to answer all comments received during the work on the second draft, implementing all comments and proposals that are deemed useful and technically sound. The second drafts have to be delivered at the end of April 2017, starting the above mentioned procedure.

The final draft has to be delivered to NEN in October 2017. NEN will directly forward this document to the National Standardization Bodies (NSBs) for a three-month enquiry. Following that, the PTs have two months to prepare the final documents, taking into account the comments received from the NSBs. The delivery of the final documents and the background documents, marking the end of the work of the PTs, is in April 2018.

6 STRUCTURE OF THE FIRST DRAFT

EN 1995-1-1 [2] in its current version does not contain provisions on reinforcement. Hence, a decision on the structure of this new section had to be taken. The obvious approach is to write a separate but continuous section on the design of reinforcement for timber members. This solution, however might not fully suit the designers needs in terms of applicability and navigation, hence might not fully obey to the principles on “Ease-of-Use”. The current proposal, which was accepted by WG 7 “Reinforcement”, is to integrate the provisions on reinforcement into the existing main part, i.e. following the sequence of a typical design task: general considerations – design of members in the unreinforced state – design of reinforcement for these members. Figure 4 contains the proposed structure. The main proposed contents of the sections on reinforcement are described in the following. Proposed *standard text* will be highlighted in form of *italic writing*.

6.4 Design of members with tensile stresses perpendicular to the grain
6.4.1 General
6.4.2 Moisture induced stresses
6.4.3 Design of cross-sections in members with varying cross-section or curved shape
6.4.3.1 General
6.4.3.2 Single tapered beams
6.4.3.3 Double tapered, curved and pitched cambered beams
6.4.3.4 Reinforcement of double tapered, curved and pitched cambered beams
6.4.4 Notched members
6.4.4.1 General
6.4.4.2 Beams with a notch at the support
6.4.4.3 Reinforcement of rectangular notches in members with rectangular cross-section
6.4.5 Holes in beams
6.4.5.1 General
6.4.5.2 Holes in beams with rectangular cross-section
6.4.5.3 Reinforcement of holes in beams with rectangular cross-section
6.4.6 Additional rules for the design of reinforcement
6.4.6.1 Reinforcement of members with concentrated compression stresses perpendicular to the grain
8 Connections with metal fasteners
8.1 General
8.1.4 Connection forces at an angle to the grain
8.1.4.1 Design of connections with a tensile force component perpendicular to the grain
8.1.4.2 Reinforcement of connections with a tensile force component perpendicular to the grain
8.5 Bolted connections

Figure 4: *Proposed structure for sections on reinforcement (new sections in* **bold**, *sections on reinforcement in* ***bold italic****)*

7 CONTENTS OF THE FIRST DRAFT

7.1 General

In the following, the core contents of the sections on reinforcement are given in form of *italic writing*, followed by relevant background information on these clauses. For a comprehensive overview of the current state of the art in the design of reinforcement including design equations and extensive background information, the interested reader is referred to [11] and [12]. The Figures shown do not represent the Figures for the standard text as they also include graphical representations produced to exemplify background information. Since the strength verifications required for the reinforcement are rather independent of the member or detail to be reinforced, these will be presented in consolidated form at the end of this section.

General

Standard text:

- *In the following clauses, the tensile capacity perpendicular to the grain of the timber is neglected in the determination of the load on the reinforcement.*
- *Pitched cambered beams, notched members and holes in beams should be reinforced for tensile stresses perpendicular to the grain. Curved and double tapered beams should be reinforced if the design tensile stresses perpendicular to the grain exceed 60 % of the design tensile strength perpendicular to the grain.*

Background for the clauses given above:

Even if the verification of systematic, load-dependent tensile stresses perpendicular to the grain can be met, it is state of the art to reinforce double tapered, curved and pitched cambered beams against tensile stresses perpendicular to the grain. Reason is the superposition of the load-dependent stresses with moisture induced stresses perpendicular to the grain due to e.g. changing climatic conditions or a drying of the beam after the opening of the building, see e.g. [13]. In the lack of a

method to reliably predict the magnitude of tensile stresses perpendicular to the grain, it was custom to apply reinforcement if the maximum load-dependent tensile stresses perpendicular to the grain exceeded 60 % of the design tensile strength perpendicular to the grain.
Since end-grain is exposed bare at a notch and in holes, the superposition of moisture induced stresses and load-dependent tensile stresses perpendicular to the grain around notches and holes can be significant [14]. Therefore, many authors recommend that notches and holes in beams should always be reinforced.

