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DESIGN OF TIMBER STRUCTURES IN VIEW OF SUSTAINABILITY BASED ON THE COMPONENT METHOD

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ABSTRACT: The component method is a flexible and easy-to-use design concept that offers significant advantages for safe and economical design. Considering both the load-bearing capacity and the rotational joint stiffness, this design concept leads to high-performance and resource-efficient structures. This paper presents an approach for implementing the component method in the structural design of timber structures. A first draft of a component catalogue for timber joints has been developed. The application of the component catalogue is exemplified by three different frame corner joints, two of which are reusable. It is shown in this paper, that different types of timber joints can be broken down into a spring model consisting only of basic components. However, further investigations, including experimental validation, are required to improve the component properties and evaluate their influence on the moment-rotation behaviour. Ongoing research at the University of Stuttgart aims to validate the derived spring models through tests on the presented frame corner joints and their basic components, to extend the component catalogue and to support the implementation of the component method in the design of timber construction to increase the application of timber as a building material in complex structures.

KEYWORDS Component method, moment-resisting joints, rotational stiffness

1 – INTRODUCTION

In statically indeterminate frame systems, the load-deformation behaviour of joints is crucial for the distribution of internal forces. By accounting for semi-rigid joints in column bases or frame corners, slender and, therefore, more resource-efficient components or larger spans can be achieved. At the same time, realistic consideration of joint stiffness is essential to ensure reliable structural designs. To realistically account for the load-deformation behaviour of complex joints, flexible and easy-to-use design concepts are required for practical use.

The key idea behind such easy-to-use design concepts is based on the component method, which is a proven method for steel structures according to EN 1993-1-8 [6]. The approach is to identify the basic components of the semi-rigid joints that can be found in any type of joint. These components are then used to develop a spring model by connecting the equivalent spring for each basic component in parallel or in series - depending on its function in the joint. Finally, the stiffness for different types of joints can be determined using only the same set of basic components.

A component-based design concept for determining the rotational stiffness of moment-resisting timber joints has been investigated in only a few previous studies (see e.g. [2], [14], [15], [28], [31]). However, most of these studies focus on a small number of basic components or investigate specific use cases. Therefore, systematic investigations of the general applicability of a component-based design concept for various types of moment-resisting timber joints are still lacking.

A current research project at the University of Stuttgart [19] thus aims to investigate and facilitate the applicability of the component method by moment-resisting timber frame corner joints. Frame corners are an essential element of frame systems, offering a wide range of individual design solutions. They are, therefore, a good example to illustrate the broad applicability of the component-based design concept. Various solutions of frame corner joints have been developed in [19], among them also those capable of re-use in its structural integrity.

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As a first step, a comprehensive literature review was carried out to develop a component catalogue that provides an overview of the current state of knowledge on the basic component properties, such as load-bearing capacity and stiffness. This catalogue was also updated in accordance with FprEN 1995-1-1 [12]. Using this extended version of the component catalogue, which is part of this paper, the approach of the component-based design concept will be demonstrated by means of the frame corner joints developed in [19].

The paper is divided into three parts. The first part explores the basic principle of the component method according to EN 1993-1-8 [6] and gives an overview of previous investigations on the component method for timber construction. In the second part of the paper, the proposal for a component catalogue for timber joints is presented. Finally, a number of application examples are provided to show how the presented component catalogue can be applied to various frame corner joints.

2 – STATE OF THE ART AND SCIENCE

2.1 COMPONENT METHOD ACCORDING TO EN 1993-1-8

The component method, according to EN 1993-1-8 [6], has already become a well-established design concept for evaluating the stiffness, strength, and rotational capacity of semi-rigid steel joints. Based on the idea of transforming an individual joint into a spring model consisting only of basic components, the joint stiffness can be considered independently of the joint complexity. Thus, the component method enables a detailed yet efficient design for all types of joints.

The design process is demonstrated by an example of a semi-rigid beam-to-column steel joint in Fig. 1 and follows three steps.

1. Identification of relevant basic components.
2. Determination of component properties, such as stiffness and load-bearing capacity, using equations given in the component catalogue in EN 1993-1-8 [6].
3. Combination of component behaviour into an equivalent rotational spring (see Fig. 1 *static model*) to derive the moment-rotation behaviour of the joint.

Each component is represented by a non-linear spring whose load-deformation behaviour determines the overall moment-rotation behaviour of the joint. Important parameters to specify the moment-rotation behaviour are the moment resistance $M_{j,Rd}$, the rotational stiffness S_j and the rotation capacity Φ_{Cd} (see Fig. 1).

2.2 COMPONENT METHOD FOR TIMBER JOINTS

In contrast to steel construction, neither EN 1995-1-1 [7] nor FprEN 1995-1-1 [12] provides a standardised, component-based design concept for timber joints. There are, however, a few previous investigations that have exemplified the implementation of the component method for timber joints, primarily for the determination of initial rotational stiffness. The main results of these investigations are summarised in this section.

First, it can be noted that most of the investigations focused on steel-to-timber joints (see e.g. [2], [14], [15], [31]). This allows the use of already known and standardised components in accordance with EN 1993-1-8 [6]. Nevertheless, there are first investigations done on timber-to-timber joints (see [28]) and on carpentry joints (see [1]) that demonstrate the component methods flexibility as one of its key advantages, especially for timber construction with its wide variety of joints.

Two different types of steel-to-timber joints were investigated in [15] and [31]. While [15] focused on a semi-rigid steel-to-timber joint using a steel end plate and steel bolts, [31] investigated a glulam beam-column joint with bonded-in rods. Based on a comparison between the experimentally obtained moment-rotation curves and those derived from the spring models, both investigations found overall good agreement. However, in [15] the analytically determined initial rotational stiffness is about 20 % higher than the experimental result.

Another important point to note is that, as mentioned above, both types of joint contain a relatively high number of steel components, so there is a lack of knowledge about the timber components so far. It is also mentioned in [15] that further investigations of the stiffness coefficients of the timber components are needed to achieve better agreement.

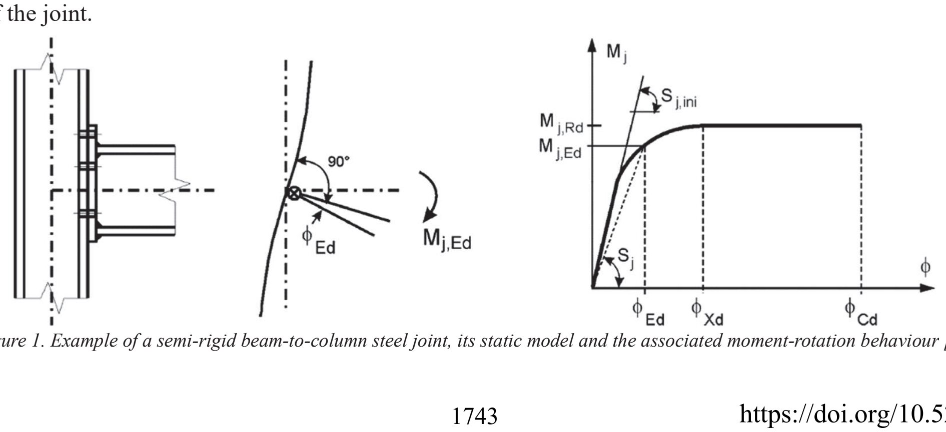

Figure 1. Example of a semi-rigid beam-to-column steel joint, its static model and the associated moment-rotation behaviour [6].

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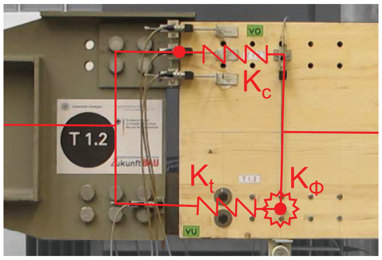


Figure 2. Derived spring model for a moment-resisting timber column base [14] (to be rotated by 90).

In addition, [14] points out that for the applicability of spring models a comprehensive and precise knowledge of the load-deformation behaviour of all basic components is required. Therefore, systematic investigations of moment-resisting timber joints and their basic components in view of the general applicability of the component method are necessary.

A first step in this direction was taken at the University of Stuttgart, where experimental tests were carried out on moment-resisting timber column bases and their basic components [14]. Based on the conducted component tests, non-linear spring models of the moment-resisting joints were derived in order to predict the moment-rotation behaviour (see Fig. 2). It was shown that spring models are a simple, but still suitable approach to simulate the moment-rotation behaviour of commonly used timber joints with dowel-type fasteners, whereas 3D FE models are far more costly.

The investigations on the timber column bases have also provided significant findings regarding the behaviour of timber components within the spring models. It was shown that although some of the components, like compression parallel to the grain, do not cause immediate joint failure, it is still important to consider their flexibility in the spring model as they will affect the joint stiffness [14]. Furthermore, both a translational spring and a rotational spring are required in fastener groups to properly account for rotational effects (see Fig. 2, K_Φ).

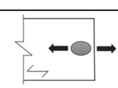
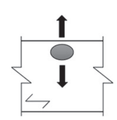
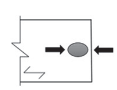
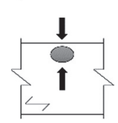
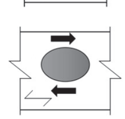
The properties of the basic timber components, such as load-bearing capacity and stiffness, were compiled in a component catalogue for timber construction. A first draft of the catalogue was presented in [14]. On this basis, in [19] an extensive literature review was carried out with the aim of updating and extending the catalogue. This revised version of the component catalogue is presented in the following chapter.