- *The following internal, dowel-type reinforcement may be applied:*
  - *glued-in threaded rods and screwed-in threaded rods with wood screw thread according to European Technical Assessment;*
  - *fully threaded screws according to EN 14592 or European Technical Assessment.*
- *The following plane reinforcement may be applied:*
  - *glued-on plywood according to EN 13986;*
  - *glued-on structural laminated veneer lumber according to EN 14374 or EN 13986 in connection with EN 14279;*
  - *glued-on laminations made of either structural solid timber according to EN 14081-1 or plywood according to EN 13986 or structural laminated veneer lumber according to EN 14374.*
  - *pressed-in punched metal plate fasteners.*

The list of applicable internal or external reinforcements is – amongst other factors - based on the necessity of a continuous interconnection between the timber and the reinforcement as well as sufficient stiffness of this connection (to prevent cracking). Due to the latter argument, perforated metal plates or wood-based panels, both nailed onto the timber member, are not adequate reinforcements, see e.g. [14], [15].

- *The distance between the peak tensile stresses perpendicular to the grain and the dowel-type reinforcement should be minimized but should not be below the minimum values stated below.*
- *The spacing between internal, dowel-type reinforcement perpendicular to the grain, a_2, should not be less than 3·d. The edge distance in grain direction, $a_{3,c}$, edge as well as the edge distance perpendicular to the grain, $a_{4,c}$, should not be less than 2.5·d. unless otherwise stated below.*
- *Reinforcement with fully threaded screws should be assessed in analogy to reinforcement with glued-in threaded rods.*
- *The reduction in the cross-sectional area due to internal reinforcement should be considered in the design of the timber member.*
- *In block glued members, each component within the block should be reinforced, either by internal dowel type reinforcement or by plane reinforcement glued to both side faces of each component. The reduction in the cross-sectional area due to glued in plane reinforcement should be considered in the design of the block glued member.*

The edge and end distances of internal, dowel-type reinforcement are reduced compared to the minimum edge and end distances given in Chapter 8 of [2], since such reinforcements are loaded by axial forces and their continuous interconnection with the wood prevents splitting [15]. The reinforcing effect of the applicable reinforcement elements over the width of a timber member is limited, hence each component of a block-glued timber member should be reinforced separately.

7.2 Moisture induced stresses

- *Stresses caused by the effects of moisture content changes in the timber shall be taken into account.*

Changes in wood moisture content lead to changes of virtually all physical and mechanical properties (e.g. strength and stiffness properties) of wood. An additional effect of changes of the wood moisture content is the shrinkage or swelling of the material and the associated internal stresses. If these stresses locally exceed the very low tensile strength perpendicular to the grain of wood, the result will be a stress relief in form of cracks, which can reduce the load-carrying capacity of structural timber elements in e.g. shear or tension perpendicular to the grain. Multiple evaluations of damages in timber structures, e.g. [16], [17], [18] show, that a prevalent type of damage is pronounced cracking in timber elements. Almost half of the damages in large-span glued-laminated timber structures can be attributed to low or high moisture content or severe changes of the same.

- *Moisture induced stresses from moisture content changes should be minimized. Potential measures to reduce moisture induced stresses include:*
  - *Before being used in construction, timber should be dried as near as practicable to the moisture content appropriate to its climatic condition in the building in use, unless the structure is able to dry without any effect on the load-carrying capacity of its members;*
  - *In dry environments, controlled drying of the timber to service conditions should be planned, e.g. through adequate surface treatment.*
    NOTE: In the case of structures or members sensitive to moisture changes, temporary moisture control is recommended.
- *Stresses perpendicular to the grain, caused by connections or reinforcement restraining moisture induced deformations of the timber member, should be minimized.*
  NOTE: External, plane reinforcement glued onto the entire surface area under tensile stresses perpendicular to the grain decelerates the process of moisture changes or drying of the timber member, hence such reinforcement may be favorable in applications with permanently dry or frequently changing climate.

Shrinkage cracks can be attributed to two different phenomena.

1. Large moisture gradient over the timber cross-section due to strong and fast wetting or drying (the latter prevailing in building practice) of the timber member, e.g. throughout the process production – transport –

storage – assembly – interior works – opening – operation (heating). Careful planning and moisture control during this process is recommended, especially if a dry environment is to be expected in the finished building. Specifications on moisture control could be given in an execution standard for timber structures.
2. Prevention of free shrinkage or swelling deformation of the cross section by restraining forces, e.g. from dowel-type connections or dowel-type reinforcements. In these cases, equilibrium of tensile and compressive moisture induced stresses is impeded, resulting in stresses of higher magnitude and eventually in deep shrinkage cracks.

- *Potential measures to reduce restraining effects from reinforcement include:*
  - *larger distances between reinforcement;*
  - *reduction of height of the reinforced areas in the timber member;*
  - *reducing the angle between dowel-type reinforcement and grain direction of the timber member.*

The restraining effect of dowel-type reinforcement was experimentally and analytically investigated in [19] and [20], demonstrating the positive effect of measures such as increased distance, reduced height or reduced angle of dowel-type reinforcement.

7.3 Reinforcement of double tapered, curved and pitched cambered beams

Standard text:

- *For beams in which reinforcement to carry the full tensile stresses perpendicular to the grain is applied, the reinforcement should be designed for a tensile force $F_{t,90,d}$:*

$$F_{t,90,d} = k_A \cdot \frac{\sigma_{t,90,d} \cdot b \cdot a_1}{n_r} \qquad (1)$$

where

$\sigma_{t,90,d}$ *is the design tensile stress perp. to the grain;*

b *is the beam width;*

a_1 *is the spacing of the reinforcement in longitudinal direction of the beam at the height of its axis;*

k_A *factor to account for the distribution of tensile stresses perpendicular to the grain along the beam axis*

k_A = 1,0 for the inner quarters of the area exposed to tensile stresses perp. to the grain in curved and pitched cambered beams

k_A = 0,67 for the outer quarters of the area exposed to tensile stresses perpendicular to the grain in curved and pitched cambered beams

n_r *is the number of reinforcement elements within the spacing a_1.*

Background for the clause given above:
The approach given is based on an integration of the sum of tensile stresses perpendicular to the grain in the plane of zero longitudinal stresses. Since in most cases, only the maximum tensile stresses perpendicular to the grain in the apex are determined, the distribution of tensile stresses perpendicular to the grain along the beam axis has to be accounted for in simplified format. Depending on the form and loading of the beam, the tensile stresses perpendicular to the grain decrease with increasing distance from the apex (an exception being the not yet standardized curved beams with mechanically fixed apex, i.e. secondary apexes [11]). For simplification, the full tensile stresses perpendicular to the grain are used to design the reinforcement in the inner quarters of the area exposed to tensile stresses perpendicular to the grain. In the outer quarters, the tensile stresses perpendicular to the grain are assumed to reach 2/3 of the maximum tensile stresses perpendicular to the grain.

- *Internal, dowel-type reinforcement should cover the full height of the beam excluding the outer lamellas in bending tension. The spacing at the top side of the beam should not be less than 250 mm but not greater than $0.75 \cdot h_{ap}$.*
- *Plane reinforcement, e.g. panels or laminations should be glued to both sides of the member and should cover the full height of the beam.*

The spacing between the reinforcements is limited to ensure that the reinforcing effect of the reinforcement is assured over the whole beam length exposed to tensile stresses perpendicular to the grain.