3 – PROPOSAL OF A COMPONENT CATALOGUE

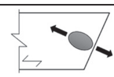
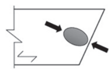
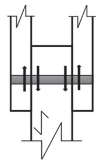
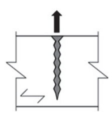
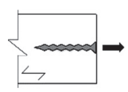
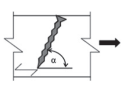
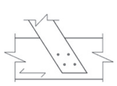
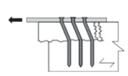
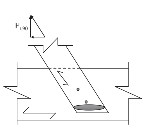
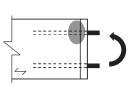
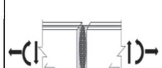
Tab. 1 shows the current proposal of the component catalogue for timber construction (version of March 2025). The structure is similar to that of the component catalogue according to EN 1993-1-8 [6]. In the left column, the basic components are specified by means of a brief description, a formula symbol and an illustrative representation. The components are numbered consecutively from 1 to 16. In the right column, references are given for calculating the load-bearing capacity and stiffness of the corresponding basic component.

As part of an extensive literature review, the component catalogue was extended and updated in accordance with FprEN 1995-1-1 [12]. Tab. 1 provides a selection of the underlying literature of the current draft. A complete version is given in [22]. The main new developments in the current draft are explained in detail below.

Table 1: Proposal of a component catalogue for timber construction

Component				Reference to calculation	
				Load-bearing capacity	***Stiffness***
1	Timber, tension 0°	*t,0*		6.1.2, EN 1995-1-1:2004 [7] 8.1.2, FprEN 1995-1-1:2024 [12]	EN 338:2016 [8] EN 14080:2013 [9]
2	Timber, tension 90°	*t,90*		6.1.3, EN 1995-1-1:2004 [7] 8.1.4, EN 1995-1-1:2004 [7] 8.1.3, EN 1995-1-1:2004 [7] Sec. 11.6, FprEN 1995-1-1:2024 [12]	EN 338:2016 [8] EN 14080:2013 [9]
3	Timber, compression 0°	*c,0*		6.1.4, EN 1995-1-1:2004 [7] 8.1.5, FprEN 1995-1-1:2024 [12]	EN 338:2016 [8] EN 14080:2013 [9]
4	Timber, compression 90°	*c,90*		6.1.5, EN 1995-1-1:2004 [7] 8.1.6, FprEN 1995-1-1:2024 [12] 11.11.2, FprEN 1995-1-1:2024 [12]	EN 338:2016 [8] EN 14080:2013 [9]
5	Timber, shear	*v*		6.1.7, EN 1995-1-1:2004 [7] 8.1.11, FprEN 1995-1-1:2024 [12] 11.11.1.4, 11.11.2, 11.11.3.3, FprEN 1995-1-1:2024 [12]	EN 338:2016 [8] EN 14080:2013 [9] 11.3.7.6, FprEN 1995-1-1:2024 [12]

Continuation of Table 1: Proposal of a component catalogue for timber construction

Component					Reference to calculation			
					Load-bearing capacity		***Stiffness***	
6	Timber, tension, angle α	*t,α*			8.1.4, FprEN 1995-1-1:2024 [12]		-	
7	Timber, compression, angle α	*c,α*			6.2.2, EN 1995-1-1:2004 [7] 8.1.7, FprEN 1995-1-1:2024 [12] 11.11.1.3, FprEN 1995-1-1:2024 [12]		[1]	
8	Dowel-type fastener, shearing	*v,f*			*steel*	*timber*	*steel*	*timber*
				screwed or pushed-in	Clause 8, EN 1995-1-1:2004 [7] 11.2.3, 11.7, Annex K, FprEN 1995-1-1:2024 [12]	11.2.3.2 (13), FprEN 1995-1-1:2024 [12], [13], [21]	Tab. 7.1, EN 1995 -1-1:2004 [7] Tab.11.13 Annex K, FprEN 1995-1-1:2024 [12]	[13], [30]
				glued-in	11.10.6, FprEN 1995-1-1:2024 [12]	-	Tab.11.13 FprEN 1995-1-1:2024 [12]	-
9	Dowel-type fastener perpendicular to grain, axial loading	*ax,f,perp*		*screwed or pushed-in*	6.1.4, 8.3.2, 8.5.2, 8.7.2, EN 1995-1-1:2004 [7] 11.2.2, FprEN 1995-1-1:2024 [12]	-	Tab.11.14 FprEN 1995-1-1:2024 [12]	[30]
				glued-in	11.10.5, FprEN 1995-1-1:2024 [12]	[17]	Tab.11.14 FprEN 1995-1-1:2024 [12]	[17]
10	Dowel-type fastener parallel to grain, axial loading	*ax,f,par*		*screwed or pushed-in*	[10], [29]	-	[10]	-
				glued-in	[26]	[17]	-	[17]
11	Dowel-type fastener, combined axial and lateral loading	*ax,v,f,α*		*screwed or pushed-in*	-	-	11.3.7.4, Annex K, FprEN 1995-1-1:2024 [12]	[30]
				glued-in	-	-	-	-
12	Dowel-type fastener, group effects	*group,f*			8.1.2, EN 1995-1-1:2004 [7] Sec. 11.3, FprEN 1995-1-1:2024 [12]		[18], [23]	
13	Brittle failure, lateral load parallel to grain	*br,par*			Annex A, EN 1995-1-1:2004 [7] Sec. 11.5, FprEN 1995-1-1:2024 [12]		-	
14	Brittle failure, lateral load perpendicular to grain	*br,perp*			Sec. 11.6, FprEN 1995-1-1:2024 [12]		-	
15	End plate in bending on timber in compression	*c,ep*			[4]		[15], [27]	
16	Flat fastener, loaded in plane	*fl,f*			[5]		[5]	