7.4 Reinforcement of rectangular notches in members with rectangular cross-section

Standard text:

- *The reinforcement of a rectangular notch on the loaded side of a member support (see Figure 5) may be designed for a tensile force $F_{t,90,d}$:*

$$F_{t,90,d} = 1.3 \cdot V_d \cdot [3 \cdot \left(1 - h_{ef}/h\right)^2 - 2 \cdot \left(1 - h_{ef}/h\right)^3] \qquad (2)$$

where

V_d *is the design value of the shear force;*

h_{ef}, h *see* Figure 5

Background for the clause given above:
The tensile force perpendicular to the grain, $F_{t,90,d}$, can be approximated by integration of the shear stresses below the notch, between the loaded edge and the corner of the notch, see Figure 5. A more detailed analysis of the magnitude of the tensile stresses perpendicular to the grain around the notch has shown that these stresses are even higher [21]. For relationships $x \le h_{ef}/3$, the tensile force perpendicular to the grain, $F_{t,90,d}$, can be sufficiently estimated by applying an increase factor of 1.3.

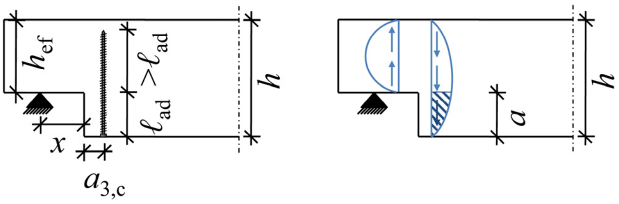

Figure 5: *Notched beam: reinforcement (left) and distribution of shear stresses (right).*

- *The depth of the reinforcement, see Figure 5, should be larger than 0.7·h, measured from the beam edge on the side of the notch. In all other cases, the possibility of splitting caused by the tensile force component perpendicular to the grain, should be satisfied at the tip respectively edge of the reinforcement facing the beam edge opposite to the notch.*
- *If the tensile force, $F_{t,90,d}$, according to expression (2) is carried by internal, dowel-type reinforcement, arranged according to Figure 5, the load-carrying capacity is limited to twice the load-carrying capacity of the unreinforced notched beam.*

The depth of the reinforcement should be sufficient such as to avoid tensile failure perpendicular to the grain of the timber member at the tip / upper edge of the reinforcement. In analogy to the experiences and rules for connections with a tensile force component perpendicular to the grain, see Section 7.6, no verification is necessary for relationships $h_{ef}/h > 0.7$. The limitation of load-carrying capacity of notched members reinforced with dowel-type reinforcement arranged perpendicular to the grain is based on [22], where it was experimentally and analytically verified that the load-carrying capacity of reinforced notched members is not infinite but limited by the shear component on fracture of notched members.

- *Only one row of internal, dowel-type reinforcement at a distance $a_{3,c}$ from the edge of the notch should be considered.*
- *The minimum length of each internal, dowel-type reinforcement is $2 \cdot \ell_{ad}$, see Figure 5, the outer thread diameter d should not be greater than 20 mm.*
- *The reinforcement panels or laminations should be glued to both sides of the member with the following limits:*

$$0.25 \leq \frac{l_r}{h - h_{ef}} \leq 0.5 \tag{3}$$

where

l_r is the width of the reinforcement panel or lamination in direction of the beam axis at the side of the notch;

h, h_{ef} see Figure 5.

Only one row of internal, dowel-type reinforcement at a edge distance in grain direction, $a_{3,c}$, should be considered as reinforcement. The distance between the internal, dowel-type reinforcement and the notch, $a_{3,c}$, should be as small as possible. Reason is the limited distribution length of the tensile stresses perpendicular to the grain outside the corner of the notch. The applicable width of reinforcement panels is limited due to the same reason. In addition, this limitation is also implicitly directed at assuring panels of adequate thickness to prevent failure due to the stress singularities at the notch.