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In particular, components 8 to 11, describing the load-deformation behaviour of dowel-type fasteners, were extended. Due to the increasing importance of bonded-in rods, a distinction is now made between screwed or pushed-in (e.g. screws, bolts, dowels) and glued-in (e.g. bonded-in rods) fasteners. In addition to conventional steel fasteners, timber fasteners, such as hardwood dowels, are now also taken into account.

In addition, the component catalogue was extended to include new basic components that emerged from the literature review. For instance, component 10 *dowel-type fastener parallel to grain under axial loading* was added. This includes a number of experimental investigations that provide data on the load-bearing capacity and, in some cases, the stiffness of screws [29], screwed-in rods [10] and bonded-in rods [26].

Furthermore, the analysis of various connections described in the literature resulted in the addition of component 15 to the catalogue. This new basic component, entitled *end plate in bending on timber in compression*, is relevant to the connection of a moulded steel part through an end plate to the end grain of a timber member, e.g. by means of bonded-in rods parallel to the grain. As a result, bending of the end plate causes stress parallel to the grain in the compression zone of the timber element. This component is based on a component used in steel construction, which has been successfully modified for timber construction (see [4], [15], [27]). Thus, this component exemplifies multi-material design as a key advantage of component-based design.

Component 16 *flat fastener loaded in plane* was also added to the catalogue. This component includes design approaches for flat steel fasteners such as perforated plates and nail plates, thus establishing a link to the components *plate in tension* and *plate in compression* according to EN 1993-1-8 [6]. In addition, a design proposal is given in [5] specifically for perforated plates.

The application of the component catalogue presented in this section is illustrated and explained in the following section by means of three examples of frame corner joints. These examples are also used to demonstrate the approach for determining the total rotational joint stiffness, which can then be taken into account in the design of frame and truss structures.

4 – APPLICATION EXAMPLES

4.1 GENERAL

Frame corners represent an important and elementary part of frame systems, for which there are many individual design solutions. Therefore, the frame corner joint is an appropriate example to demonstrate the universal applicability of the component-based design concept for timber joints. This section takes a closer look at three different types of frame corner joints (see Fig. 3-5):

- Type I: Joint with slotted-in steel plate and dowel-type fasteners
- Type II: Joint with bonded-in rods
- Type III: Joint with screwed-on timber sleeves

As part of the mentioned research project [19], these three frame corner joints will also be investigated by means of experiments to validate the corresponding spring models.

4.2 FRAME CORNER JOINT TYPE I: SLOTTED-IN STEEL-PLATE AND DOWELS

In this section, the load-bearing behaviour and the resulting spring model of frame corner joint type I, shown in Fig. 3, is presented. Frame corner joint type I consists of a timber column and beam forming a mitre joint using a slotted-in steel plate and dowel-type fasteners. The steel plate is made of a single section. As a result, the centre section of the plate transfers the deviation force in the mitre joint, which is a compressive force for a closing moment. By splitting the closing moment into a couple of forces, a tensile force is applied to the outer fastener group and a compressive force is applied to the inner fastener group. Part of this compressive force is also expected to be transferred directly by contact between the timber elements.

Considering this load-bearing behaviour, the frame corner joint can be converted into a spring model (see Fig. 3, right). As a first step, the basic components of the tension and compression zones are identified. Next, the equivalent springs of the tension and compression zones are connected in series. Relevant components in the tension zone are *dowel-type fasteners, shearing* (no. 8, *v,f*) as well as *brittle failure, lateral load parallel to grain* (no. 13, *br,par*). These components are to be considered for both the fastener group in the column and in the beam.

Similarly, the basic component *dowel-type fasteners, shearing* (no. 8, *v,f*) is also relevant in the compression zone. As pointed out in section 2.2, a rotational spring is required in fastener groups in addition to the tension spring to properly account for rotational effects. These rotational springs are also connected in series in both the compression and tension zone as shown in Fig. 3. Furthermore, component 3 *timber, compression 0°* (*c,0*) has to be taken into account in the compression zone.

Based on the spring model, the total rotational joint stiffness $C_{rot,tot}$ can be determined. For this purpose, the stiffness of the equivalent spring in tension ($c_{t,tot}$) and compression ($c_{c,tot}$) is calculated by summing up the reciprocals of the stiffness coefficients of the basic components as the springs are connected in series (see (1) and (2)). Although the steel plate transfers the compressive deviation force, the stiffness calculation does not consider the basic steel component *plate in compression* (*c,p*). This is because the stiffness coefficient for this component should be assumed to be infinite [6], [11].