7.5 Reinforcement of holes in beams with rectangular cross-section

Standard text:

- *The reinforcement of holes, which comply with the geometrical boundary conditions given in Table 1, may be designed for a tensile force, $F_{t,90,d}$, according to expression (4).*

$$F_{t,90,d} = \frac{V_d \cdot h_d}{4 \cdot h} \cdot \left[3 - \frac{h_d^2}{h^2}\right] + 0,008 \cdot \frac{M_d}{h_r} \tag{4}$$

where

V_d is the design shear force at the edge of the hole;

M_d is design bending moment at the edge of the hole;

h, h_d, h_r see Figure 6.

In the case of rectangular holes, the tensile force, $F_{t,90,d}$, should be assumed to act on a plane defined by the corners of the hole which are exposed to tensile stresses perpendicular to the grain. In the case of round holes, the tensile force, $F_{t,90,d}$, should be assumed to act under 45° from the center of the hole with regard to the beam axis (see Figure 6). All areas prone to splitting from tensile stresses perpendicular to the grain should be analyzed. The minimum and maximum dimensions given in Table 1 apply:

***Table 1:** Minimum and maximum dimensions of reinforced holes in beams with rectangular cross-section*

$\ell_v \geq h$	$\ell_z \geq h$, *not less than 300 mm* [c]	$\ell_A \geq h/2$
$h_{rl(ru)} \geq 0.25 \cdot h$	$a \leq h$ $a/h_d \leq 2.5$	$h_d \leq 0.3 \cdot h$ [a] $h_d \leq 0.4 \cdot h$ [b]
[a] *for internal, dowel-type reinforcement* [b] *for plane reinforcement, e.g. panels or laminations* [c] l_z *is the spacing between two holes*		

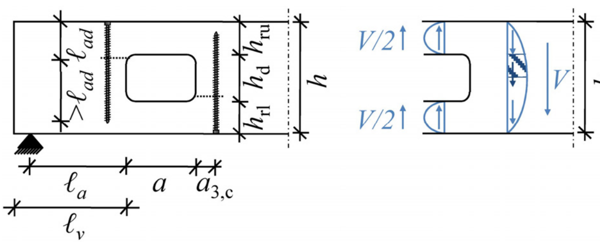

***Figure 6:** Hole in beam: reinforcement (left) and distribution of shear stresses (right)*

- *The application of internal, dowel-type reinforcement, arranged according to Figure 6, should be limited to locations in the timber member that are subjected to low shear stresses.*
  NOTE: It is recommended to apply internal, dowel-type reinforcement, only in locations in which the shear stresses do not exceed XX % of the shear strength determined according to expression (6.13, i.e. common verification of shear stresses [2]), applying the full section height, h.

Background for the clauses given above:

The tensile force perpendicular to the grain, $F_{t,90,d}$, can be approximated by integration of the shear stress between the axis of the member and the corner of the hole prone to cracking. The limitation of the permissible relative dimensions of the holes in dependency of the type of reinforcement, is described in [23], [24].

The limitation of applicability of dowel-type reinforcement to areas exposed to low shear stresses is based on the fact that dowel-type reinforcement arranged perpendicular to the grain restrains free shrinkage (see Section 7.2). This results in reduced shear capacity of the reinforced timber member which, in the vicinity of holes, is exposed to increased shear stresses. The discussion on how the application of dowel-type reinforcement can best be limited to areas featuring low shear stresses to prevent failure due to shrinkage cracking leading to shear failure of the beam is ongoing.

- *In members with holes and internal, dowel-type reinforcement, the increased shear stresses in the area of the edges of the holes should be accounted for. The maximum shear stress, τ_{max}, to be applied in expression (6.13) [2], should be calculated as follows:*

$$\tau_{max} = 1.84 \cdot \left[1 + \frac{a}{h}\right] \cdot \left(\frac{h_d}{h}\right)^{0.2} \cdot \frac{1.5 \cdot V_d}{b_{ef} \cdot (h - h_d)} \quad (5)$$

where

V_d *is the design value of the shear force;*

b_{ef} *is the effective beam width, see 6.1.7. [2](taking into account the impact of shrinkage cracks on shear capacity);*

a, h, h_d *see Figure 6. In the case of round holes* h_d *may be replaced by* $0,7 \cdot h_d$.