Taking into account the internal lever arm z between the tensile and compressive forces, the resulting rotational stiffness $C_{rot,t+c}$ is determined according to (3). Finally, the

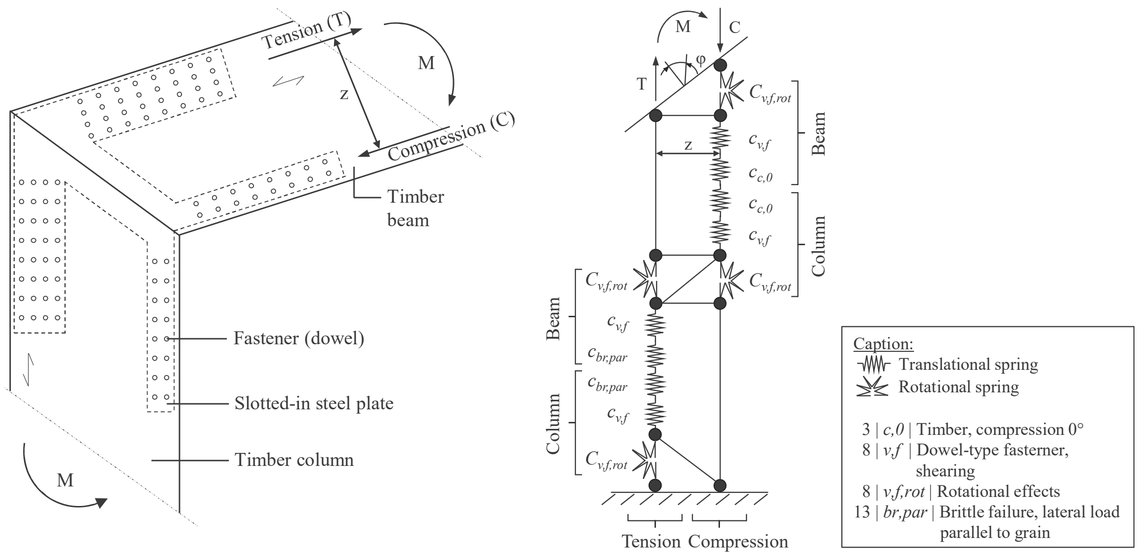

Figure 3. Frame corner joint type I with slotted-in steel plate and dowel-type fasteners (left) and corresponding spring model (right).

rotational stiffness $C_{rot,v,f}$ due to the rotational springs of the fastener groups has to be considered. Therefore, the lateral slip modulus K_{ser} of the fastener group, e.g. according to FprEN 1995-1-1, Tab. 11.12 [12], is multiplied by the corresponding polar moment of inertia I_p (see (4)). By summing up these rotational stiffnesses according to (5), the total rotational joint stiffness $C_{rot,tot}$ can be derived.

$$c_{c,tot} = \frac{1}{\frac{1}{c_{v,f}}+\frac{1}{c_{c,0}}+\frac{1}{c_{c,0}}+\frac{1}{c_{v,f}}} \quad (1)$$

$$c_{t,tot} = \frac{1}{\frac{1}{c_{v,f}}+\frac{1}{c_{br,par}}+\frac{1}{c_{br,par}}+\frac{1}{c_{v,f}}} \quad (2)$$

$$C_{rot,t+c} = \frac{z^2}{\frac{1}{c_{t,tot}}+\frac{1}{c_{c,tot}}} \quad (3)$$

$$C_{rot,v,f} = I_p \cdot K_{ser} \quad (4)$$

$$C_{rot,tot} = C_{rot,t+c} + \sum_i C_{rot,v,f,i} \quad (5)$$

4.3 FRAME CORNER JOINT TYPE II: BONDED-IN RODS

Fig. 4 shows frame corner joint type II and its corresponding spring model. In this case, the timber beam is supported on the column forming a butt joint, as common in frame structures. Again, the closing moment is transferred by a couple of forces, with the tensile force being taken up by bonded-in rods. The rods are only bonded into the column, while the holes in the beam are pre-drilled slightly larger to allow the rods to pass through. This allows the joint to be detached and the components to be re-used. At the top of the beam, the rods are tightened against a steel plate using nuts. To prevent compression failure perpendicular to grain of the beam in this area, additional fully threaded self-tapping screws are provided vertically between the rods.

For a clear load distribution, the rods should not carry any shear force, which also facilitates the derivation of the corresponding spring model. This can be achieved by a separate connection of steel or hardwood dowels to transfer the shear forces. However, the hole clearance of the dowels must then be smaller than that of the rods.

The compressive force is transferred directly by contact between the timber elements. A steel plate is provided in this area in order to on one hand achieve a defined load application surface. On the other hand, it is also necessary for the required reinforcement of the beam with fully threaded self-tapping vertical screws to prevent premature compression failure perpendicular to grain.