In the case of rectangular holes it is necessary to take into account the increased shear stresses around the edges of the holes. A description as well as an associated design equation is given in [25]. In [15] it is recommended to apply the same verification for round holes as well. The same publication describes a method to verify the bending stresses above respectively below rectangular holes, including the additional longitudinal stresses from the frame action (lever of the shear force) around the hole (see also [26].

- *Only one row of internal, dowel-type reinforcement at a edge distance in grain direction,* $a_{3,c}$, *from the edge of the hole should be considered.*
- *The minimum length of each internal, dowel-type reinforcement is* $2 \cdot \ell_{ad}$, *see Figure 6, the outer thread diameter d should not be greater than 20 mm.*
- *The reinforcement panels or laminations should be glued to both sides of the member with the following limits:*

$$0.25 \cdot a \le a_r \le 0.6 \cdot l_{t,90} \quad (6)$$

$$h_1 \ge 0.25 \cdot a \quad (7)$$

where

$$l_{t,90} = 0.5 \cdot (h_d + h) \quad (8)$$

a_r *is the width of the reinforcement panel or lamination in direction of the beam axis at the sides of the hole;*

h_1 *is the height of the panel above or below the hole;*

a, h_d, *h see Figure 6.*

The reasoning for the clauses given above is similar to the reasoning for the geometrical limits of reinforcement applied for notched members, see Section 7.4.

7.6 Reinforcement of connections with a tensile force component perpendicular to the grain

Standard text:

- *The reinforcement of connections with a tensile force component perpendicular to the grain (see Figure 7) may be designed for a tensile force* $F_{t,90,d}$:

$$F_{t,90,d} = [1 - 3 \cdot (h_e/h)^2 + 2 \cdot (h_e/h)^3] \cdot F_{v,Ed} \quad (9)$$

where

$F_{v,Ed}$ *is the design value of the tensile force component perpendicular to the grain;*

h, h_e *see Figure 7.*

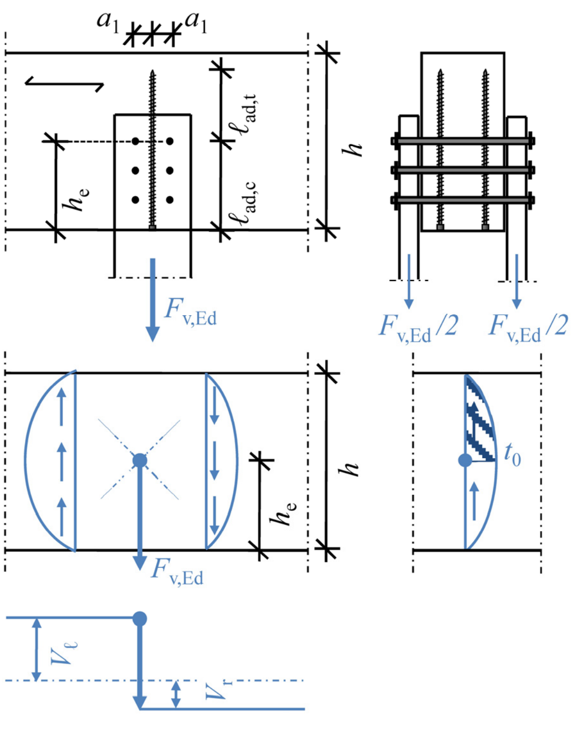

Figure 7: *Reinforced cross-connection: reinforcement (above) and distribution of shear stresses and shear flow (below)*