Relevant components in the compression zone are therefore *timber, compression 90°* (no. 4, *c,90*) in the area of the beam as well as *timber, compression 0°* (no. 3, *c,0*) in the area of the column (see (6)). As part of the validation of the spring model, it is necessary to clarify the extent to which the reinforcement by fully threaded screws in the area of compression perpendicular to grain needs to be taken into account.

The tension zone mainly includes the components related to the bonded-in rods. For each bonded-in rod, the appropriate springs are connected in series (see (7)). These are *dowel-type fastener parallel to grain, axial loading* (no. 10, *ax,f,par*) considering the load-deformation behaviour of the rods bonded into the column. In addition, the

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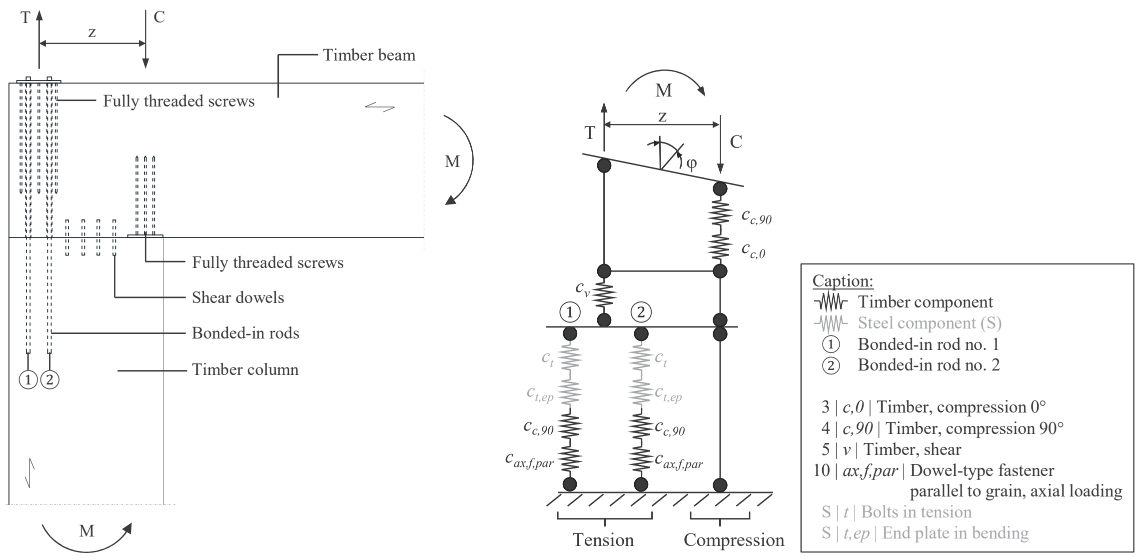

Figure 4. Frame corner joint type II with bonded-in rods (left) and corresponding spring model (right).

steel components *bolts in tension* (*t*) and *end plate in bending* (*t,ep*) have to be taken into account. As mentioned above, there is compression perpendicular to grain at the top of the beam, so component 4 *timber, compression 90°* (*c,90*) has to be considered as well. In this case, the new basic component 15 *end plate in bending on timber in compression* (*c,ep*) cannot be used because the end plate causes compression perpendicular rather than parallel to the grain.

As the bonded-in rods are connected in parallel to each other, a single equivalent stiffness coefficient $c_{t,rod,eq}$ is required as described in FprEN 1993-1-8, B.4.2.1 [11]. In this example, this coefficient is calculated using (9). For this purpose, an equivalent lever arm z_{eq} is first determined according to (8), since each of the bonded-in rods have different lever arms h_i to the resultant of the compression zone.

Subsequently, other basic components of the tension zone can be connected in series to the equivalent stiffness coefficient $c_{t,rod,eq}$ describing the bonded-in rods. In this case, the total stiffness coefficient of the tension zone $c_{t,tot}$ is determined according to (10) considering not only the bonded-in rods ($c_{t,rod,eq}$) but also the basic component *timber, shear* (no. 5, *v*). This basic component is required because the deviation of forces in the corner causes a shear field in the area of the beam (see [20]).

In the case of steel joints, the load-deformation behaviour of the web panel in shear is usually represented by a translational spring that is located in the compression zone [16], [25]. In this example of a timber joint, however, the spring representing the shear field is assigned to the tension zone due to the expected failure mechanism. Whereas the failure of the shear panel in the steel joint is due to buckling (compression failure), the timber beam will fail by longitudinal shear, which is closer to splitting perpendicular to the grain (tensile failure). However, since all translational springs in the tension and compression zones are connected in series (see (3)), it is mechanically irrelevant to which side the spring modeling the shear field is located.

Furthermore, the shear dowels are a separate component but are not included in the spring model (see Fig. 4). This is because the moment is transferred only by the couple of tensile and compressive forces, while the shear dowels transfer the horizontal forces. It is, therefore, initially assumed that the shear dowels have no (significant) effect on the moment-rotation behaviour of the joint and can therefore be neglected in the spring model. Nevertheless, they always have to be taken into account when calculating the load-bearing capacity.

As part of the validation of the analytically derived moment-rotation curves by means of the spring model, the extent to which the shear dowels might influence the rotational stiffness of the joint should be investigated. It might then be possible to consider the shear dowels by a horizontal spring, which is connected in series with the springs of

$$c_{c,tot} = \frac{1}{\frac{1}{c_{c,90}} + \frac{1}{c_{c,0}}} \tag{6}$$

$$c_{t,rod,i} = \frac{1}{\frac{1}{c_t} + \frac{1}{c_{t,ep}} + \frac{1}{c_{c,90}} + \frac{1}{c_{ax,f,par}}} \tag{7}$$

$$z_{eq} = \frac{\sum_i c_{t,rod,i} \cdot h_i^2}{\sum_i c_{t,rod,i} \cdot h_i} = \frac{c_{t,rod1} \cdot h_1^2 + c_{t,rod2} \cdot h_2^2}{c_{t,rod,1} \cdot h_1 + c_{t,rod2} \cdot h_2} \tag{8}$$

$$c_{t,rod,eq} = \frac{\sum_i c_{t,rod,i} \cdot h_i}{z_{eq}} = \frac{c_{t,rod1} \cdot h_1 + c_{t,rod2} \cdot h_2}{z_{eq}} \tag{9}$$

$$c_{t,tot} = \frac{1}{\frac{1}{c_{t,rod,eq}} + \frac{1}{c_v}} \tag{10}$$

the tension and compression zone and has a vertical lever arm to the centre of rotation. This approach will be investigated within the mentioned research project [19].

Finally, the total rotational stiffness $C_{rot,tot}$ of the whole frame corner joint type II is determined according to (3), taking into account the lever arm z between the compression and tension resultants (see Fig. 4).

4.4 FRAME CORNER JOINT TYPE III: SCREWED-ON TIMBER SLEEVES

The third application example is given in Fig. 5 and is presented in the following section. The frame corner joint type III has a structure comparable to that of type II mentioned above and is also capable of re-use. Again, the closing moment is transferred by a couple of forces, with the deviation of the forces in the corner resulting in a shear field in the area of the beam. The bonded-in rods of joint type II are replaced by screwed-on timber sleeves in joint type III, which are located both in the tension and in the compression zone. This frame corner joint was originally developed in [24] as a moment-resisting “quick-connect” joint for prefabricated timber frame structures.

The timber sleeves are screwed onto the timber beam and timber column, respectively, using continuously arranged fully threaded self-tapping screws. The two-part sleeves are tightened by means of the rods, which are contained within the U-shaped timber sleeves. The sleeves are fixed to both the front and back of the beam and column (see Fig. 5). A more detailed explanation of the structure of this frame corner joint can be found in [24].

The derived spring model of joint type III shown in Fig. 5 is similar in principle to model type II shown in Fig. 4. In the compression zone, a simplified assumption is made that the compressive force is only transferred by contact between the beam and the column. The corresponding stiffness coefficient $c_{c,tot}$ is then determined according to (6). However, it is likely that part of the force is also transmitted through the sleeves. Therefore, in order to correctly recalculate the experimental moment-rotation curve using the spring model, the planned tests [19] should investigate how high the load share is in the sleeves and which basic components of the sleeves may be taken into account in the spring model.

Similar to the bonded-in rods of the second example in section 4.3, the timber sleeves are connected parallel to each other in the spring model, while the required springs of each sleeve are connected in series (see Fig. 5). As the screws are inclined at 45°, component 11 *dowel-type fastener, combined axial and lateral loading* (ax,v,f,α) is relevant. Due to the shear component, a rotational spring is required for each fastener group, as indicated in section 4.2. The pre-tensioned rods push the bearing plate against the sleeves, causing compression parallel to the grain. For this reason, component 15 *end plate in bending on timber in compression* (c,ep) is relevant as well. The other basic components are similar to those of the frame corner joint type I and II explained in the previous examples in sections 4.2 and 4.3.