- *The depth of the reinforcement (*$\ell_{ad,c} + \ell_{ad,t}$, see Figure *7) should be larger than* $0.7 \cdot h$, *measured from the loaded beam edge. In all other cases, the possibility of splitting caused by the tensile force component perpendicular to the grain, should be satisfied at the tip respectively edge of the reinforcement facing the unloaded beam edge.*

Background for the clauses given above:
The tensile force perpendicular to the grain, $F_{t,90,d}$, is the resultant of the tensile stresses perpendicular to the grain on the plane defined by the loaded edge distance to the centre of the most distant fastener, h_e (see e.g. [27]). According to beam theory, the connection force component perpendicular to the grain results in a step in the shear force distribution. The tensile force perpendicular to the grain, $F_{t,90,d}$, is determined by integration of the shear stress in the area between the row of fasteners considered and the unloaded edge. The term in brackets in equation (9) is the result of this integration, a derivation can be found in e.g. [28].
The depth of the reinforcement should be sufficient such as to avoid moving the location of tensile failure perpendicular to the grain from the connection to the tip / edge of the reinforcement. In analogy to the experiences and rules for connections with a tensile force component perpendicular to the grain ([2], [3]), no verification is necessary for relationships $(\ell_{ad,c} + \ell_{ad,t})/h > 0.7$.

- *Only one row of internal, dowel-type reinforcement at a distance $a_{3,c}$ from the edge of the connection should be considered.*
- *The reinforcement panels or laminations should be glued to glued to the member according, with the following limits:*

$$0.25 \le \frac{l_r}{l_{ad}} \le 0.5 \tag{10}$$

where

$$l_{ad} = min\ \{l_{ad,c};\ l_{ad,t}\}\text{, see Figure 7} \tag{11}$$

l_r *is the width of the reinforcement panel or lamination in direction of the beam axis at the sides of the connection;*

The distance between the internal, dowel-type reinforcement and the connection is limited to take into account the limited distribution length of the tensile stresses perpendicular to the grain outside the connection. The same is valid for the applicable width of reinforcement panels.

7.7 Bolted connections

Standard text:

- *Where splitting of the timber is prevented through sufficient reinforcement perpendicular to the grain, the effective number of fasteners according to expression (8.34, i.e. determination of n_{ef} [2]) may be taken as $n_{ef} = n$.*
- *The tensile force in the reinforcement may be taken as $0,3 \cdot F_{v,Rk}$, with $F_{v,Rk}$ determined according to expressions (8.9) – (8.13) [2].*

Background for the clauses given above:
The load carrying capacity per dowel in connections with multiple dowels placed in a row parallel to the grain and loaded by a load component parallel to the grain is smaller than the load carrying capacity of a connection with one single dowel. This reduction in load carrying capacity in connections with multiple dowel-type fasteners is mainly the result of premature splitting of the timber in the direction of the rows of dowels. The effective number of dowels, according to equation (8.34) [2] is based on [29]. Splitting may be prevented by reinforcing the connection area, e.g. by self-tapping screws or wood-based panels. [30] demonstrated that in connections with sufficient reinforcement between the dowels, the timber does not split and the effective number, n_{ef}, equals the actual number, n, of dowels in one row. With reference to [31] it is stated in [30] that timber splitting is prevented, if the axial load-carrying capacity, $F_{v,Rk}$, of each screw exceeds 30 % of the lateral load-carrying capacity, $F_{v,R}$, per shear plane of each dowel.

7.8 Strength verifications required for the reinforcement

The following standard text is given in comparable form and phrasing in the different sections on reinforcement, here Sections 7.3 - 7.6.