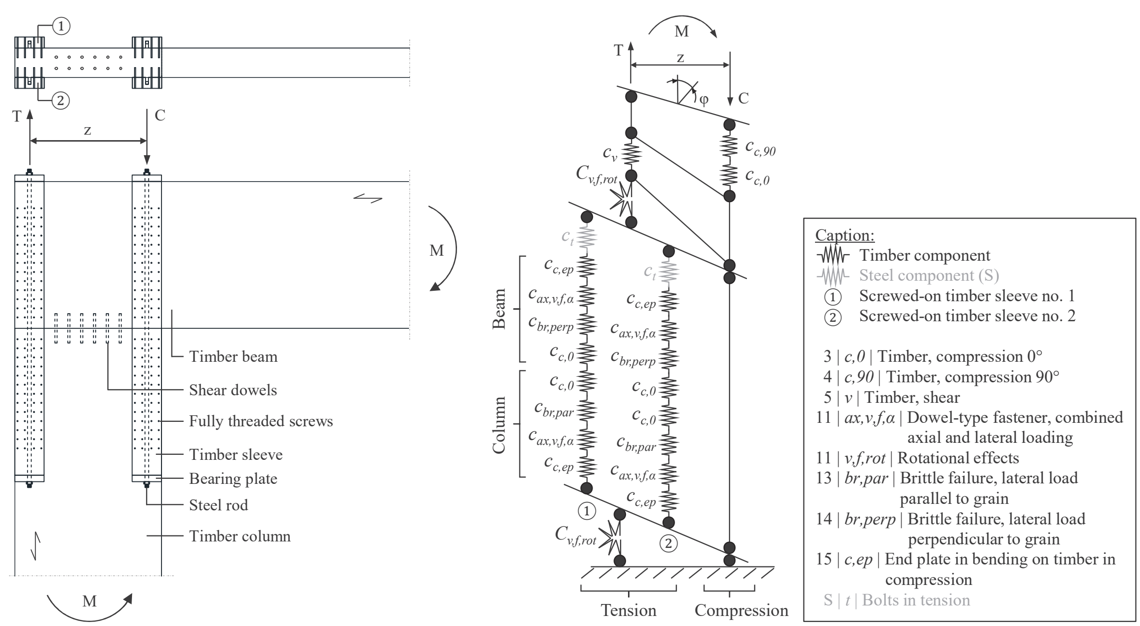

Figure 5. Frame corner joint type III with screwed-on timber sleeves (left) and corresponding spring model (right).

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All in all the stiffness coefficient of one sleeve $c_{t,sleeve}$ can be determined according to (11). The coefficients $c_{t,sleeve,i}$ can simply be added up to obtain the equivalent stiffness coefficient for all sleeves, as they are connected parallel. In contrast to joint type II in section 4.3, no equivalent lever arm has to be calculated in this case because each of the sleeves have the same lever arm to the resultant of the compression zone. Subsequently, the total stiffness coefficient of the tension zone is calculated using (12), additionally considering the shear component (v) due to the shear field. The further steps of the calculation of the total rotational stiffness $C_{rot,tot}$ correspond to those explained in section 4.2.

$$c_{t,sleeve,i} = \frac{1}{\frac{1}{c_t}+2\cdot\frac{1}{c_{c,ep}}+2\cdot\frac{1}{c_{ax,v,f,\alpha}}+\frac{1}{c_{br,perp}}+2\cdot\frac{1}{c_{c,0}}+\frac{1}{c_{br,par}}} \tag{11}$$

$$c_{t,tot} = \frac{1}{\frac{1}{\sum_i c_{t,sleeve,i}}+\frac{1}{c_v}} \tag{12}$$

5 – CONCLUSIONS AND OUTLOOK

A component-based design concept combines several key advantages that are decisive for a safe and economical design of timber structures in view of sustainability. On one hand, this includes an efficient design that takes into account not only the load-bearing capacity but also the rotational stiffness of even complex joints based on the same set of basic components. On the other hand, this design concept enables multi-material design, which in turn leads to high-performance yet resource-efficient structures.

Within this paper, an approach for implementing a component-based design concept in timber construction has been presented. It is based on the component method according to EN 1993-1-8 [6], an established design concept in steel construction. Based on an extensive literature review, a first draft of a component catalogue for timber joints was developed. The component catalogue has been updated in accordance with FprEN 1995-1-1 [12] and extended with new basic components, such as bonded-in rods or dowel-type fasteners inserted parallel to grain that enable the design of advanced timber structures.

The application of the component catalogue presented in this paper has been exemplified by three different frame corner joints, two of which are reusable. With many individual design solutions, frame corners are an important and elementary part of frame systems and are therefore an appropriate example to demonstrate the general applicability of the component method for timber joints. In addition to commonly used timber joints with dowel-type fasteners and slotted-in steel plate, joints with bonded-in rods and screwed-on timber sleeves have also been investigated.

The development of the spring models has shown that it is possible to break down different types of timber joints into the currently known basic components. However, it has also been shown that it is not yet known how each basic component affects the moment-rotation behaviour. For example, the possible influence of the timber reinforcement by screws to prevent premature compression failure perpendicular to grain as well as the influence of the shear dowels should be investigated. It is also necessary to consider whether each basic component of the spring models presented in this paper is essential to the final result, or whether individual basic components could be neglected because they do not affect the rotational stiffness decisively.

To address these issues, the three frame corner joints presented here are also being investigated experimentally as part of an ongoing research project at the University of Stuttgart [19] to validate the analytically derived moment-rotation curves. In addition to the tests on the frame corner joints, a wide range of tests on the corresponding basic components are planned to obtain realistic input values for the spring models. The test results will then also be used to extend the component catalogue. Overall, this research project is contributing significantly to increasing the use of timber also in complex structures through a component-based design concept and thus taking an important step towards sustainable construction.

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