- *If the tensile force, $F_{t,90,d}$, according to expression* (expression will be provided at a later drafting stage) *is carried by glued-in or screwed-in steel rods, the stresses in the glue line, respectively the circumference around the thread, should satisfy the following expression:*

$$\frac{\tau_{ef,d}}{f_{k,1,d}} \le 1 \tag{12}$$

$$\tau_{ef,d} = \frac{F_{t,90,d}}{n_r \cdot \pi \cdot d \cdot l_{ad}} \tag{13}$$

where
$F_{t,90,d}$ *is the design tensile force;*
d *is the outer thread diameter (≤ 20 mm);*
ℓ_{ad} *is the relevant effective anchorage length,* (determined in accordance with the geometry of the detail to be reinforced);
n_r *is the number of internal, dowel-type reinforcement. Only one row of internal, dowel-type reinforcement at a distance $a_{3,c}$ from the location featuring the peak tensile stresses perpendicular to the grain should be considered* (with the exception of curved and pitched cambered beams)*;*
$f_{k,1,d}$ *is the design strength of the glue line, taking into account the distribution of stresses.*

- *The tensile stresses in the dowel-type reinforcement should be assessed by applying the relevant cross-section.*
- *If the tensile force, $F_{t,90,d}$, according to* (expression will be provided at a later drafting stage) *is carried by panels or laminations glued to the member, the stresses in the glue line, assumed to be evenly distributed, should satisfy the following expression:*

$$\frac{\tau_{ef,d}}{f_{k,2,d}} \le 1 \tag{14}$$

$$\tau_{ef,d} = \frac{F_{t,90,d}}{n_r \cdot l_{ad} \cdot l_r} \qquad (15)$$

where

$F_{t,90,d}$ *is the design tensile force;*

ℓ_{ad} *is the relevant depth of the reinforcement panel or lamination above or below the beam axis* (determined in accordance with the geometry of the detail to be reinforced);

ℓ_r *is the width of the reinforcement panel or lamination in direction of the beam axis;*

n_r *is the number of panels or laminations used for reinforcement (typically 2, respectively 4);*

$f_{k,2,d}$ *is the design strength of the glue line between member surface and reinforcement panel / lamination for an approximately triangular stress distribution*

NOTE: $f_{k,2,k} = 0.75\ N/mm^2$ *may be assumed if the values have been verified for the glue system used. This value represents a minimum value. Higher values can be declared if the glue system is tested in accordance with relevant test standards (*not yet developed*).*

- *The tensile stresses in the panels or laminations, glued to the member, should satisfy the following expression:*

$$\frac{\sigma_{t,d}}{f_{t,d}} \leq 1 \qquad (16)$$

$$\sigma_{t,d} = k_k \cdot \frac{F_{t,90,d}}{n_r \cdot t_r \cdot l_r} \qquad (17)$$

where

$F_{t,90,d}$ *is the design tensile force;*

ℓ_r *is the width of the reinforcement panel or lamination in direction of the beam axis;*

t_r *is the thickness of the reinforcement panel or lamination;*

n_r *is the number of panels or laminations used for reinforcement (typically 2, respectively 4);*

k_k *is a factor to account for the non-uniform distribution of stresses; without further verification,* $k_k = 2.0$ *may be assumed* (for reinforcement of connections with a tensile force component perpendicular to the grain, $k_k = 1.5$ may be assumed, for reinforcement of curved or pitched cambered beams, $k_k = 1.0$ may be assumed);

$f_{t,d}$ *is the design tensile strength of the panel or lamination in direction of the tensile force* $F_{t,90,d}$.

Background for the clauses given above:

The approach to verify the reinforcement as given above is presented and explained in [32]. The factor k_k is applied to take into account the non-uniform distribution of stresses and the concentration of stresses at the panel edge facing the location of peak tensile stresses perpendicular to the grain. The characteristic strength values of the glue lines, when used for reinforcement, are based on [33] and [32].

8 CONCLUSIONS AND OUTLOOK

Due to the fact that CEN/TC 250/SC 5/WG 7 "Reinforcement" has started the technical discussions at quite an early stage, the first draft of the section on reinforcement is already at a comparatively advanced stage. For the second draft, all comments received that are deemed useful and technically sound will be implemented. In addition, the section on reinforcement of members with concentrated compression stresses perpendicular to the grain will be drafted, based on e.g. [34] and information given in current ETAs. In addition, a clear verification procedure for reinforcement in form of fully-threaded screws will be implemented.

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